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MEASURED EFFECTS OF THE VARIOUS COMBINATIONS OF NUCLEAR RADIATION, VACUUM, AND CRYOTEMPERATURES ON ENGINEERING MATERIALS

BIENNIAL REPORT

1 May 1964 through 1 May 1966

Prepared for
George C. Marshall Space
Huntsville, Alabama

Contract NAS8-2450

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BIENNIAL REPORT

1 May 1964 through 1 May 1966

E. E. Kerlin
E. T. Smith

Prepared for
George C. Marshall Space Flight Center
Huntsville, Alabama

Contract NAS8-2450

GENERAL DYNAMICS
Fort Worth Division

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FOREWORD

This report was prepared by the Fort Worth Division of General Dynamics under Contract No. NAS8-2450, Measured Effects of the Various Combinations of Nuclear Radiation, Vacuum, and Cryotemperatures on Engineering Materials, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Propulsion and Vehicle Engineering Division, Engineering Materials Branch of the George C. Marshall Space Flight Center, with Eugene C. McKannan acting as project manager.

A series of tests was performed during the total contractual period from 9 November 1961 to 1 May 1966 to measure the effects of the various combinations of nuclear radiation, vacuum, and cryotemperatures on nonmetallic engineering materials. The purpose of the tests was to evaluate materials for potential use in spacecraft containing nuclear reactors, where these reactors would be used either as a source of propulsion or for the generation of electrical power. The work was performed by the Nuclear Aerospace Research Facility (NARF) at the Fort Worth Division.

The tests were divided into three main groups, with each group being successively conducted within a 12- to 24-month period. During each of the three periods, monthly and quarterly progress reports, plus one annual (or biennial) report, were submitted to describe general progress in the work and results of specific tests conducted during the reporting period. Each of the first two annual reports was published in two volumes. They are listed in the References section at the back of this document (Refs. 1-4). This biennial report, which covers the period from 1 May 1964 through 1 May 1966, presents the data on the third and final group of tests to be conducted under the program and constitutes the final report to be submitted under the contract.

The authors wish to acknowledge the valuable assistance of a number of scientific and engineering personnel at NARF in the conduction of these tests: Dr. R. P. Lightfoot for material selection, specimen preparation, and data analysis; W. E. Dungan and F. F. Fleming for nuclear radiation measurements; E. E. Baggett and D. C. Butson for assistance in equipment design; R. E. Miller for design and operation of electronic test instrumentation; J. E. Warwick for operation of vacuum systems and specimen testing; W. C. McMillan, M. R. Self, and G. D. Martin for conduction of dielectric and bearing-lubricant tests; H. G. Thornton, W. M. Laney, and R. L. Burtnett for assistance in conduction of the liquid-hydrogen tests and assistance in data reduction; and J. B. Wattier for statistical analyses.

The authors also wish to acknowledge the special services of David Rocray of the Miniature Precision Bearing Company for balancing the flywheels, supplying the test bearings and lubricants, applying the test lubricants, and testing the operating conditions of the bearings and motors in the bearing-lubricant tests.

Additional valuable assistance was rendered in the tests by people at the Material Division of the Propulsion and Vehicle Engineering Laboratory of the George C. Marshall Space Flight Center: R. L. Gause of the Engineering-Physics Branch for his contribution to the design of the Dielectric Tester, and the group at the Physics Branch for conducting the weight-loss tests that are documented in previous reports.

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PROGRAM SUMMARY TABLE

MATERIALS TESTED UNDER NASA CONTRACT NAS8-2450

Trade Name	Material Description	Numerical Code Identifying Report Containing Test Data[a] — Irradiation or Control Test Environment: Air	Vac	Cryo	Cryo-Vac
	STRUCTURAL ADHESIVES				
Aerobond 422J	Epoxy-phenolic	4,5		4,5	
Aerobond 430	Epoxy-phenolic	3,5	3,5		
APCO 12[illegible]	Polyurethane	3,5	3		5
Epon 422J (Aerobond 422J)[b]	Epoxy-phenolic		1		
Epon 929	Epoxy	3	3		
Epon 934	Epoxy	3,5	3	5	
Epon 951	Proprietary	5			
Epon VIII	Epoxy		1		
FM-47	Vinyl-phenolic	3	1,3		
FM-1000	Epoxy-nylon	3,5	1,3	5	
Hexcel 1252	Polyurethane	2		2	
HT-424	Epoxy-phenolic	3,5	3	5	
Metlbond 302	Epoxy-phenolic		1		
Metlbond 406	Epoxy-polyamide	1,2	1	2	
Metlbond 408	Epoxy-nylon		1		
Metlbond 4021	Nitrile-phenolic	3	3		
Narmco A	Modified epoxy	3,5	3	5	
Narmco C	Polyurethane	3	3		
Scotchweld AF-6	Nitrile-phenolic		1		
Scotchweld AF-40	Epoxy-nylon	4		4	
	STRUCTURAL LAMINATES				
Conolon 506 (Narmco 506)[b]	Phenolic-fiberglass	1,2	1	2	5
CTL 91-LD	Phenolic-fiberglass	4,5	1	4,5	
DC 2104	Silicone-fiberglass	3,4,5	3	4,5	
DC 2106	Silicone-fiberglass		1		
Epon 828/A	Epoxy	5	1	5	
HRP Honeycomb	Phenolic-fiberglass	3	3		
Mobaloy AH-81 (AH7-81)[b]			1		
Mobaloy AH7-81	Phenolic-fiberglass	3,5	3	5	
Paraplex P-43	Polyester-fiberglass	2,3,5	3,5	2	3
Selectron 5003	Polyester-fiberglass	3,5	3	5	
	POTTING COMPOUNDS				
DC R-7521	Silicone		1		
Durock D-133	Ceramic	3	3		
EC-2273B/A	Proprietary	3,4	3	4	
Epon 828/Z	Epoxy	3,4	1	4	3,5
RTV-60	Silicone Elastomer	3	1,3		
RTV-501	Silicone Elastomer	3	3		3,5
Scotchcast 212	Epoxy	3	3		
Sylgard 182 (DC 93-002)[b]	Silicone	5	5		5
	ELECTRICAL INSULATIONS				
DC 7-170	Silicone	3	1,3		
Duroid 5600	Tetrafluoroethylene-fiberglass	4		4,5	5
Estane 5740X1	Polyurethane (ester type)	3	3		3,5
Geon 2046	Polyvinyl chloride	3	3		
Geon 8800	Polyvinyl chloride	3,4	3	4	
H-Film	Polyimide	1,2,3,5	1,3	2	3
Kel F-81	Chlorotrifluoroethylene	1,2,3	1,3,5	2	
Kynar	Vinylidene fluoride-fiberglass	3	3		
Kynar 400	Vinylidene fluoride	5	5	5	5
Lamicoid 6038E	Melamine fiberglass	4,5	5	4,5	5
Lexan	Polycarbonate	5	5		5
Mylar	Polyester		1		
Mylar A	Polyester	3	1,3		
Mylar C	Polyester	1,2,3,5	1,3,5	2	
Plaskon CTFE X2204	Chlorotrifluoroethylene	5	5		
Silastic 950	Silicone	5		5	
Silastic 1410	Silicone	5	5	5	
	DIELECTRICS				
AC-1220	Polyethylene	3			
Marlex 6001	Polyethylene	5			
Marlex 6002	Polyethylene	3	1,3,5		
Polymer SP-1	Polyimide				3
Tedlar	Polyvinyl fluoride film	3,5	3		
Teflon FEP	Fluorinated copolymer of ethylene and propylene (films)	3,5	3,5		
Teflon TFE-7	Tetrafluoroethylene	2,3,5	1,3,5	2,4,5	3,5
Teflon 100 (Teflon FEP)[b]			1		
Teslar (Tedlar)[b]			1		
Thermofit RNF	Polyvinyl Chloride	3	3		

[a]1 - NARF Report No. FZK-161-1, Investigation of Combined Effects of Radiation and Vacuum and of Radiation and Cryotemperatures on Engineering Materials, Volume I: Radiation-Vacuum Tests

2 - NARF Report No. FZK-161-2, Investigation of Combined Effects of Radiation and Vacuum and of Radiation and Cryotemperatures on Engineering Materials, Volume II: Radiation-Cryotemperature Tests

3 - NARF Report No. FZK-188-1, Measured Effects of the Various Combinations of Nuclear Radiation, Vacuum, and Cryotemperatures on Engineering Materials, Volume I: Radiation-Vacuum Tests

4 - NARF Report No. FZK-188-2, Measured Effects of the Various Combinations of Nuclear Radiation, Vacuum, and Cryotemperatures on Engineering Materials, Volume II: Radiation-Cryotemperature Tests

5 - NARF Report No. FZK-290, Measured Effects of the Various Combinations of Nuclear Radiation, Vacuum, and Cryotemperatures on Engineering Materials

[b]Current trade name of material

MATERIALS TESTED UNDER NASA CONTRACT NAS8-2450 (cont'd)

Trade Name	Material Description	Numerical Code Identifying Report Containing Test Data[a]			
		Irradiation or Control Test Environment			
		Air	Vac	Cryo	Cryo-Vac
	THERMAL INSULATIONS				
CPR-200-2 (CPR-20-2)[b]	Polyurethane (polyether-polyester rigid foam)	3,5	3,5	5	
CPR-1021-2	Polyurethane (rigid foam) CO_2 blown	3,4,5	3	4,5	
DS-620	Urethane (polyester, flexible foam)		1		
EFS-175	Epoxy (rigid, spray foamed)	5	5	5	
Refrasil Batting B-100	Silicia oxide		1		
Stafoam AA-402	Polyurethane (polyether) rigid-halocarbon blown	1,2	1	2	
Stafoam H-1502	Polyurethane (polyether) rigid-halocarbon blown	5	5	5	
Styrofoam 22	Styrene	1,2	1	2	
	THERMAL CONTROL COATINGS				
Kemacryl Black No. W49BC12	Acrylic lacquer with P40GCLK primer		1		
Skyspar A-423 SA9185	Epoxy with epoxy primer SA9184	2	1	2	
W.P. Fuller 517-W-1	Silicone with TiO_2 pigment		1		
W.P. Fuller 172-A-1	Silicone-aluminum filled, no primer		1		
Sherwin Williams W49BC12	Proprietary	2		2	
	SEALS				
Buna N (Parker 66-581)	Acrylonitrile-butadiene copolymer	1,3	1,3		
Buna N (PRP 737-70 FLX)	Acrylonitrile-butadiene copolymer	3,5	3,5		
Buna N (RA-30760)	Acrylonitrile-butadiene copolymer	1	1		
Natural Rubber (RA-33860)	Natural Rubber	3	1,3		
Neoprene (PRP 2277)	Chloroprene	3,5	3,5		
Neoprene (RA-24160)	Chloroprene	1	1		
Polymer SP-1	Polyimide	4,5		4,5	
Viton A (RA 26360)	Copolymer of vinylidene fluoride and hexafluoropropylene	1	1		
Viton A (V495-7)	Copolymer of vinylidene fluoride and hexafluoropropylene	5			
Viton B (PRP 19007)	Copolymer of vinylidene fluoride and hexafluor[illegible]	1,3,5	1,3,5	[illegible]	
	SEALANTS				
DC 92-018	Silicone	5			
DC 94-002	Silicone	5	5		
EC-1663	RTV silicone	4		4	
EC 1949	Vendor proprietary	4		4	
	LUBRICANTS				
Almasol SFD-238	MoS_2 plus PbO plus organic binder (dry film)	5	5		
DC-705	Phenyl silicone fluid	5	5		
Duroid Retainer	Fiberglass reinforced Teflon impregnated with MoS_2	3	3,5		
Electrofilm 66-C	MoS_2 epoxy-resin binder (dry film)	3	1,3,[illegible]		
ETR-H	F-50 with indanthrene thickener	3	1,[illegible]		
F-50	Chlorophenyl methyl polysiloxane (silicone oil)	3	1,3,5		
FS-1265	Fluorosilicone fluid		5		
Kynar (filled)	Modified vinylidene fluoride [illegible] filler of MoS_2	5	5		
Minapure	Proprietary		5		
MLF-5	MoS_2-sodium silicate binder (dry film)	3	3,5		
Molykote X-15	Dry film inorganic binder		1		
OS-124	Polyphenyl ether fluid	5	5		
Vespel (Polymer SP-F)	Polyimide with filler (retainer)	5	5		

PROGRAM SUMMARY

This program was initiated under NASA Contract NAS8-2450 from the George C. Marshall Space Flight Center on 9 November 1961. The objectives were to develop equipment and procedures sufficient to measure various mechanical properties of selected organic materials in environments of (initially) vacuum and reactor radiation, to conduct the planned tests, and to report the data received. The environments were designed to approximate those which would be experienced by the component parts of spacecraft vehicles containing operating nuclear reactors. The materials selected for testing were representative of those most likely to be used in spacecraft of this type.

During the first year of operation under the contract, a requirement was added to investigate the combined effects of radiation and cryotemperatures on selected organic materials. Then, with the start of the second annual contract period on 9 November 1962, a third requirement was added to the scope of tests, namely, to test organic materials under the triple-combination environment of radiation, vacuum, and cryotemperature.

During the conduction of this overall program, several items of static and dynamic test equipment were designed, built, and operated at the Fort Worth Division. This equipment includes:

1. A vacuum system to operate in a reactor radiation field and sustain a vacuum of 10^{-7} torr.

2. Dynamic test equipment to measure the mechanical properties of organic materials in vacuum immediately after reactor irradiation.

3. Apparatus to measure the lubricating properties of various lubricating materials in a bearing application while in air, vacuum, and reactor radiation environments.

4. Apparatus to measure the volume resistivity, dielectric constant, and dissipation factor or organic materials while in the environments of air, vacuum, cryotemperature, and radiation.

5. A tensile tester to measure the tensile strength of materials at cryotemperatures while in the environments of vacuum and radiation.

6. Apparatus to measure the thermal conductivity of rigid foam-type insulation materials while in the environments of reactor radiation and either air, LN_2, or LH_2.

7. Equipment to measure the tensile strength and elongation properties of materials while in the environments of radiation and either LN_2 or LH_2.

Standard (and modified) ASTM tests, using the above equipment in conjunction with the Ground Test Reactor (GTR) at NARF, were conducted on approximately 5000 specimens of 90 different spacecraft materials. The data thus obtained were tabulated, reduced, plotted, analyzed, and periodically reported to NASA.

The tests were successfully conducted within three main periods. The first two periods were for approximately 1 year each and the last period was for 2 years. During each of these three periods, monthly and quarterly progress reports were submitted to describe general progress of the work. These reports were published in limited quantities and served only as status reports to NASA. At the end of each of the first two periods, an annual report, having a wider distribution than the quarterlies, was published to document the results of all tests conducted during that period. The present biennial report serves the same purpose for the third period. These reports are comprehensive in every respect and contain all details of equipment, tests, and data relative to the annual or biennial period. The two annuals are two-volume reports. This biennial report, however, is confined to a single document that contains not only all information concerned with the current testing period but also summary descriptions of equipment, tests, and data connected with the entire program. The complete details of the work conducted prior to the current testing period can be obtained only from the prior annual reports.

To facilitate the location of the data compiled throughout the entire program, a tabulation of all materials tested is given on pages vii and viii. Also, for each material listed, its corresponding chemical classification is given. The materials are arranged in application categories, which, in most instances, is the arrangement used in reporting data in the annual reports. In Appendix A of this report, materials tested during the third period of the program are described, and the sections of this document that describe the work on these materials are referenced.

One main objective in the current period was to complete the data cycles on the various test materials. A few materials not previously tested were added to the program during this period to replace materials that were dropped from the program because of their poor response in previous experiments.

In the overall program, materials from the following classifications were evaluated: adhesives, seals, thermal insulations, structural laminates, electrical insulations, potting compounds, dielectric materials, lubricants, sealants, and thermal control coatings. Tests performed on the material specimens included those sufficient to measure lap-shear strength, ultimate tensile strength, ultimate elongation, stress-strain characteristics, weight loss, lubricity, compression strength, dissipation factor, dielectric strength, spectral reflectivity, thermal conductivity, and potted-wire pull-out strength.

These were first-order experiments to evaluate the combined effects of the many environmental conditions and also to demonstrate synergistic effects on the various materials tested.

Results of the work showed that many of the materials could be used in the extreme environments associated with a nuclear reactor in space. For a particular application, additional data may be required to completely evaluate some of the materials. However, for many materials, there are enough data presented to definitely qualify them for use in specific applications.

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REPORT SUMMARY

This biennial report (which is also the final report under NASA Contract NAS8-2450) consists of descriptions and discussions of equipment and procedures used in, and results obtained from, mechanical and physical property tests conducted on nonmetallic spacecraft materials under various environmental combinations of temperature, pressure, and radiation. All data obtained from the tests are tabulated and plotted in the applicable material results sections of the report.

The materials selected for testing in the current program (see pages xvii and xviii) are considered representative of those most likely to be used in spacecraft utilizing nuclear reactors. They consist of 8 materials in the category of adhesives; 7 materials in the category of structural laminates; 5 materials in the category of seals; 2 materials in the category of sealants; 19 materials in the categories of electrical insulations and dielectric materials; 4 materials in the category of thermal insulations; and 12 materials in the category of lubricants.

Representative tests included those sufficient to measure the ultimate lap-shear strength, ultimate tensile strength, ultimate elongation, stress-strain characteristics, lubricity,

thermal conductivity, dissipation factor, dielectric strength, and volume resistivity.

The radiation source for the tests was the Ground Test Reactor (GTR) located at the Nuclear Aerospace Research Facility (NARF) of the Fort Worth Division of General Dynamics.

The procedure for the static vacuum-irradiation tests was to fit groups of tensile and compression specimens to expanded-metal racks which, in turn, were bolted to the underside of the vacuum-system test-volume cover plate. Then, with this assembly installed in the vacuum system located in irradiation position, the specimens were subjected to a simultaneous exposure of high vacuum and nuclear radiation. After completion of the irradiation under vacuum conditions, the specimens were moved to the Irradiated Materials Laboratory (IML) and tested in an Instron machine under atmospheric conditions.

For the dynamic vacuum-irradiation tests (irradiation and testing of specimens without interruption of the vacuum), low- and high-force dynamic tensile testers were used in conjunction with the vacuum systems. These testers consist of specimen-loading devices attached to pull rods which are, in turn, attached to remotely operated hydraulic cylinders. The specimen-loading devices are designed to apply either tensile or compressive loads

Comprehensive Summary of Specimens Tested Under Variou

Tester[a] →	Instron Tester																LFT					HFT		Cryote.s'le				
Environment (Irradiation) - (Test) →	Air - Air										Vac - Air						Air	Vac - Vac						LN_2				
Gamma Dose [ergs/gm(C)] →	0	1(7)	5(7)	2(8)	5(8)	1(9)	5(9)	1(10)	3(10)	1(11)	5(7)	1(8)	5(8)	1(9)	5(9)	1(10)	0	0	5(8)	3(9)	5(9)	0	1(10)	0	5(9)	1(10)	3(10)	0
MATERIALS																												
ADHESIVES																												
Aerobond 422J	5									5																		4
Aerobond 430	5								5	5				5		5												
APCO 1252	5								5	5																		
Epon 934	5							5	5	5														4		4	4	4
Epon 951	4					4	4	4																				
FM-1000	5							5	5	5														4		4	4	4
HT-424	5							5	5	5														4		4	4	4
Narmco A	5							5	5	5																		4
LAMINATES																												
Conolon 506																												
CTL-91-LD										3																		4
DC 2104	5									6																		4
Mobaloy AH7-81	5							5	5	5														4		3	3	4
Paraplex P-43	6									5						5						4	4					
Selectron 5003	5							5	5	5														4		3	3	4
SEALS																												
Buna N (PRP-737-70 FLX)																												
O-Rings	9			5	5				6	6				5	5			5		5								
Compression Buttons	5								5	5																		
Neoprene (PRP-2277)																												
O-Rings	5						5	5							4	4												
Compression Buttons	5								5	5																		
Polymer SP-1										5																		3
Viton A (V495-7)	5								5	5																		
Viton B (PRP 19007)																												
O-Rings	9			5	5				5	5				5	5			4	5		5							
Compression Buttons	5								5	5																		
SEALANTS																												
Dow Corning 92-018	10			10		10		10																				
Dow Corning 94-002	5				5	5	5						5	5	5													
ELECTRICAL INSULATIONS																												
Duroid 5600																												4
Estane 5740X1																												
Epon 828/Z																												
H-Film	10								10	10																		
Kel F-81																		2		2								
Kynar 400	5				5	5	5	10	5	5			5	5		5						4	4	4	4	4		4
Lamicoid 6038E	4									5						5						4	4					4
Lexan	5				5	5		5	5	5			7	5	2	5	2	2	2		2							
Marlex 6001	5								5	5																		
Marlex 6002																5						4	4					
Mylar 100C	10				10		10	10	10	10			7			5	3	6	3		3							
Plaskon CTFE X2204	3					3	3							3	3	3												
RTV 501																												
Silastic 950	8				5	5	8	5																4	4	4		4
Silastic 1410	9				5	5	9	5					5	5	5									4	4	4		4
Sylgard (DC 93-002)	5				5	5		5								5												
Tedlar	10								10	10																		
Teflon FEP-200A (2 mil)	5					5	5	5						5	5	5												
Teflon FEP-1000A (10 mil)	5					5	5	5						5	5	5												
Teflon FEP-4000A (40 mil)	5					5	5	5						5	5	5												
Teflon TFE-7 (2 5 mil)	5	5	5	5	5						5	5	5	5														
Teflon TFE-7 (5 mil)	5	5	5	5	5						5	5	5	5														
Teflon TFE-7 (10 mil)	5	5	5	5	5						5	5	5	5			3	3		3								
Teflon TFE-7 (20 mil)	5	5	5	5	5						5	5	5	5														
Teflon TFE-7 (40 mil)	5	5	5	5	5						5	5	5	5														
Teflon TFE-7 (125 mil)																												4

…s Environmental Conditions In the Current Contractural Period

Tester				CMT		Dielectric Tester										Thermal-Conductivity Tester										Bearing-Lubricant Tester										
LH_2				TE		Air					TE					Air - Air				LN_2 - LN_2				LH_2-LH_2		Air - Air					Vac - Vac					Total Tests
1(9)	5(9)	1(10)	3(10)	0	1(10)	0	1(7)	1(8)	1(9)	1(10)	0	1(7)	1(8)	1(9)	1(10)	0	5(9)	1(10)	3(10)	0	5(9)	1(10)	3(10)	0	3(10)	0	1(7)	1(8)	1(9)	1(10)	0	1(7)	1(8)	1(9)	1(10)	
		4	4																																	22
																																				25
				4	4																															23
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4	4										2	2	2	2	2																					22

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Comprehensive Summary of Specimens Tested Under Various Environme

Tester[a] →	Instron Tester																LFT					HFT		Cryotensile Tester							
Environment (Irradiation) - (Test) →	Air - Air										Vac - Air						Air	Vac - Vac						LN_2				LH_2			
Gamma Dose [ergs/gm(C)] →	0	1(7)	5(7)	2(8)	5(8)	1(9)	5(9)	1(10)	3(10)	1(11)	5(7)	1(8)	5(8)	1(9)	5(9)	1(10)	0	0	5(8)	3(9)	5(9)	0	1(10)	0	5(9)	1(10)	3(10)	0	1(9)	5(9)	[illegible]
<u>THERMAL INSULATIONS</u>																															
CPR 200-2																															
Thermal Conductivity																															
Compression Buttons																	2	2	2												
CPR 1021-2																															
Thermal Conductivity																															
EFS-175																															
Thermal Conductivity																															
Compression Buttons																	2	2	2	2											
Stafoam H-1502																															
Thermal Conductivity																															
Compression Buttons																	2	2	2												
<u>LUBRICANTS</u>																															
Almasol SFD-238																															
DC-705																															
Duroid																															
Electrofilm 66-C																															
ETR-H																															
ES-1265																															
GE F-50																															
Kynar (filled)																															
Minapure																															
MLF-5																															
OS-124																															
Polymer SP-F																															

[a]Abbreviations: LFT - Low-Force Tester
HFT - High-Force Tester
CMT - Cryomechanical Tester
TE - Triple Environment (Vacuum, LN_2, and Radiation)

ntal Conditions in the Current Contractural Period (cont'd)

		CMT		Dielectric Tester										Thermal-Conductivity Tester										Bearing-Lubricant Tester										
		TE		Air					TE					Air - Air				LN_2 - LN_2				LH_2 - LH_2		Air - Air					Vac - Vac					Total Tests
1(10)	3(10)	0	1(10)	0	1(7)	1(8)	1(9)	1(10)	0	1(7)	1(8)	1(9)	1(10)	0	(9)	1(10)	3(10)	0	5(9)	1(10)	3(10)	0	3(10)	0	1(7)	1(8)	1(9)	1(10)	0	1(7)	1(8)	1(9)	1(10)	
														1	1	1	1	1	1	1	1	1	1											10
																																		6
														1	1	1	1	1	1	1	1	1	1											10
														1	1	1	1	1	1	1	1	1	1											10
																																		8
														1	1	1	1	1	1	1	1	1	1											10
																																		6
																								2	2	2	2	2	2	2	2	2	2	20
																								2	2	2	2	2	5	2	2	2	2	23
																													4					4
																													4					4
																													4					4
																													4					4
																													6					6
																								2	2	2	2	2	5	2	2	2	2	23
																													4					4
																													4					4
																								2	2	2	2	2	6	2	2	2	2	24
																								2	2	2	2	2	6	2	2	2	2	24

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to the specimens. A flange plate that mates to the vacuum-system test-volume port separates the slave-cylinder end of the apparatus from the specimen (or vacuum-chamber) end.

An additional dynamic tensile tester, similar in testing capability to the tensile apparatus described above, was used to maintain the test specimens at cryotemperatures during a vacuum irradiation and subsequent tensile tests.

A dynamic vacuum-irradiation tester was used for testing the operating characteristics of lubricants. This tester uses small servomotors to test the lubricating efficiency of selected lubricants in simulated motor-operating conditions. The motors were run at high and low speeds and with varying amounts of electrical power loading to simulate various operating loads. Out of a total of 12 lubricants scheduled for testing during the program, five that operated best during control tests were irradiated in vacuum and air. The motors containing these lubricants were then operated for 500 hours, or to failure, whichever occurred first, in a postirradiation test.

A dielectric tester was developed during the current program to test the dielectric constant, dissipation factor, and volume resistivity of materials in a combined environment of vacuum, cryotemperature, and radiation. This tester was also operated in air at ambient temperature to determine the difference in effects between the two environments and to determine the corresponding cryotemperature and synergistic effects.

For the ambient-air irradiation, tensile specimens were tied to expanded metal racks and positioned next to the face of the reactor core in a framework open to the atmosphere. Subsequent tests were carried out with the Instron machine in the IML.

For the cryotemperature irradiation tests in the current program (irradiation and tensile testing of specimens immersed in cryogens), a new tensile tester was developed and built. The unit was used in the LN_2 and LH_2 control and irradiation tests. Also, for the LN_2 tests, a new dewar with improved radiation-dose-rate geometry and LN_2 safety handling procedures was built. For the LH_2 tests, a separate dewar with particular provisions for liquid-hydrogen safety was used. This improved cryotemperature test equipment operated satisfactorily throughout all scheduled tests.

It should be emphasized that the cryotemperature and vacuum control data presented in this and the two previous annual reports published under the contract will be useful in other materials tests not concerned with a radiation environment. It was understood by those working in this program when it was originally set up that some of the materials scheduled for testing in a cryotemperature environment would not perform outstandingly in this medium. Their possession of various properties indispensible to space applications, however, led to the decision to obtain cryo-temperature data on them, and the LN_2 and LH_2 control data show that many of the plastic and rubber materials tested can be used in these environments if certain application limitations are followed.

In general, the data contained herein should be used in conjunction with that shown in the previous annual reports. No attempt is made in this report to reprint previous data or to correlate previous data with the data generated in the current period.

A complete description of all materials tested in the current period is given in Appendix A. Representative vacuum-chamber pressure curves and specimen temperature plots are given in Appendix B. A complete description of the irradiation test facility is given in Appendix C. The methods and procedures used in the dosimetry for these tests are given in Appendix D.

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I. INTRODUCTION

Radiation-effects research has shown that changes are induced in various mechanical and physical properties of engineering materials by incident nuclear radiation and also by the coincident influence of associated pressure, temperature, and chemical environments. This work has also shown, however, that materials can be used successfully in radiation fields, provided that they have first been properly screened for retention of their properties in specific applications involving radiation and other associated environments. This screening process involves the measurement of individual environmental effects and also the synergistic effects of various combination environments.

Efforts during this final two-year contractual period were directed toward continuing tests initiated in the two previous annual periods and were concerned both with generating data on new materials and obtaining new data points on previously tested items. Some new test equipment was designed and built, and other existing items of equipment were modified to facilitate data accumulation. Major items involved were a new cryotensile tester and an extensively modified dielectric tester.

A primary objective of the current program was to obtain additional information on the properties of materials tested in the previous annual program, with major emphasis being put on the radiation-cryotemperature tests. Some new materials, having particularly desirable properties, were also added to the program to replace several materials that did not qualify under irradiation conditions.

This report is organized to provide the reader with a ready access to data associated with specific materials tested. Each main section from V through XI is concerned with a particular material class and is broken down in accordance with individual materials tested under that classification. The materials tested under each classification are listed, along with the associated test parameters, on the colored section-divider pages in the report. Each material section is organized to show (1) reasons for testing the material, (2) test methods (including the test hardware used), and (3) test results.

II. TEST EQUIPMENT

The 1964-65 materials test program under Contract NAS8-2450 was conducted, primarily, with equipment developed during previous years. However, a few items of new equipment were added during this program and some modifications to existing equipment were made to improve and refine testing capabilities. Previously developed equipment that was used in its original form in the current tests is discussed in detail in References 1, 2, 3, and 4 and will only be mentioned briefly in this report. Modified and new equipment will be discussed in detail in this section.

The irradiation tests were performed in the GTR Radiation-Effects Testing Facility at NARF (see Appendix C). Figures C-1 and C-2 of Appendix C show the 3-Mw Ground Test Reactor and the Irradiation Test Cell. Items to be irradiated can be placed at any or all of the three irradiation positions (north, east, and west) adjacent to the reactor closet.

The vacuum equipment used to contain specimens during irradiation tests consists of two Vacuum-Irradiation Systems - one used on the east and one on the west side of the reactor closet. A third vacuum system, used for control tests, is located in the Irradiated Materials Laboratory (IML). Test fixtures containing specimens for irradiation were attached to the underside of the cover plate of the Vacuum-Irradiation System so that with the cover in place the test fixture was suspended within the vacuum-chamber volume. The various types of test fixtures designed for use in conjunction with the two Vacuum-Irradiation Systems and with the IML system are:

- Static Specimen Racks
- Low-Force Dynamic Tester
- High-Force Dynamic Tester
- Bearing-Lubricant Tester
- Cryomechanical Tester
- Dielectric Tester

In addition to the equipment used for vacuum and vacuum-cryotemperature testing, a Cryotensile Tester was used to maintain specimens at cryotemperature during irradiation and post-irradiation testing. Specimens were submerged in either liquid nitrogen or liquid hydrogen for these tests. Special dewars designed for use with these cryogens were used in conjunction with the Cryotensile Tester and also with apparatus used to determine the thermal conductivity of materials.

2.1 Vacuum Control System

The Vacuum Control System (Fig. 2.1) is located in the IML and is used for testing control specimens. It is also used for preirradiation outgassing, leak-checking of dynamic systems, and postirradiation testing of materials and components. The system is capable of maintaining reduced pressures as low as 6 x 10^{-7} torr in a test-chamber volume equivalent to that in a Vacuum-Irradiation System. The test chamber is mounted above a liquid-nitrogen baffle on a 16-in. diffusion pump.

2.2 Vacuum-Irradiation Systems

2.2.1 General

Two additional vacuum systems used in these tests are called Vacuum-Irradiation Systems (Fig. 2.2) and are designed to fit next to the east and west faces of the GTR closet. Figure 2.3 shows both systems in irradiation position. The systems were built to NARF specifications by Consolidated Vacuum Corporation (CVC), Palo Alto, California. During irradiation tests, lead and water shields protect the mechanical forepump, diffusion pumps, and system accessories from the reactor radiation (Fig. 2.3). The usable test volume in each system, located at the front of the vacuum chamber near the centerline of the reactor when the system is in irradiation position, is a right circular cylinder 20 in. in diameter and 34 in. in depth.

2.2.2 Vacuum Pumps

Each system contains a Model 212-H Stokes mechanical forepump and two 10-in. diffusion pumps, CVC Model PMC 4100. Pumpdown time of the vacuum-irradiation chamber to a reduced pressure of 1 x 10^{-6} torr is approximately 3 hr, depending on the materials, moisture, and condensable gases present in the system at startup.

The diffusion pumps use silicone DC-704 pumping fluid, which has a vapor pressure of approximately 1 x 10^{-7} torr. This particular silicone was selected because of its low outgassing rates during irradiation. During preliminary evaluation, the systems demonstrated pumping speeds of at least 3100 liters/sec at 10^{-6} torr.

2.2.3 Pressure Gages

The primary pressure gage used in the vacuum chambers is a nude Bayard-Alpert-type ionization gage, Type 6578, manufactured by the Vacuum Tube Division of Hughes Aircraft. This gage utilizes the vacuum chamber for its enclosure, thus eliminating the tubulation and self-pumping problems inherent with enclosed gages. A Hughes IGC-101 Ionization Gage Controller is used for excitation and readout. The gages and their electronic equipment were calibrated by the Fort Worth Division Standards Laboratory.

Since the Hughes gage can only be used at pressures below 1 x 10^{-4} torr, a CVC Phillips cold-cathode gage, Type PHG-09, is incorporated in each vacuum system for use in obtaining pumpdown data at higher pressures and for use in leak checks. This secondary gage can also substitute for the Hughes gage in the lower-vacuum region.

A more complete description of the systems is given in Reference 1.

2.3 Low-Force Tester

The Low-Force Dynamic Tester (Fig. 2.4) is used to test material specimens in either tension, compression, or bending while in an environment of high vacuum and nuclear radiation. The tester is designed to operate inside one of the Vacuum Irradiation Systems during irradiation and testing. A maximum force of 200 lb can be applied to the specimens in these tests, and a maximum specimen extension of nearly 4 in. can be obtained.

The tester has 16 test positions: eight for testing specimens in tension, six for testing specimens in compression, and two for testing specimens in bending (flexure). A hydraulic cylinder located at the top of the tester is slave-driven by an identical cylinder remotely located in the facility control room. The cylinder on the tester applies the desired loads to the test specimens and is coupled to a dynamometer used for generation of applied-tensile-load signals and a potentiometer for generation of test-specimen-deflection signals. Temperatures are monitored by copper-constantan thermocouples attached to the test specimens.

2.4 High-Force Tester

The High-Force Dynamic Tester (Fig. 2.5) is used to perform mechanical-property tests on high-tensile-strength materials in an environment of high vacuum and nuclear radiation. Tensile tests are possible for structural lap-shear-adhesive and structural-tensile specimens. A maximum force of 5000 lb can be applied to the specimens by actuation of a hydraulic cylinder in the tester. Each of the four pull rods in the tester is attached to a clevis that can hold five adhesive lap-shear or four tensile specimens. The specimens have varying-length slots to allow each specimen to be picked up and pulled, sequentially, during one continuous upward stroke of the pulling cylinder. The pull rod is coupled to a load cell which transmits an electrical signal sufficient to determine the applied loads on the specimens. An LVDT was used previously for rod-movement indication, but has since been replaced by a Helipot wire-wound potentiometer. The potentiometer yields rod-motion data similar in form and accuracy to that obtained in the Low-Force Tester and the Cryotensile Tester. The tester is designed to be used in one of the Vacuum-Irradiation Systems.

2.5 Cryomechanical Tester

The Cryomechanical Tester (Fig. 2.6) is a device designed to apply tensile forces to material specimens while maintaining the specimens under a combination environment of high vacuum, cryo-temperature, and nuclear radiation. The tester is built to operate within one of the Vacuum-Irradiation Systems.

The tester contains six pull positions, each capable of exerting a force of 5000 lb on a specimen. Four specimens can be tested consecutively at each position. Each of the six pull positions is operated by an independent hydraulic cylinder. Each cylinder is driven from a remote location by a master cylinder which is mounted in, and driven by, an Instron machine. Coupled with each cylinder actuating rod is a load cell and potentiometer for transmission of applied-load and actuator-rod-movement signals.

The tester contains three sealed chambers. These are: (1) the upper vacuum chamber, (2) the main vacuum chamber, and (3) the cryogen chamber. In the upper vacuum chamber, a vacuum of the order of 10 microns is maintained to minimize conductive heat flow. Two tubes pass through this chamber into the cryogen chamber, one for cryogen exhaust and the other to serve as a path for the liquid-level-control probe and for connections to safety equipment. The latter consists of a rupture disc, rated at 99 psi, and a 70-psi pop relief valve.

The cryogen inlet, thermocouple probes, and pull rods pass through the vacuum-system mounting plate. All components passing through the mounting plate are vacuum sealed. The cryogen flows through a coil of 0.50-in.-diam stainless-steel tubing which surrounds the specimens, and into a 5.0-in.-diam chamber. It boils off in this chamber and the evaporate is exhausted through a facility exhaust system. Cryogen flow is regulated (see Section 3.3) to maintain a two-thirds-full condition in the cryogen chamber.

2.6 Bearing-Lubricant Tester

The Bearing-Lubricant Tester is used to measure the lubricating properties of materials during exposure to an environment of air or high vacuum, and air or high vacuum in combination with nuclear radiation. Ten servomotors with SR3-type bearings are used to test paired samples of five types of lubricants. Lubricating characteristics of the materials are determined by measuring the coastdown time of the motors, motor speed, field current, time of operation, and bearing temperature.

The Bearing-Lubricant Tester is shown in Figure 2.7. Essentially, the tester consists of ten small servomotors and flywheels, two water-cooled aluminum mounting blocks, ten magnetic reed switches, and necessary wiring and support members.

The electrical instrumentation, shown in Figure 2.8, consists of a power control panel with ten milliammeters for reading currents drawn by the field windings of each motor; an electronic counter, printer, and oscilloscope for motor-speed determination; a reed-switch selector panel and pulse-shaping network; and a dc power supply for reed-switch signals.

Motor speed is measured by use of the magnetic reed switches, which are actuated by a magnet on the periphery of the flywheel of each motor. The reed switch is in series with a dc power supply so that when the switch is closed an electrical pulse is produced. The pulses are fed through a pulse-shaping network to an electronic counter and/or an oscilloscope.

The bearings used in the tests were types SR3RHH and SR3M manufactured by Miniature Precision Bearings, Inc., Keene, New Hampshire. Type SR3RHH bearings, having ribbon-type retainers and two shields, were used to test all lubricants except Duroid, Polymer SP-F, and Kynar (filled). The SR3M type bearings had retainers machined from the test materials. No shields were employed, and the outer race was bore-ground on one side to a diameter equal to the major diameter of the outer ball groove.

Additional detailed information on the Bearing-Lubricant Tester is included in Reference 3.

2.7 Dielectric Testers

The Dielectric Testers shown in Figures 2.9 and 2.10 were designed to determine the changes in dielectric constant, dissipation factor, and volume resistivity of solid dielectric specimens, that are produced by high vacuum and cryotemperatures with and without nuclear radiation. Tests were also conducted to determine the effects of nuclear radiation and an air environment on these same properties.

2.7.1 Basic Equipment

The basic equipment consists of eight aluminum dielectric test cells mounted vertically on two stainless-steel panels. The test cells (Fig. 2.11) are fabricated in accordance with ASTM D 160-59T, "A-C Capacitance, Dielectric Constant, and Loss Characteristics of Electrical Insulating Materials." The unguarded electrode and guard ring are 4.5 in. in diameter. The guarded electrode is 3.96 in. in diameter, and the gap width between the guarded electrode and guard ring is 0.020 in. The guarded electrode and guard ring of each test cell are secured to a boron-nitride disc 5.1 in. in diameter by 0.25 in. in thickness which, in turn, is secured to the steel panel. A spring-loaded aluminum plunger in contact with the unguarded electrode secures the test specimens between the electrodes. Specimens varying in thickness from 0.002 to 0.250 in. can be tested.

A copper-constantan thermocouple is embedded ~0.12 in. into each guarded electrode and is sealed in place with a boron-nitride adhesive.

The instrumentation (Fig. 2.12) associated with the testers consists of (1) a capacitance-measuring assembly, Type 1610-A, manufactured by General Radio Company, which is used for determination of ac capacitance and loss characteristics; (2) a Tera-Ohmmeter (Model FT-H4) manufactured by Federal Telephone and Radio Company, used for resistance measurements; and (3) an electronic recorder manufactured by Minneapolis-Honeywell, used for test-cell temperature monitoring.

2.7.2 Cryotemperature Dielectric Tester

The Cryotemperature Dielectric Tester used in the current period is a redesigned version of the tester used previously (Ref. 3). It is shown in two views in Figures 2.10 and 2.11. The purpose of the modifications was to obtain lower specimen temperatures than were previously possible. The major changes were involved with the cryopanels, electrode material, and electrical insulation used between the guarded electrode and the cryopanel.

Two rectangular, hollow, stainless-steel cryopanels serve as the mounting surfaces for the test cells. With these panels filled with liquid nitrogen, specimens are maintained at a cryotemperature. Liquid nitrogen is supplied to the bottom of the tester through a 1/2-in.-OD fill tube incorporating a 4-in.-long bellows joint. Rectangular end plates are bolted to the front and back of the tester. Liquid nitrogen flows into each cryopanel and surge tank at the bottom and is vented at the top. A liquid-level probe consisting of a rake of seven carbon resistors and three copper-constantan thermocouples is immersed in the surge tank for cryogen-level monitoring and control.

Boron-nitride discs and adhesive are used for electrical insulation and for good heat transfer between the guarded electrodes and cryopanels and between the aluminum plungers and the unguarded electrodes. Heat conductive paths are provided from the test cells to both cryopanels. In addition, radiant heat transfer occurs from the test cells to the cryopanels and end plates of the tester. The main part of the tester is wrapped with several layers of aluminum foil (Fig. 2.13) to minimize radiant heat transfer between the tester and vacuum chamber walls.

2.7.3 Air-Environment Dielectric Tester

The dielectric tester (Fig. 2.9) used in an air environment is similar to the cryogenic tester except for the cryotemperature and vacuum provisions in the latter. Solid 0.25-in. stainless-steel plates replace the hollow cryopanels, and the cryogen fill tube, surge tank, and liquid-level probe are omitted.

2.8 Cryotensile Tester

2.8.1 Basic Equipment

The Cryotensile Tester is designed for use with the dewars described in Section 2.10 for testing specimens in LH_2 and LN_2 immediately after irradiation. The system (Fig. 2.14) is designed to apply vertical tensile loads to slotted specimens located in four clevis assemblies. Each clevis assembly can contain as many as 20 tensile specimens, the quantity being limited by the specimen thickness and difference in successive slot lengths.

The overall height of the tester is approximately 8 ft, the width 3-1/2 ft, and the depth 1-1/2 ft. The structure is made of aluminum which, because of rapid radioactive decay rates, permits repeated use of the system in neutron irradiation tests over relatively short time periods. A horizontal dewar-mounting flange is located approximately one third of the way up from the bottom. The portion of the tester below the flange fits into a dewar, as shown in Figure 2.15.

Tensile data, in the form of applied tensile load in pounds and linear pull-rod travel in inches, are obtained with the equipment. The applied loads to the specimens are obtained through actuation of a vertically mounted hydraulic cylinder. The cylinder has a net piston area of 6.8 in.^{2} and a stroke of 9.0 in. The cylinder is mounted in the upper section of the tester. The piston rod of the hydraulic cylinder is coupled to a strain-gage-type load cell which provides electrical signals to instrumentation for determining loads to specimens. Double pull rods extend from the load cell, through the dewar mounting flange, to the clevis assemblies. These pull rods are sealed to the flange with stainless-steel bellows to ensure a vacuum-tight connection. A gear rack is mounted to the upper portion of the pull rod and engages a pinion gear mounted on the shaft of a potentiometer. Rod travel is thus transmitted to instrumentation in the form of varying potentiometer voltages. The entire upper portion of the tester is covered with an aluminum housing, or shroud. All connections to the tester are routed through this shroud.

The lower section of the double-pull-rod system connects to the upper end of the clevis assembly in which the tensile test specimens are loaded. The specimens themselves are the connecting link between the upper and lower sections of the clevis assembly. The lower section of the clevis assembly is secured to the lower extremity of the aluminum structure, forming a continuous tensile linkage between the lower clevis and the actuating hydraulic cylinder.

Each tensile test specimen contains a circular mounting hole near the bottom of the specimen through which the lower-clevis connecting pin passes, thus securing it to the clevis. The upper end of the tensile test specimen contains a slot for attachment with the upper-clevis connecting pin. The slots are varied in length to permit sequential loading of successive specimens by the upper-clevis connecting pin as the upper clevis is moved vertically upward by the hydraulic cylinder. Actuation of individual hydraulic cylinders in the tester is accomplished by slaving them to one master hydraulic cylinder mounted between the load-cell fitting and the crosshead member of an Instron machine. The crosshead downward motion in the Instron machine results in upward linear motion of the upper section of the clevis assembly, thus applying a tensile load to the test specimen. An accurate control of the Instron machine crosshead speed yields precise vertical movement rates for the upper section of the clevis assembly and enables compliance with established ASTM tensile-testing rates for the specimens.

The cryogen container for the tester is attached to the lower surface of the dewar mounting flange and encloses the clevis assembly. This container is slotted at the top, but is designed to maintain the cryogen liquid level above the upper section of the clevis assembly. With the tester mounted in the dewar cavity, the resultant boil-off of cryogen passes over the upper edge of the cryogen container, into the cavity, and out an exhaust port.

Under testing conditions utilizing liquid hydrogen, an inert gaseous helium purge of the shroud is maintained. Gas-tight connections are provided within the test assembly for insertion of measurement devices such as liquid-level indicators, pressure sensors, and thermocouples.

A small pump is included within the hydraulic system for priming and bleeding purposes. Hand valves are incorporated to select directional flow and individual tester cylinder action. Copper tubing, of 0.25-in. diameter and 0.030-in. wall thickness, is utilized for routing the hydraulic fluid. Valving and connections are provided to bleed the system of hydraulic fluid that might have been damaged during irradiation. This fluid is flushed out, collected in an individual reservoir, and replaced with new fluid prior to initiation of tests. Pressure relief valves and manifold pressure gages are utilized to ensure proper system protection.

2.8.2 Calibration of Load Cells

Individual load cells were serialized and calibrated. The calibrations were conducted with an Instron machine for application of known loads to a given load cell. Readouts were obtained in percent of bandwidth for each of the Sanborn scales: X1, X2, X5, X10, X20, X50, and X100, with emphasis placed on X1 through

X50. A total of 33 increments were recorded from 0 to 5000 lb, and back to 0 lb. Of these 33 increments, 26 were utilized in the up-scale calibration to 5000 lb while the remaining seven were used to check down-scale readings, and repeatability, from 5000 to 0 lb.

2.8.3 Calibration of Pull-Rod-Movement Potentiometers

Individual wire-wound potentiometers (Helipot Model C, 1000 ohms) were calibrated over a total distance of 4.0 in. This distance was sufficient to measure the pull-rod travel for all given specimen configurations. The known travel was correlated with the percent of bandwidth of a Sanborn Recorder. The series of calibrations indicated that all of the potentiometers were reading out with less than 1% deviation between any two units. The calibration curve was a straight-line function having a slope of 0.061 in. of travel per 100% Sanborn bandwidth. This factor was utilized as the data-reduction function for pull-rod travel.

2.8.4 Measurement of Biasing Forces

Biasing forces that result in the deformation of component parts of the tester assembly during tests on specimens were measured for each tensile-test-specimen position. The resultant deformation correction in terms of inches per inch of elongation per total load force was plotted for specific positions. A correction factor was then determined from these plots and used during data reduction to determine correct strain values for each given test specimen.

2.9 Cryogen Dewars

2.9.1 Liquid-Nitrogen Dewar

The all-welded, aluminum, liquid-nitrogen dewar (Fig. 2.16) was designed and fabricated at the Fort Worth Division. It is obround in shape, having overall dimensions of approximately 43 in. in width, 18 in. in depth, and 37 in. in height.

The assembly consists of two concentric obround enclosures, having radially enclosed ends and bottom. A top cover plate is attached to both enclosures and is provided with an opening for insertion of a test assembly. A vacuum is maintained between the two outer walls of the dewar for thermal insulation. The vacuum space is protected by means of a rupture-disc assembly mounted to the common top plate. A rupture-disc assembly is also used to protect against overpressure within the main dewar cavity. Discharge from either rupture disc is vented to the atmosphere.

An exhaust port used to discharge evaporated cryogen is located in the common top plate. Exhaust is routed to the test-facility exhaust system. A pneumatically operated valve is located on the bottom of the assembly and is used to drain cryogen from the test cavity.

2.9.2 Liquid-Hydrogen Dewar

The liquid-hydrogen dewar used in these tests is composed of two concentric aluminum cylinders with similar 2:1 elliptical closures at the bottom (Fig. 2.17). The cylinders are connected to a common circular top plate. A rectangular opening used for insertion of the Cryotensile Tester is located in the top plate eccentric to the dewar centerline by 5 in. The dewar is approximately 4 ft in diameter and 3-1/2 ft in height. The opening is 37 in. by 9 in.

A vacuum is maintained between the cylindrical walls for insulation. A vacuum check valve provides protection for the vacuum chamber. Evaporated cryogen is exhausted from the inside bottom of the main dewar cavity through an aluminum tube extending through the top plate. The evaporate is then routed through flexible exhaust lines to the main facility exhaust stack. A secondary exhaust port is also provided within the assembly. It is sealed from normal flow by a rupture disc rated at 22 psig. Excessive pressures within the main dewar cavity will rupture this disc and exhaust through a secondary facility exhaust stack.

The mounting flange of the tester assembly is secured to the top plate by high-tensile stainless-steel bolts located around the perimeter of the rectangular hole. A 1/16-in.-thick asbestos gasket is employed between the flange and top plate.

2.10 Thermal-Conductivity Tester

A test was conducted to measure the thermal conductivity of various rigid, organic, foam-type insulation materials at temperatures ranging from +90°F to -380°F after exposure to a relatively low and a relatively high dose of nuclear radiation. Test specimens were maintained in a room-air environment or submerged in liquid nitrogen or liquid hydrogen during preirradiation control tests, during the actual irradiation, and during postirradiation tests. The postirradiation thermal-conductivity measurements at cryotemperatures were performed without the specimens having been removed from the cryogen, from the beginning of the irradiation through the postirradiation tests.

The testing device consists of an arrangement of three concentric cylinders, with the inner cylinder made up of 40-gage constantan wire spiral-wound on a 3/4-in.-diam ceramic spool, a central cylinder of test-specimen foam, and an outer aluminum cylinder serving as a container for the device. Figure 2.18 shows longitudinal and horizontal cross-sectional views of the test unit.

The figure shows that no separate guard heater is used. Instead, power dissipation in the center 2 in. only of the heater coil is used to calculate thermal-conductivity values, with the 3 in. on each end of the heater serving as effective guard heaters. In addition, 2-in.-long plugs of the test foam are placed at each end of the heater-test-specimen section to ensure virtual radial flow of heat through the test specimen.

The length of the heater and test-specimen section is 8 in. The overall length and diameter of the test unit are 12.25 in. and 3.00 in., respectively. The test foam cylinder and two foam plugs (one at each end) were carefully machined on a lathe to tolerances of +0.001 in. and -0.005 in. This ensured a press fit for the test foam cylinder into the outer container and for the heater core into the test foam. Twelve thermocouples for thermal-conductivity determinations were placed in the test foam, as shown in Figure 2.18. Six inner thermocouples were located 1/8 in. into the foam from the heater core, and six outer thermocouples were located 1/8 in. into the foam from the inner surface of the outer container.

Although some slight non-radial flow of heat from the heater might take place near its ends, heat flow from at least a 4-in.

length of heater in the center of the unit was assumed to be purely radial. This assumption was verified in a computer analysis using the N76 program in an IBM 7090 computer. All twelve thermocouples were placed within $\pm$ 1 in. of the center of the unit, as can be seen in Figure 2.18.

Placement of these thermocouples was a critical operation from the standpoint of maintaining dimensional integrity and minimizing rupture of foam cell walls near the thermocouple placement point and in the thermocouple lead-wire path. It was desirable, of course, to have maximum contact between the thermocouple junction and the immediately surrounding cell walls for good conductive heat transfer. Thermocouple placement was accomplished by attaching the thermocouple junction to the point of a hypodermic needle and puncturing the foam to the specified depth. The depth was held constant by use of a fixed flange on the needle. The heater wire was high-resistance, 40-gage constantan; the heater lead-in wire was copper. The lead-in wire for the copper-constantan thermocouples was 3-mil size. The thermocouple junction diameter was estimated to be in the order of 5 mils. Both the heater and thermocouple lead-in wires entered the test section through a passageway drilled through the top insulation plug.

The constantan heater wire was uniformly wound on the ceramic spool so that heat generated in (and dissipated from) the heater was uniform along its length. This means that heat conducted radially through the 2-in. section of test foam containing thermocouples was equal to one-fourth of that generated in the entire heater. A small amount of heat was lost by conduction out of the heater and thermocouple lead-in wires. This was calculated and subtracted during data reduction. The I^2R losses from heater lead wires were also calculated and subtracted.

Four different foam materials were tested in the current contractual period, and each test cycle used an arrangement of four test units, each containing one of these four foams. For the air control, irradiation, and postirradiation tests the units were exposed to the atmosphere, as shown in Figure 2.19. The arrangement used for testing at cryotemperatures is shown in Figure 2.20. As can be seen in the figure, the units were flanged to a tubular lead-wire housing which, in turn, was flanged to a dewar-mounting flange. During LN_2 tests the assembly was used with an LN_2 irradiation dewar, as shown in Figure 2.21. During LN_2 tests, the LN_2 level in the dewar was maintained at a point several inches above the flange on the test unit. This flange was sealed with an indium-wire gasket, and a vacuum of approximately 2000 microns was maintained in each test unit. Some degree of vacuum was necessary to prevent frost and liquid air from accumulating at various points in the units.

For tests utilizing liquid hydrogen as the cryogen, the LH_2 dewar shown in Figure 2.17 was used.

NPC 24,268
31-6521

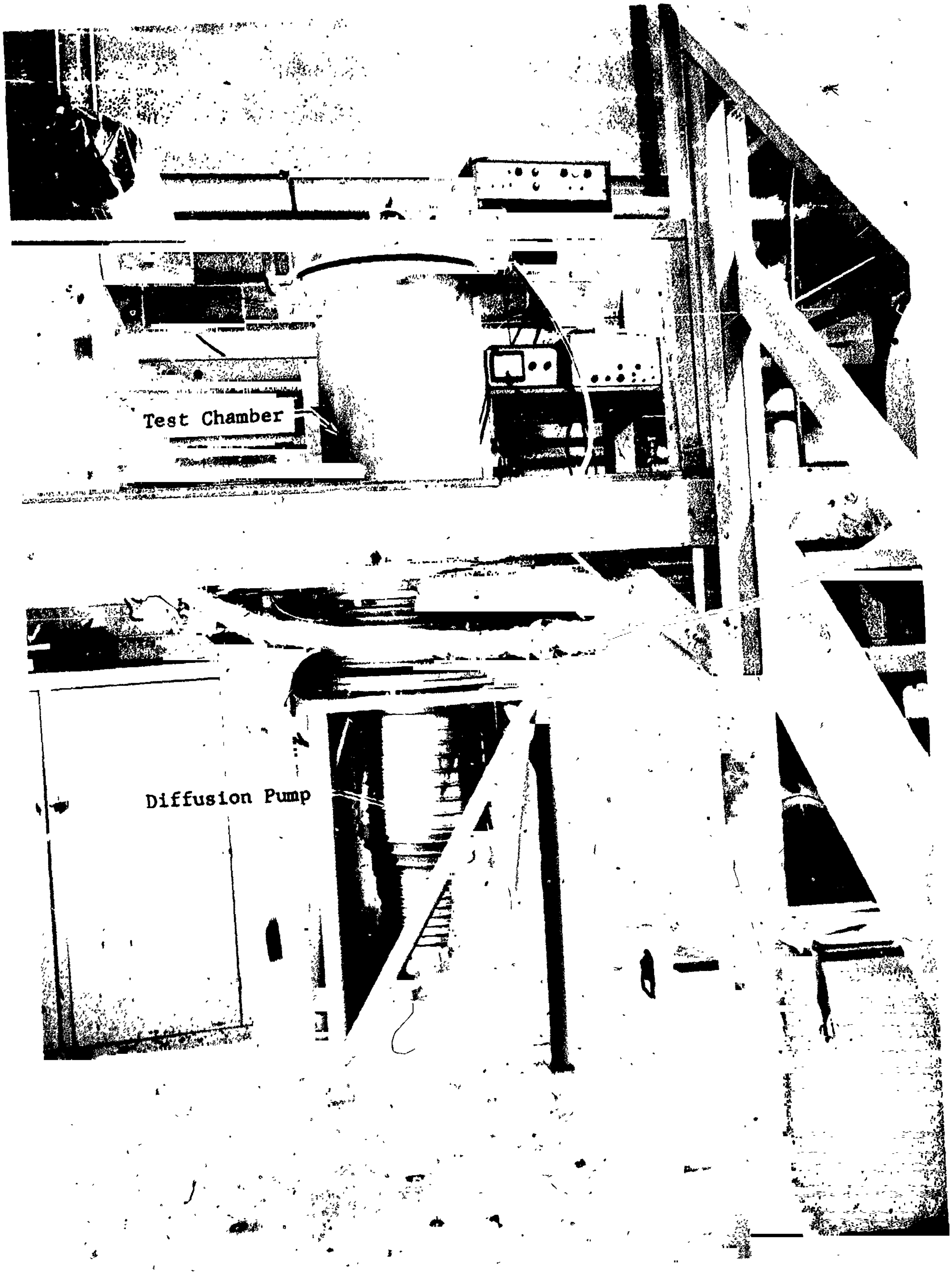


Figure 2.1 Vacuum Control System

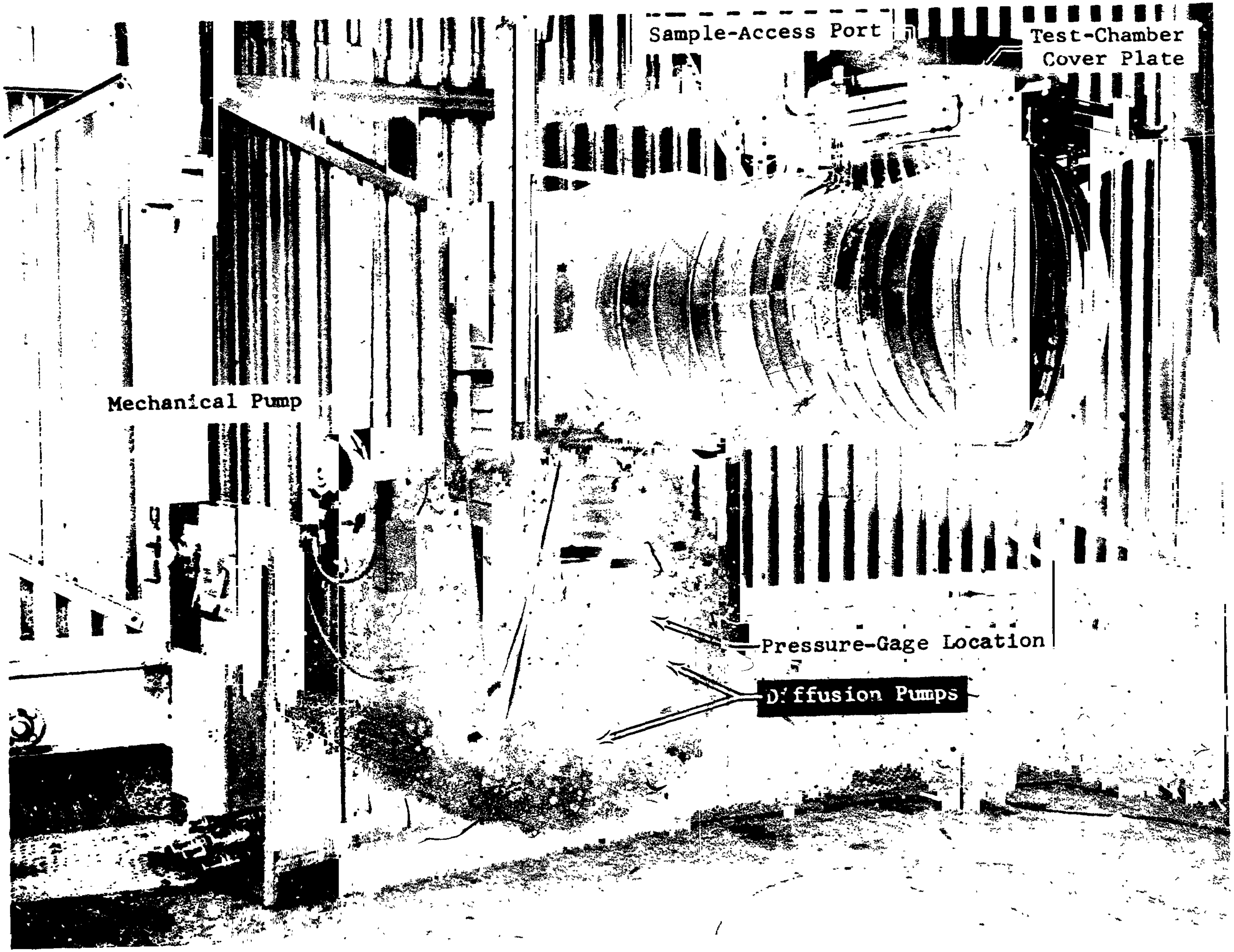
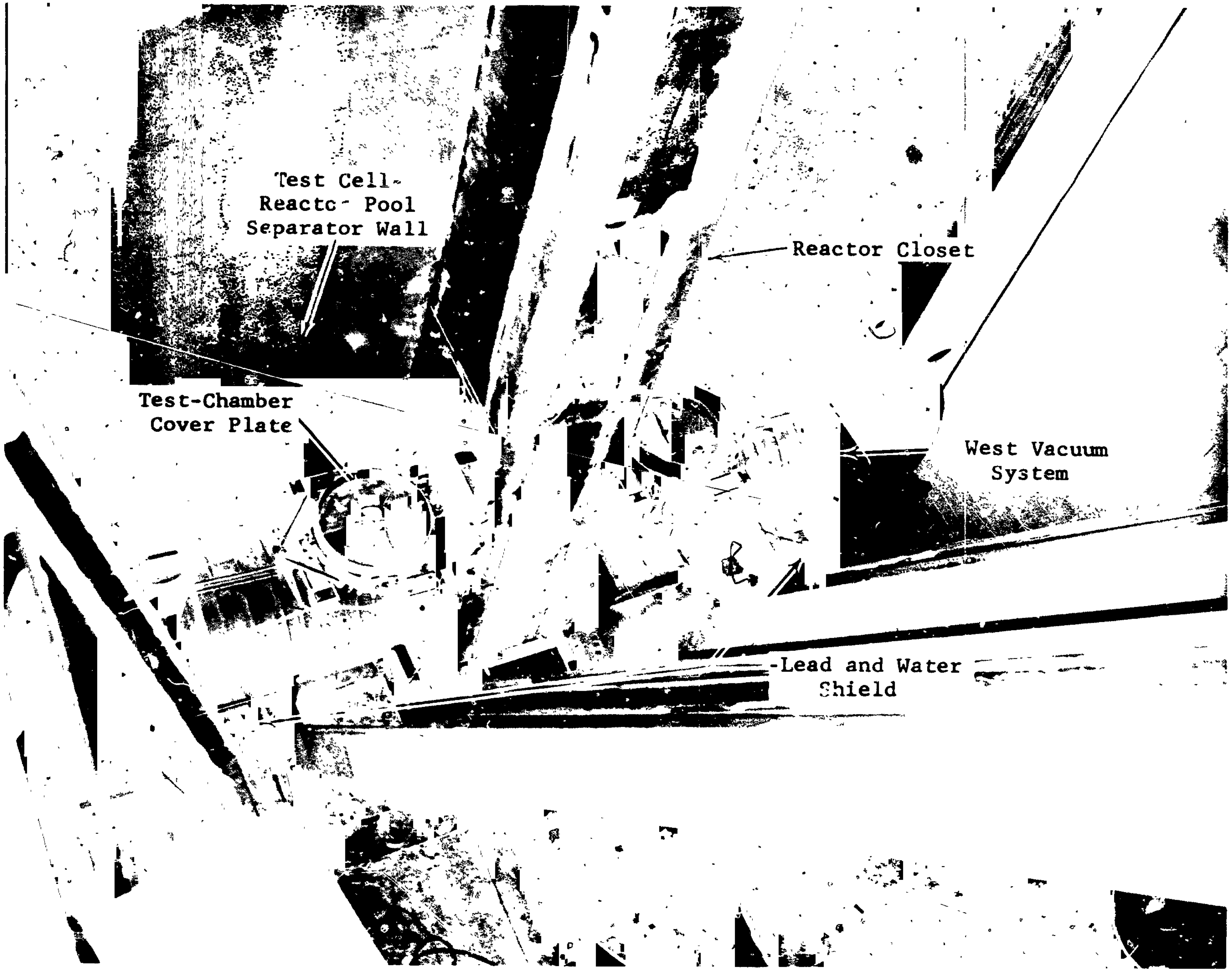


Figure 2.2 Vacuum-Irradiation System



NPC 24,270
31-7641

Figure 2.3 Vacuum Systems in Irradiation Position

NPC 24,271
31-6545

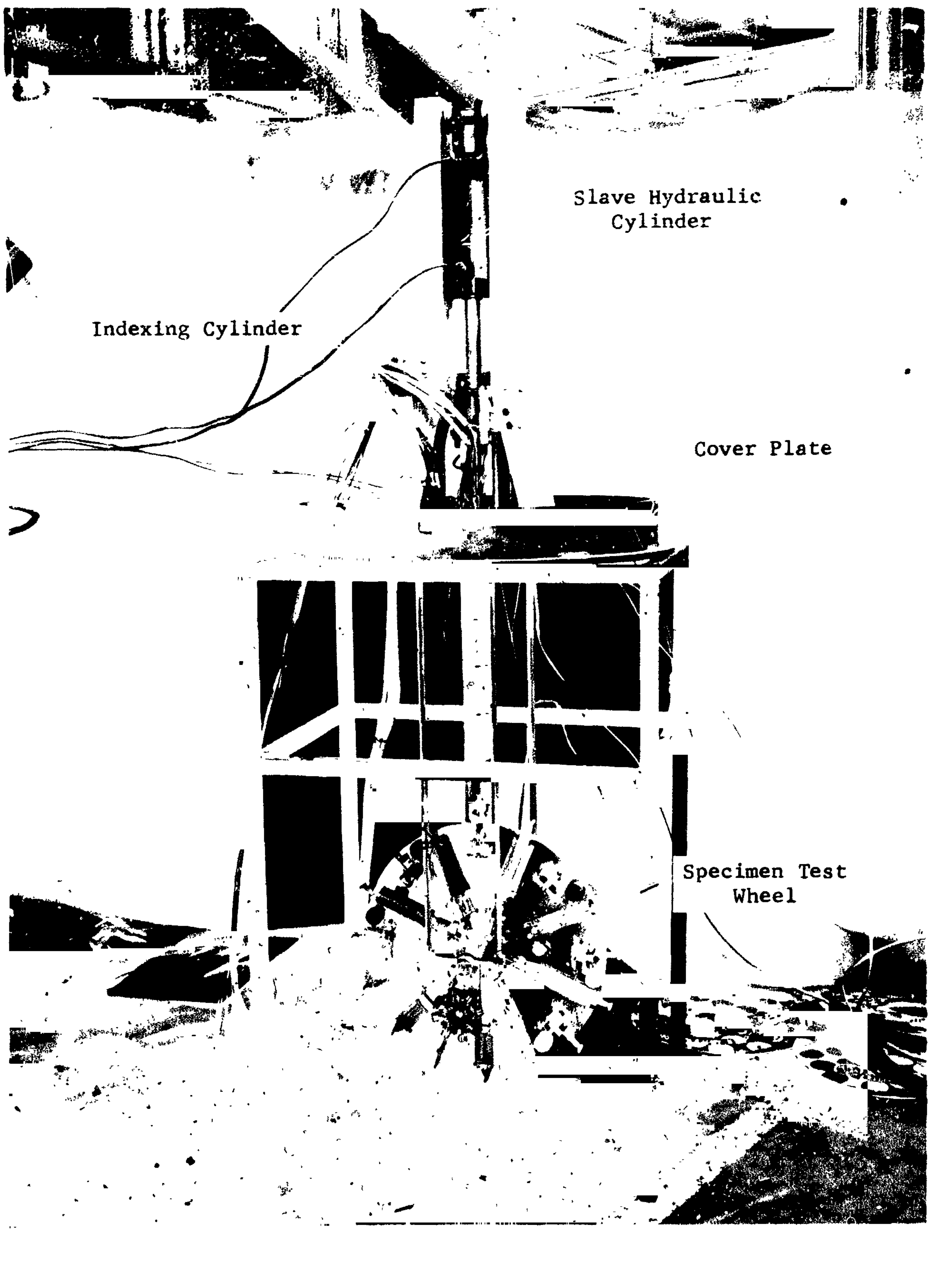


Figure 2.4 Low-Force Dynamic Tester

NPC 24,272
31-6548

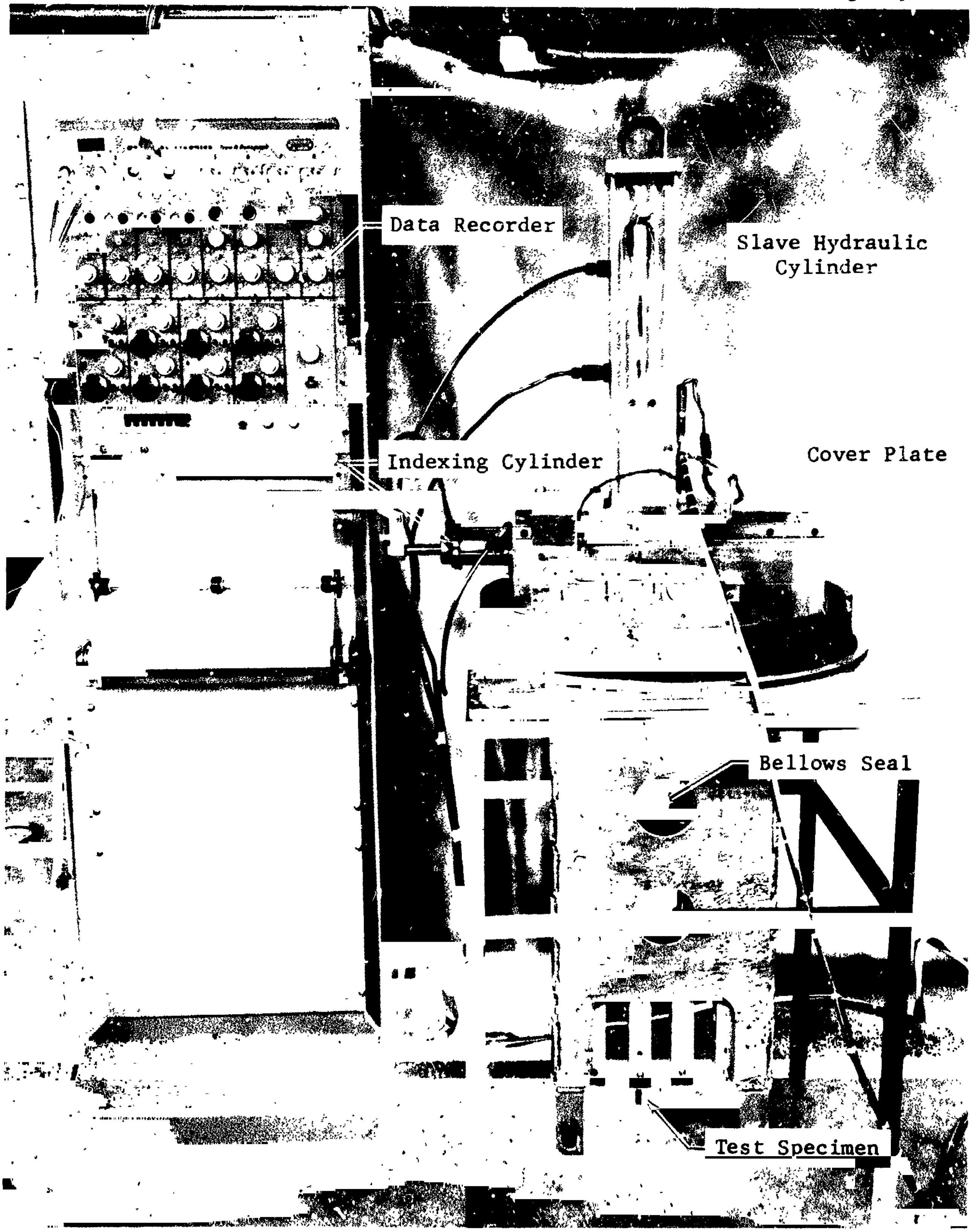


Figure 2.5 High-Force Dynamic Tester

NPC 24,273
31-7645

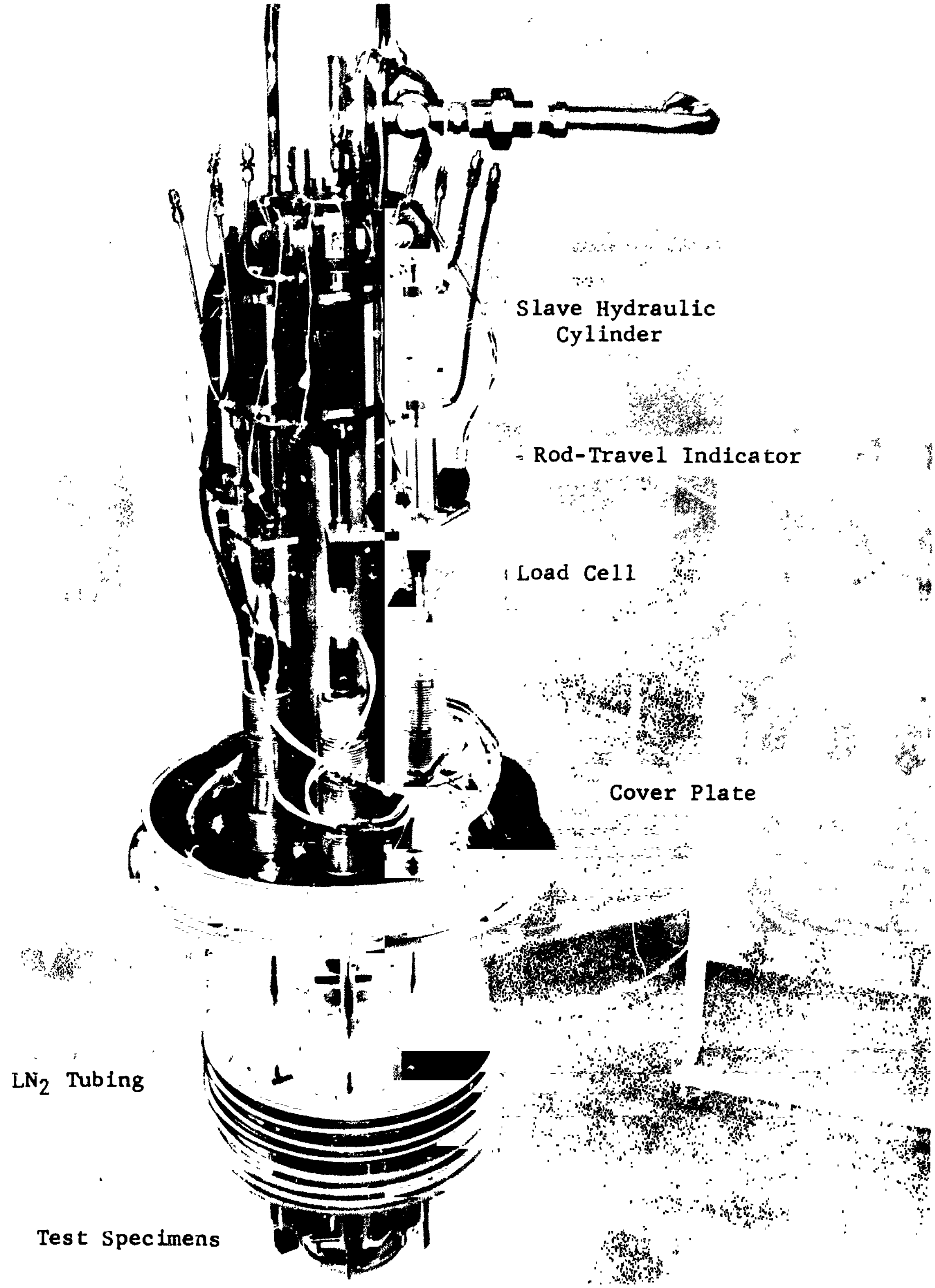


Figure 2.6 Cryomechanical Tester

Figure 2.7 Bearing-Lubricant Tester

NPC 24,275
31-8605

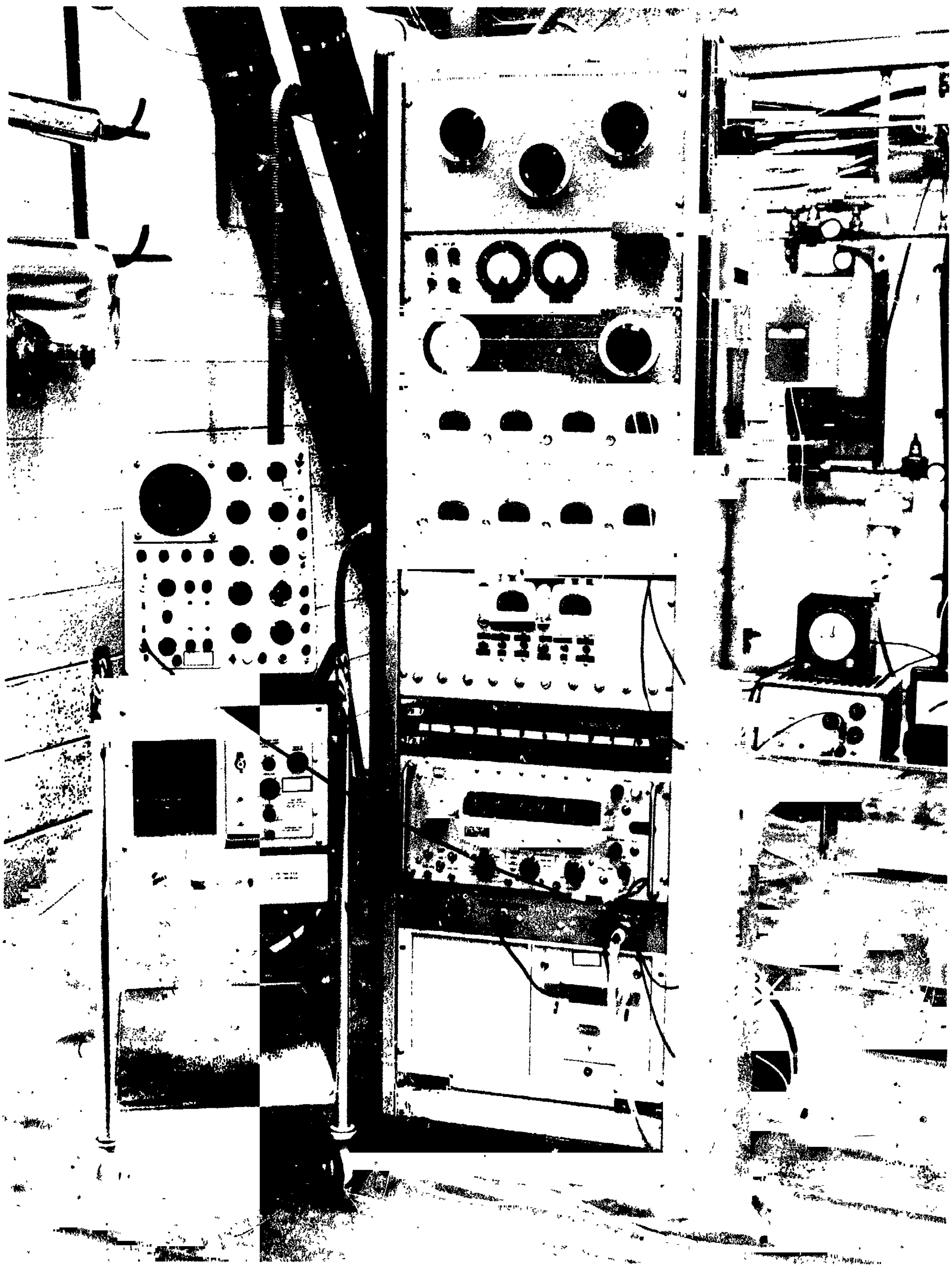


Figure 2.8 Bearing-Lubricant-Tester Instrumentation

NPC 24,276
31-8551

Figure 2.9 Air-Environment Dielectric Tester

NPC 24,277
31-8524

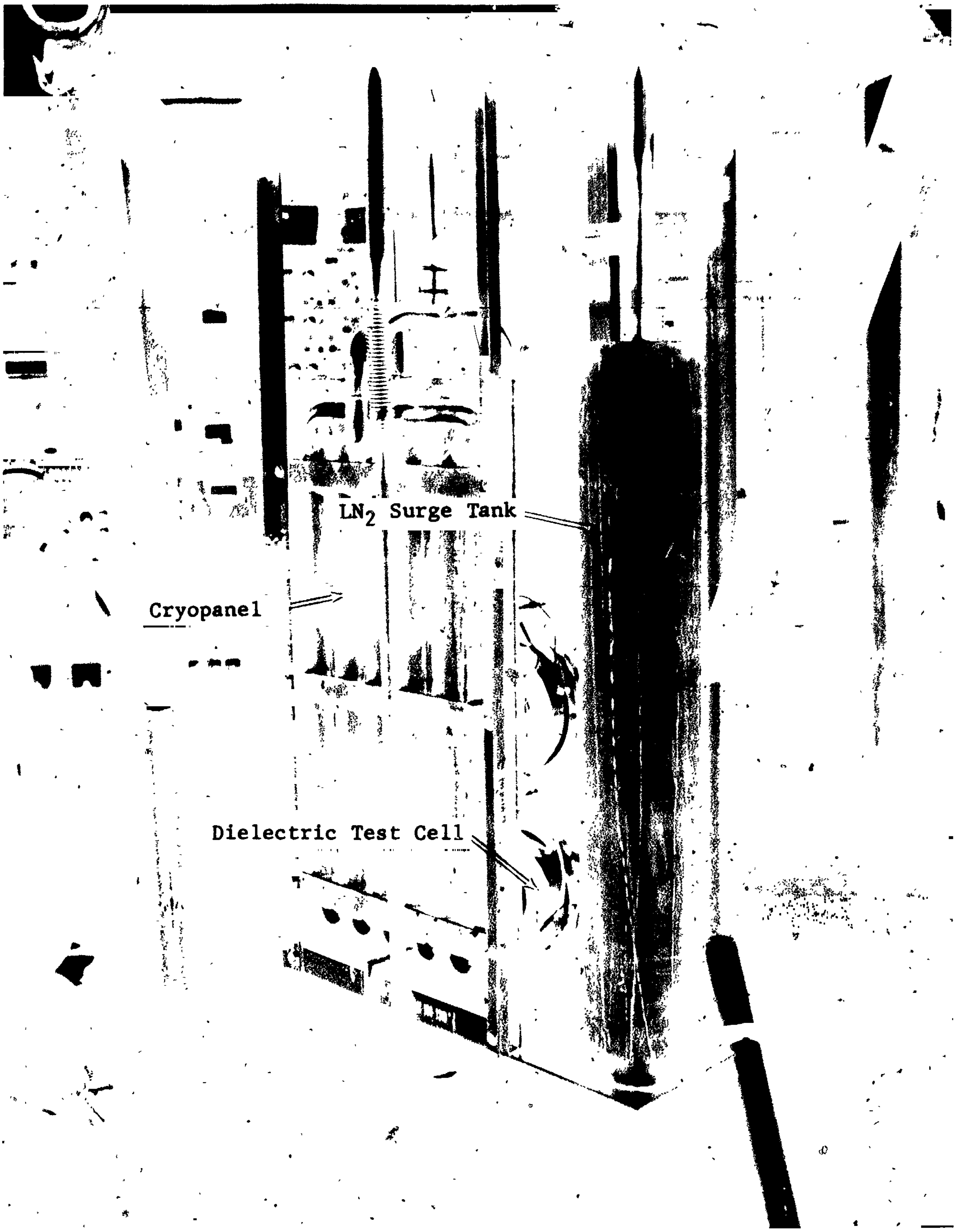


Figure 2.10 Cryogenic Dielectric Tester (Side View)

NPC 24,278
31-8523

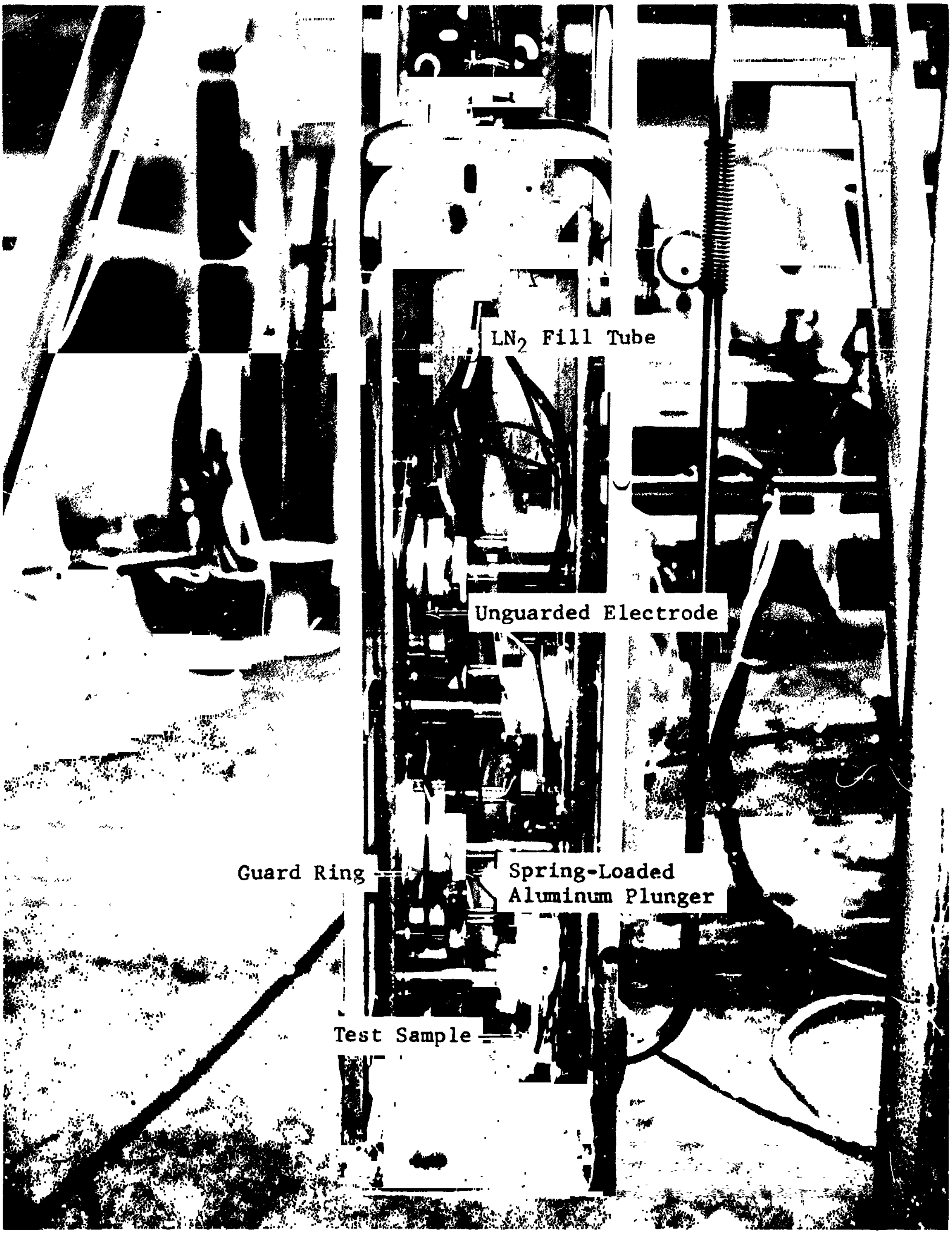


Figure 2.11 Cryogenic Dielectric Tester (Front View)

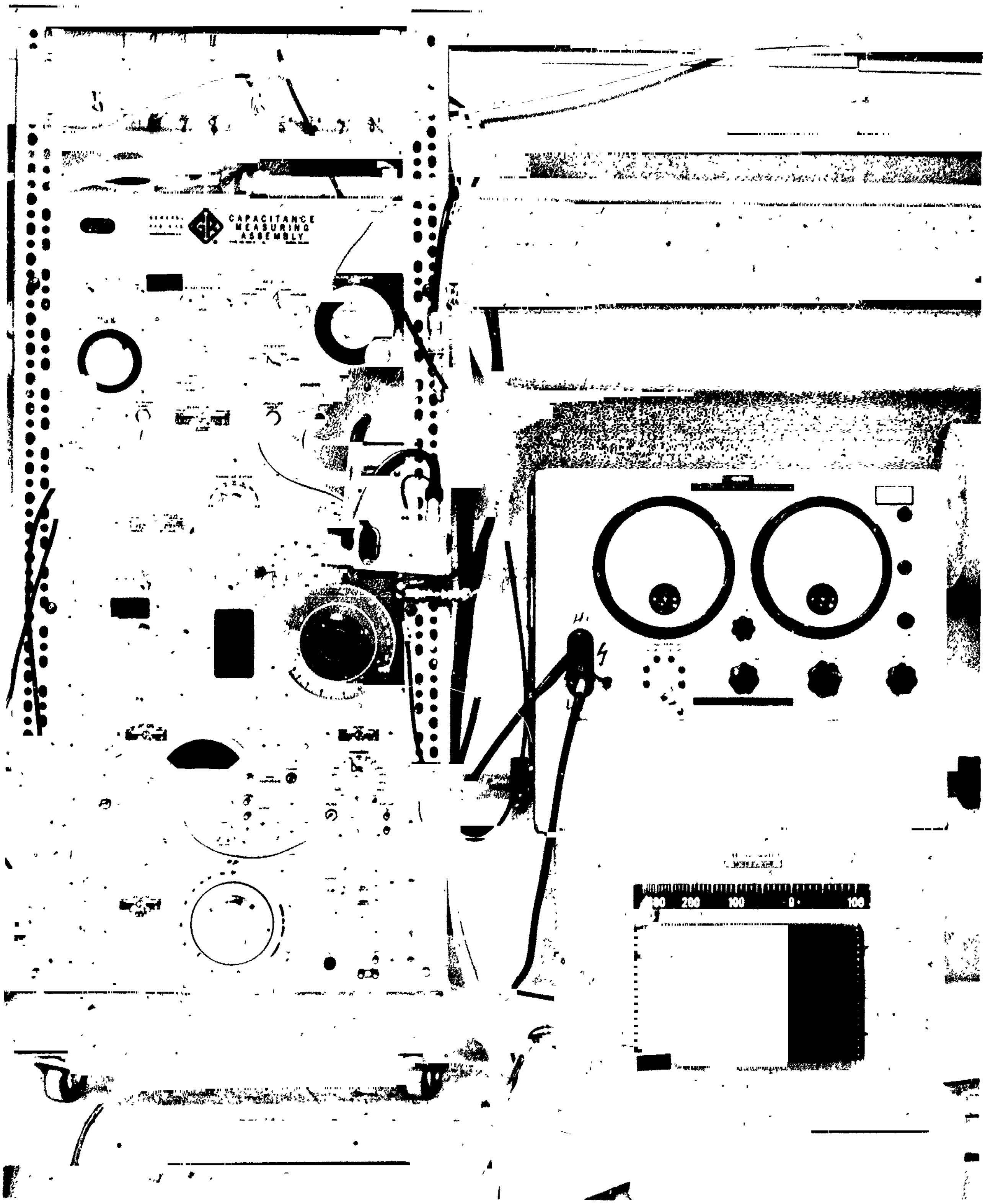


Figure 2.12 Dielectric-Test Instrumentation

NPC 24,280
31-8552

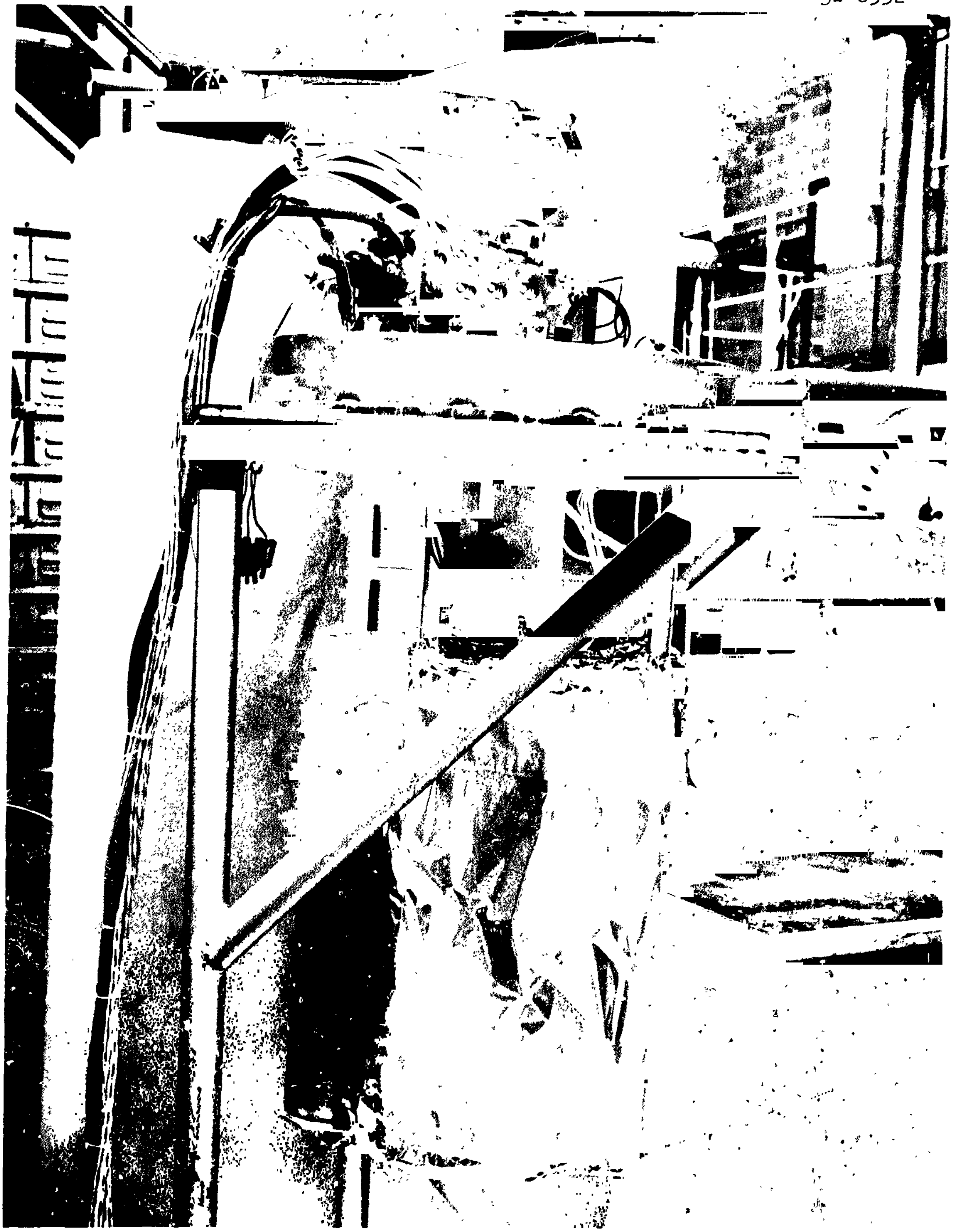


Figure 2.13 Cryogenic Dielectric Tester Covered by an Aluminum-Foil Heat Shield

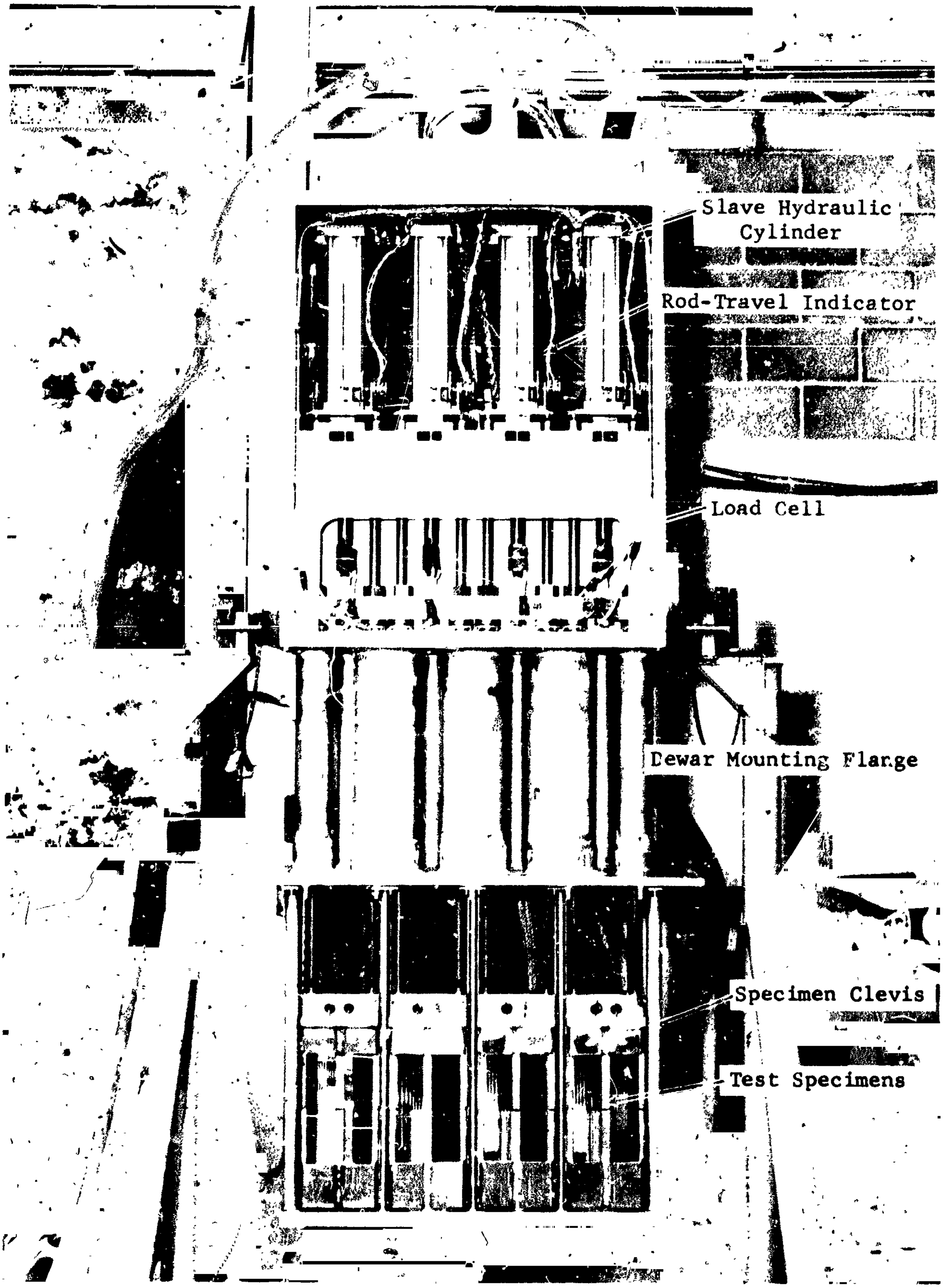


Figure 2.14 Cryotensile Tester

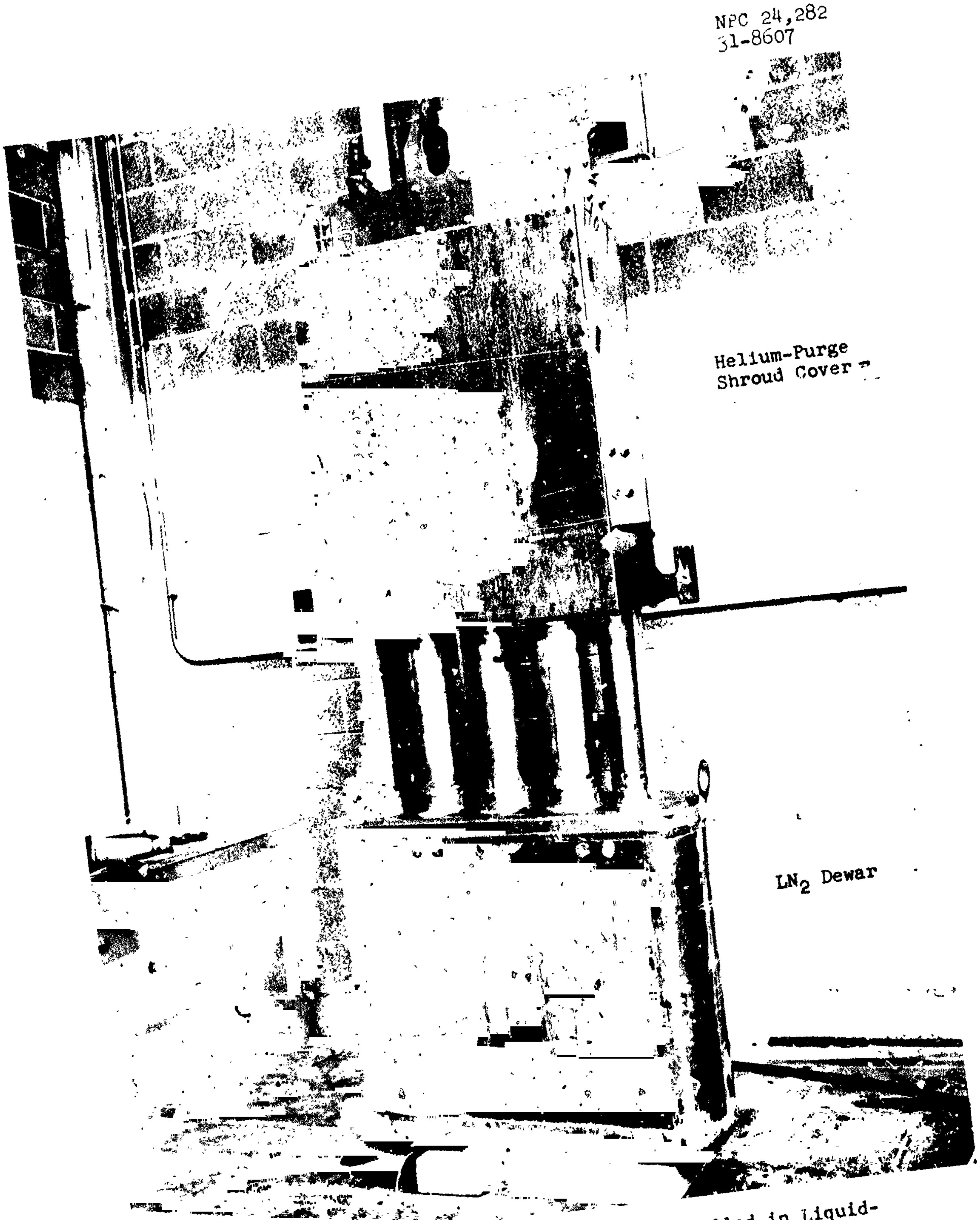


Figure 2.15 Cryotensile Tester Installed in Liquid-Nitrogen Dewar

NPC 24,283
31-8606

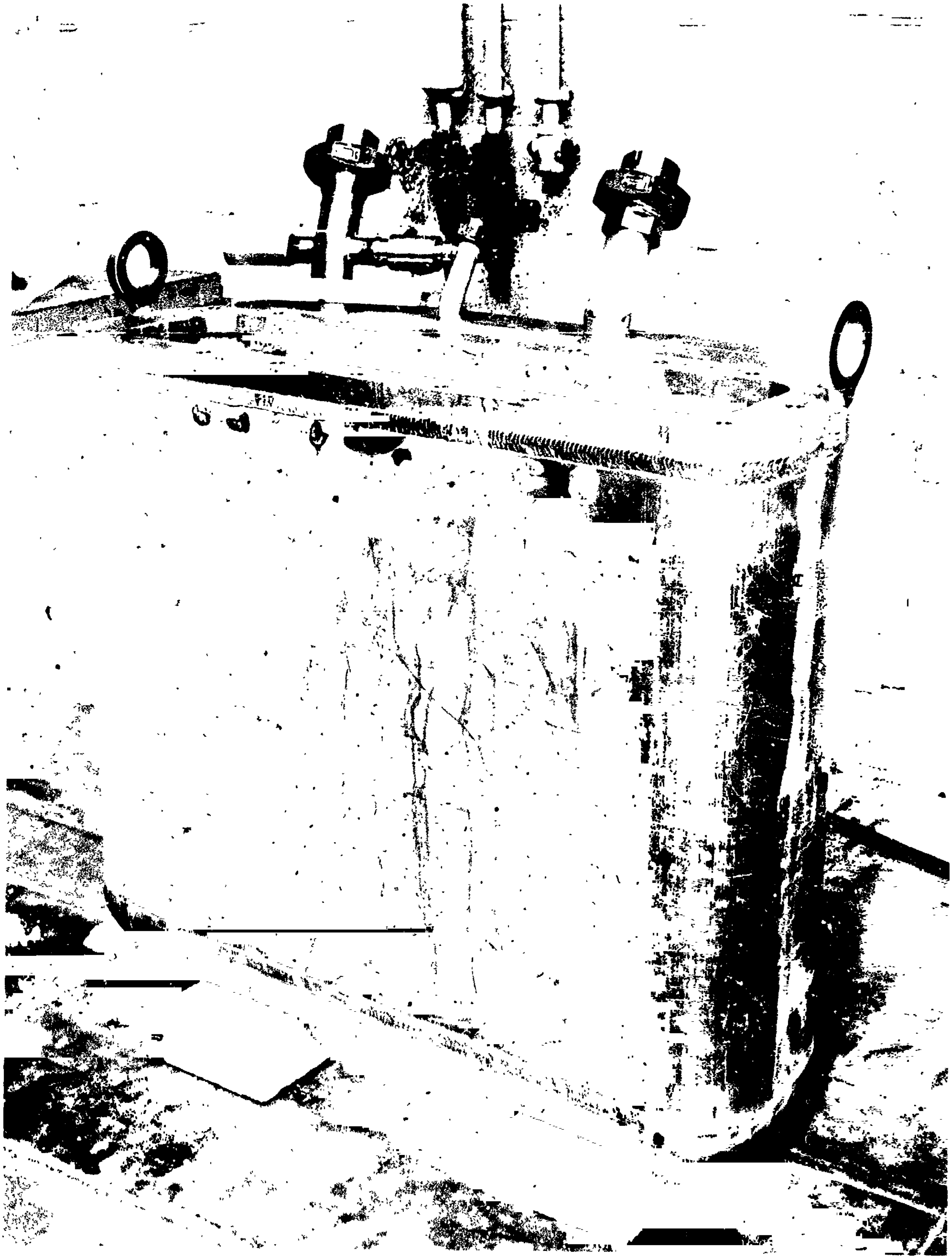


Figure 2.16 Liquid-Nitrogen Dewar

NPC 24,284
31-8210

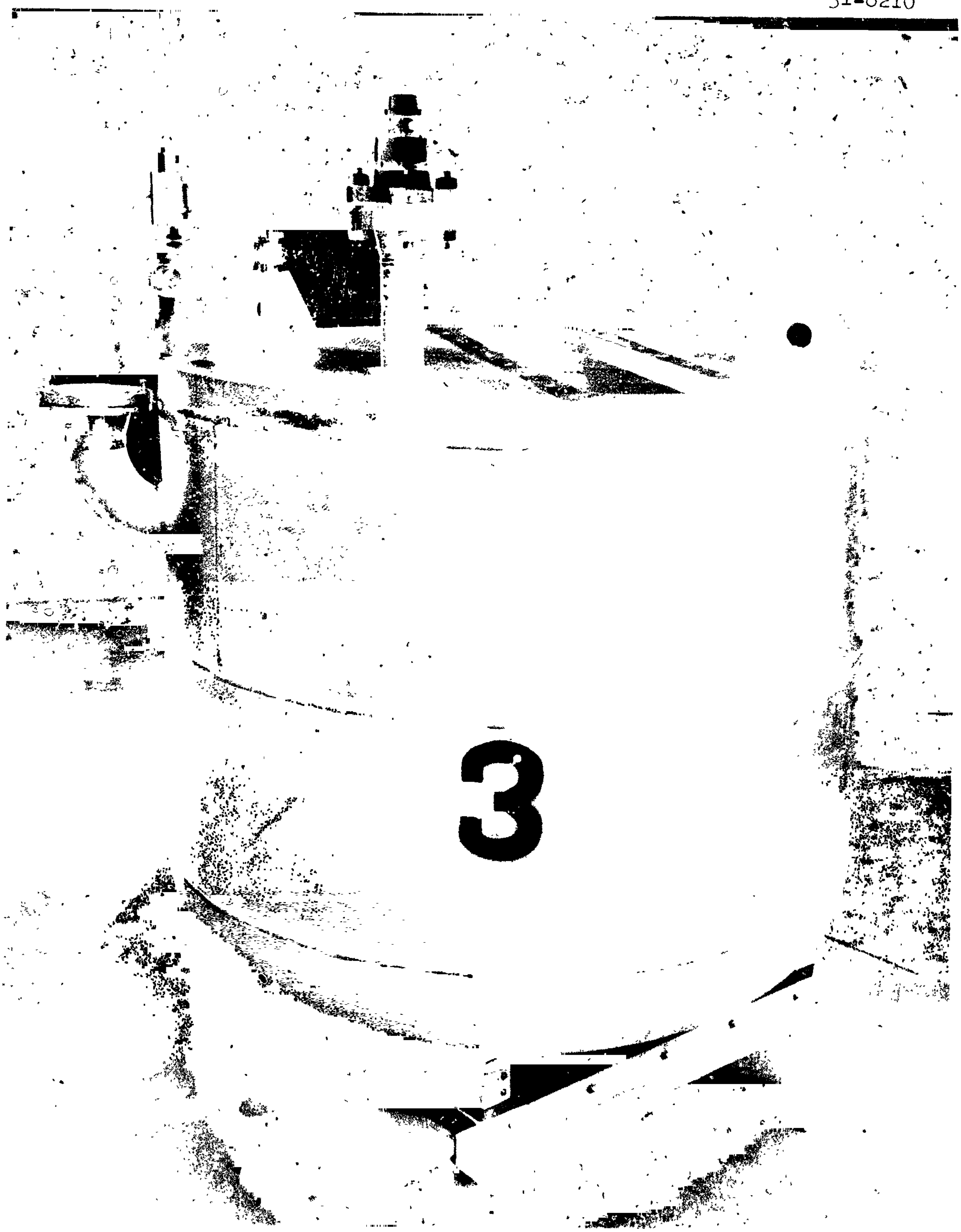


Figure 2.17 Liquid-Hydrogen Dewar

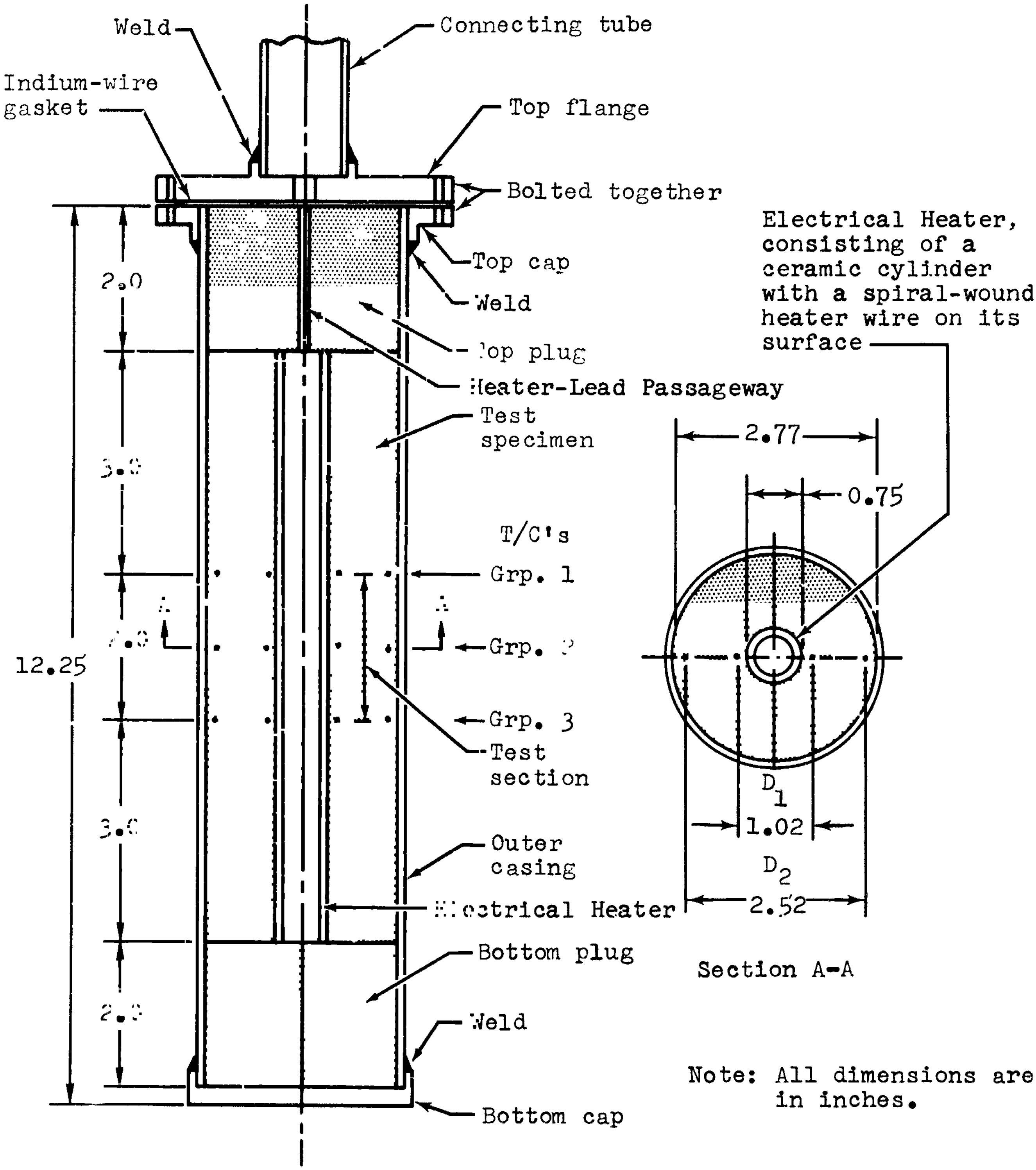


Figure 2.18 Thermal-Conductivity Test Unit: Vertical and Horizontal Cross Sections

NPC 24,285
31-8532

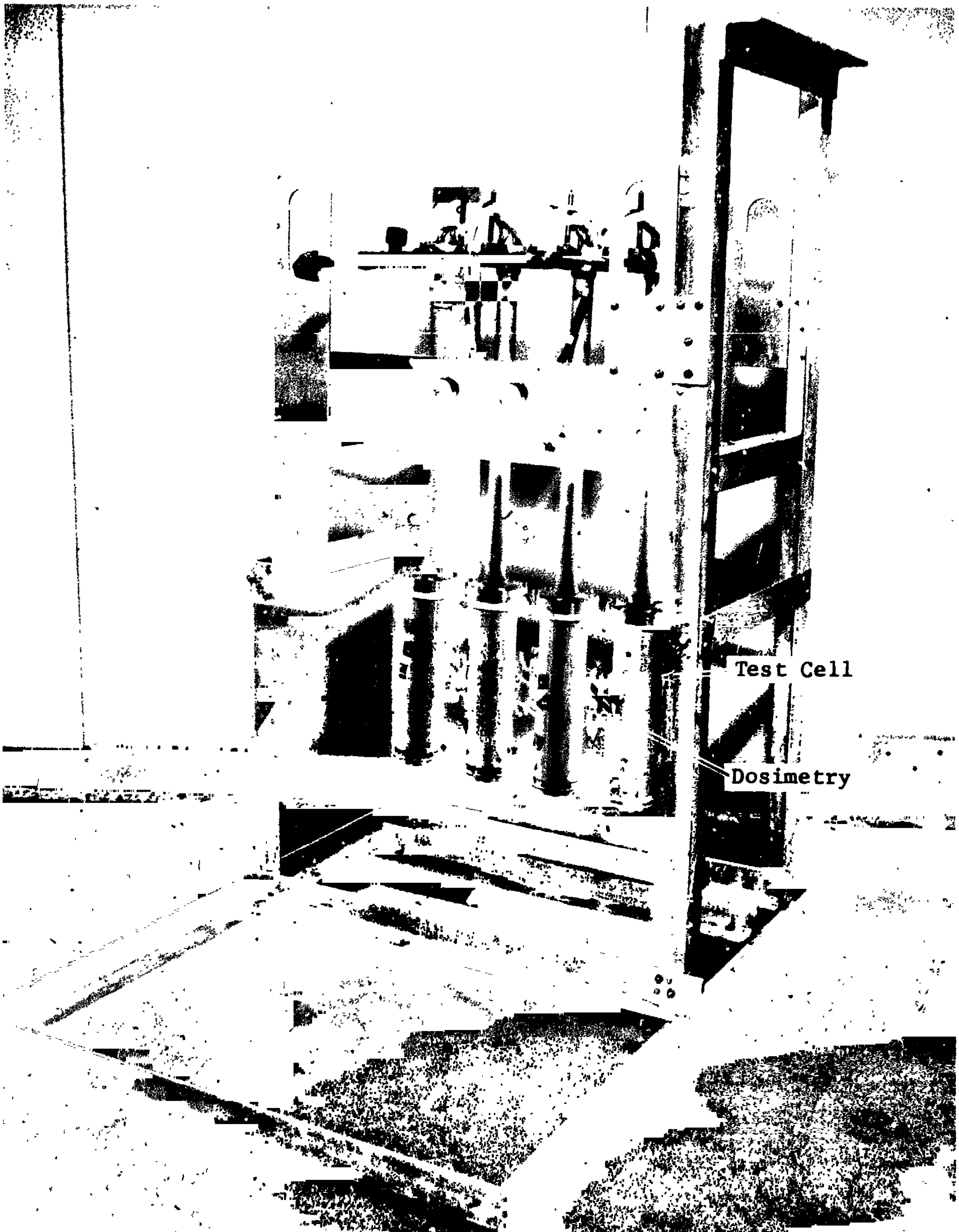


Figure 2.19 Thermal-Conductivity Air Test Arrangement

NPC 24,286
31-8414

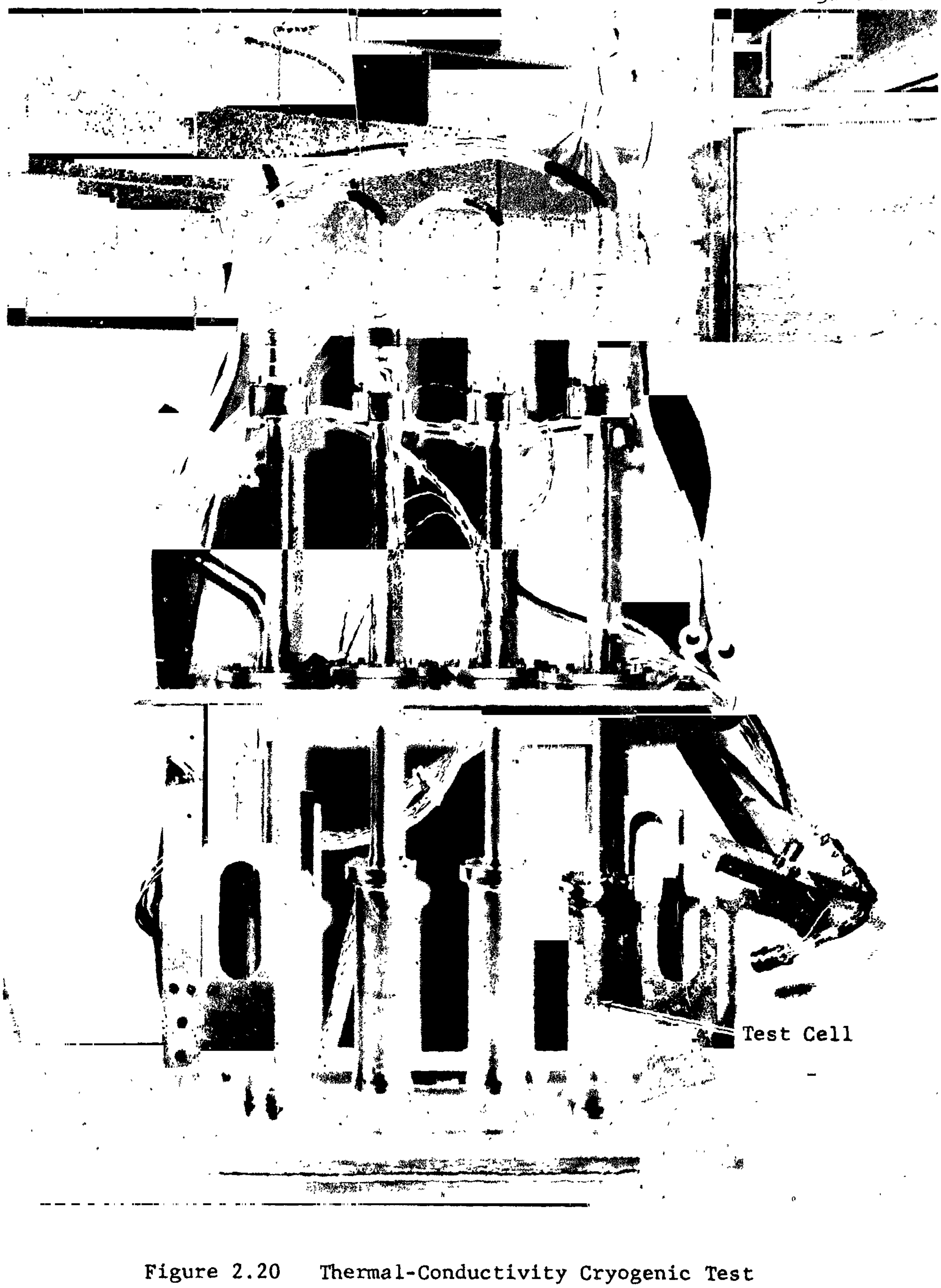


Figure 2.20 Thermal-Conductivity Cryogenic Test Arrangement

NPC 24,287
31-8415

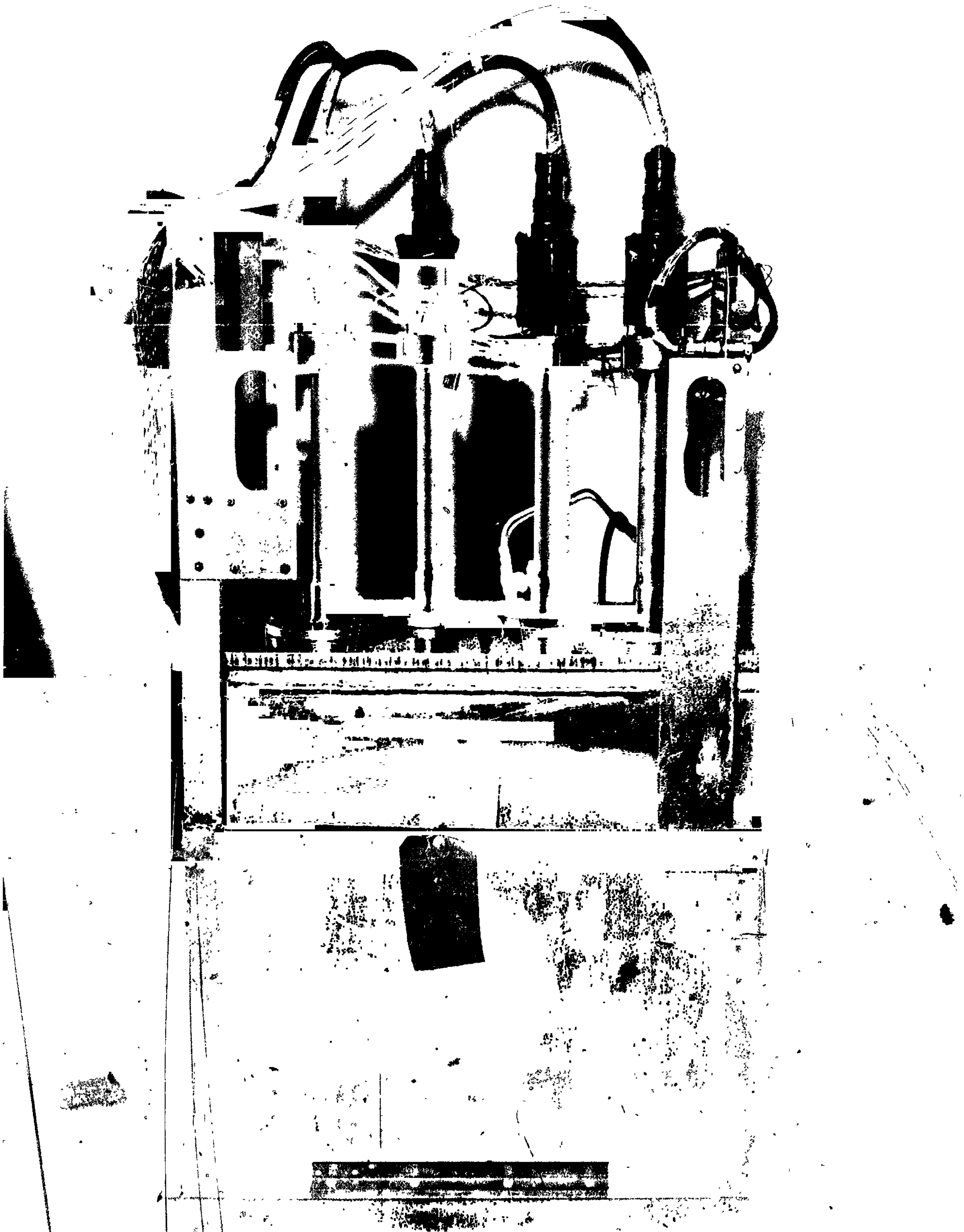


Figure 2.21 Thermal-Conductivity Tester Mated with LN_2 Dewar

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III. TEST EQUIPMENT PROCEDURES

Many different radiation exposures and test environments were required to obtain specified data cycles for all materials. In all, eleven reactor runs were made, the last being in January, 1966. The dates of these runs, the types of tests performed, and the gamma doses to which the specimens were exposed are presented in Table 3.1.

The time delay between the various radiation periods was required to allow radioactivity of the test equipment to decrease to a point where maintenance could be performed prior to subsequent tests.

The test equipment procedures used in this work are described in this section. The test-specimen configurations are given in Section IV.

3.1 Static Tests

3.1.1 Static Irradiation Tests

Static specimens to be irradiated in vacuum were mounted on an aluminum framework that attaches to the underside of the vacuum-chamber cover plate (Fig. 3.1). The specimens were clamped to a grid of expanded metal, which was then wired to the framework.

Static specimens to be irradiated in ambient air were mounted on expanded-metal racks that fit into an aluminum framework (Fig.

3.2) designed for use on the remote-controlled shuttle system of the GTR Radiation-Effects Testing System (see Appendix C). The amount of radiation received by each specimen depends not only on total exposure time but on its location on the rack and the location of the rack in the framework. By use of the shuttle system, the framework containing the racks can be removed from the radiation field at any time while the reactor is at power. Thus, racks containing specimens requiring low doses can be removed, and racks containing specimens requiring higher doses can remain at one of the irradiation positions without interruption of reactor operation.

3.1.2 Pre- and Postirradiation Static Tests

Pre- and postirradiation determinations of the tensile and compressive properties of specimens were made with a 10,000-lb, Model TT Instron machine. This machine has five tensile load cells and two compressive cells to cover the 10,000-lb range. Each cell had six load ranges. The accuracy of the load-range detection system is independent of the range in use and is better than $\pm 0.5\%$ of that range. The tests were performed in the IML.

3.2 Dynamic Tests

3.2.1 Low-Force Tests

Three irradiation test runs (3a, 4a, and 5a) were conducted with the Low-Force Tester. Prior to the irradiation, control tests were conducted on representative test specimens in the Low-Force Tester in vacuum and in air. The control data thus obtained were utilized for comparison with the irradiation data.

In the irradiation tests, gamma doses of 2.4×10^8, 2.1×10^9, and 5.3×10^9 ergs/gm(C) were obtained on the specimens. The GTR was operated at power levels to 3 Mw for the time necessary to obtain the desired doses.

Tabulations of the material types tested and the resultant data from all specimens tested in the Low-Force Tester are given in Sections V through X.

3.2.2 High-Force Tests

The High-Force Tester was used during irradiation Run 3b. Specimens were tested after irradiation to a gamma dose of 1×10^{10} ergs/gm(C). Sixteen test specimens were irradiated and tested.

Prior to irradiation, sixteen specimens identical to those irradiated were tested in vacuum with the High-Force Tester.

Data from specimens tested with the High-Force Tester are tabulated and plotted in Sections VI and IX.

3.2.3 Cryomechanical Tests

The Cryomechanical Tester was employed in the testing of specimens after irradiation (Run 4c) to a gamma dose of 1 x 10^{10} ergs/gm(C). The environment maintained on the specimens during both the irradiation and postirradiation tests included a vacuum of approximately 0.10 torr and a temperature of approximately -270°F. A total of eighteen specimens were tested after irradiation in this environment.

Unirradiated control specimens were tested with the Cryomechanical Tester while in an environment of approximately 0.10 torr vacuum and a temperature of -320°F. Other control specimens were tested in air and in vacuum for comparison. The various control-run data and irradiation test data are tabulated and plotted in Sections V, VI, and IX.

3.2.4 Bearing-Lubricant Tests

The test procedure consisted of periodically recording the parameters of motor speed, current, coastdown time, speed during coastdown, bearing temperature, operating time, and pressure (when applicable).

Motor speeds were adjusted to the desired rpm (usually 6000) by varying the phase-2 motor current. After the desired motor speed was reached, the coastdown time was obtained by starting a timer at the instant the motor currents were cut off and stopping the timer when the motor stopped. Motor speed during coastdown was obtained with an electronic printer which automatically printed motor speed at 2-sec intervals. The coastdown procedure was repeated for each of the ten motors by manual control of the instrumentation. Each motor was immediately restarted after obtaining the coastdown time.

The basic test procedure was the same for all lubricants tested, although the environment, motor input power, and operating speed varied (see Section XI). A more detailed description of the test procedures is given in Reference 3.

3.2.5 Dielectric Tests

Three irradiations were performed with the Dielectric Testers: two with the Cryotemperature Dielectric Tester in vacuum and one with the Air-Environment Dielectric Tester. Dielectric property values of normalized dielectric constant, dissipation factor, and volume resistivity were obtained.

3.2.5.1 Dielectric Test Procedures

The dielectric properties of dielectric constant (normalized) and dissipation factor were obtained by periodically measuring the ac capacitance and loss characteristics of the test cells containing the dielectric specimens. The eight test cells per tester were measured sequentially by the Capacitance Measuring Assembly (Section 2.7) and, using the substitution method of measurement, the Schering bridge was balanced with and without the test cell in the circuit. The bridge oscillator was operated at 1000 cps. Volume-resistivity values were obtained by switching the test cells to a Tera-Ohmmeter and measuring the resistance of the dielectric specimens. The Tera-Ohmmeter was operated at 500 v-dc, and a 1-min charging time was used. A Minneapolis-Honeywell temperature recorder automatically switched the eight thermocouples per tester and recorded the temperature. The vacuum pressure (when applicable) was recorded manually.

3.2.5.2 Temperature Control

Cryotemperature control of the tester was accomplished by automatic or manual control of the quantity of liquid or cold gaseous nitrogen in the tester cryopanels. Temperatures were sensed with copper-constantan thermocouples attached to each dielectric test and with three thermocouples in the liquid-level probe mounted in the tester surge chamber. The LN_2 level was monitored by observing the panel of resistance indicators connected to the seven carbon resistors in the probe. Additional temperature control was obtained by reducing the degree of vacuum to approximately 100 microns with the introduction of gaseous helium into the vacuum chamber. The gaseous-helium conductive heat transfer enhanced the cryotemperature capability of the tester and was required occasionally during extended irradiations at maximum reactor power.

Temperature control for the air-environment tester consisted of passing cool air over the tester to prevent overheating of the specimen during irradiation at maximum reactor power.

3.2.6 Cryotensile Tests

3.2.6.1 General

The Cryotensile Tester (CTT) was employed to determine the tensile characteristics of various organic materials after subjecting the test specimens to specific doses of reactor radiation and a temperature of either -320°F or -423°F. The temperature control was obtained by submerging the specimens in liquid nitrogen or liquid hydrogen.

Tensile testing of specimens of each material was initially accomplished to obtain control data in each of the stipulated temperature environments prior to irradiation. These data were used to compare with the data obtained after testing under like temperature environments and after exposure of the materials to radiation from the GTR. The resulting data from the comparison yielded the net radiation effect for the specific radiation levels and temperature environment involved. Test materials were supplied by NASA and by various material manufacturers.

These irradiations were performed: one with liquid nitrogen, and two with liquid hydrogen. After reaching the specified radiation dose, the reactor was shut off and the specimens pulled to fracture.

A listing of the materials tested in the Cryotensile Tester for specific test environments is included in the summary table given in the Report Summary.

3.2.6.2 Operating Procedures for Test Hardware

After delivery of the test specimens and Cryotensile Tester to the reactor test area, setup for the irradiation test was completed. This included the connection and operational checkout of all instrumentation, hydraulics, purge gas system, cryogen supply system, and facility controls. These initial checkouts were made to establish the operational integrity of the hardware and instrumentation before the tensile test specimens were sequentially loaded in the tester clevis assemblies. The tester was then mated with and secured to the dewar assembly (see Sec. 2.9) and the cryogen system checked for leaks.

For the liquid-nitrogen control run, the dewar was filled with liquid nitrogen and the desired liquid level established above the test specimens mounted in the clevis assemblies and enclosed within the cryogen container (see Sec. 2.8.1). After the desired temperature for test specimens had been stable for one hour, tensile testing was started and all control data obtained.

The control run for the liquid-hydrogen environment was performed similarly to that using liquid nitrogen. Some variation in cryogen handling procedures was necessary, however, because of the inherent hazards associated with the use of liquid or gaseous hydrogen. The essential deviations in procedures were those associated with purging the cryogen system with gaseous helium prior to the introduction of liquid hydrogen and the constant monitoring of the system for possible explosive gas mixtures.

Preparation of the test assembly and loading of test specimens for the liquid-nitrogen irradiation test were identical to that for the control run. The test assembly was then positioned in the north irradiation test cell. Once positioned, instrumentation was verified as operational and the cryogen system was cooled down and filled with liquid nitrogen. Control of the liquid nitrogen was automatically maintained at the prescribed level (see Sec. 2.8.1). The reactor was operated at power levels of up to 3 Mw for time periods required to yield gamma radiation doses of 5×10^9, 1×10^{10}, and 3×10^{10} ergs/gm(C). Tensile data were obtained for test specimens after irradiation to the prescribed gamma dose levels in the same manner as the data in the control run.

Two liquid-hydrogen irradiation tests were conducted. Each irradiation involved reactor power levels of up to 3 Mw for time periods required to produce gamma radiation doses of 1×10^9, 5×10^9, 1×10^{10}, and 3×10^{10} ergs/gm(C). Initial preparation of the test assembly was the same as that for the control run. Prior to placement of hardware in the irradiation test cell, the test assembly was subjected to three complete temperature cycles, each cycle including the cooling of the system with liquid hydrogen to -423°F and then allowing it to warm up to -100°F. Constant leak checks were conducted during these temperature cycles for indication of hydrogen gas leakage. Upon completion of these preparatory tasks, the test assembly was positioned in the north irradiation cell of the test facility, filled with LH_2, and the reactor operated for the specified periods. Tensile tests were performed on submerged specimens after each irradiation period. Testing was conducted precisely as it was for the control runs.

Because of the hazardous nature of LH_2, precautionary measures were observed at all times during the test. Explosive mixture detectors were mounted on the test assembly and at specified positions throughout the test facility to continuously monitor the atmosphere for the existence of hydrogen.

After completion of all postirradiation testing, the LH_2 was allowed to boil off and the test assembly purged completely with helium. The test assembly was then removed from the facility, demated, and the fractured test specimens removed for further study.

3.2.6.3 Instrumentation

Tensile stress and strain signals from the load cells and potentiometers were fed to a Sanborn Model 150 recorder. Data were recorded in the form of continuous curves measured as percent bandwidth. Correlation with the calibrations of the load cell and potentiometer units with the indicated percent bandwidth yielded tabulated data of total load and specimen elongation. The Instron machine recorder was utilized during all tensile loadings. This provided secondary, or backup, instrumentation should the Sanborn load cells or potentiometers fail.

Operation of the Sanborn included null verifications prior to each specimen loading. Drag loads were also noted and subtracted during the data tabulation to yield the net tensile load. Cross-sectional area and gage lengths for all specimens were also tabulated. Data reduction is discussed in Section IV.

Signals from copper-constantan thermocouples mounted at each tensile clevis assembly were continually monitored by a Brown recorder. This temperature indication verified that the proper liquid level was being maintained (see Sec. 2.8.1).

3.2.7 Thermal-Conductivity Tests

The procedures for operation of the test equipment are so closely related to the procedures used in taking a data cycle that only the latter are included in this report. These procedures are described in Section 10.1.1.

3.3 Cryogen Handling

3.3.1 Liquid Nitrogen

Liquid nitrogen is supplied to test equipment from a 6500-gal storage vessel. It is routed through insulated copper tubing to the facility manifold valve assembly and metered from there to the test assembly. Evaporated cryogen is exhausted to the atmosphere through the test facility exhaust system. Automatic flow control is maintained by employing a Bristol control unit with a +100^o to -430^{o}F range. The controller sensor consists of a series of copper-constantan thermocouples mounted in the liquid-level section of the cryogen container. The controller transmits signals to a pneumatic flow regulator within the facility manifold valve assembly.

Small amounts of liquid nitrogen are periodically dumped from the bottom of the test dewar during irradiation to dispose of any liquid or solid ozone that might have accumulated.

3.3.2 Liquid Hydrogen

Liquid hydrogen is handled in basically the same manner as liquid nitrogen; however, its hazardous characteristics require added precautionary procedures. Personnel working within the hydrogen inclusion area are provided with grounding straps. Explosion proof electrical equipment is used exclusively and nonsparking beryllium tools are also used.

A vacuum-jacketed stainless-steel flexible line is used to route the liquid hydrogen from the trailer to the facility manifold assembly and to the test assembly. A flexible steel exhaust line connects the test assembly exhaust port to the facility exhaust system, and a burn stack is employed to burn off the evaporated hydrogen.

Alternate purging of the entire cryogen system with helium gas and evacuation of the system with a vacuum forepump is accomplished to provide an oxygen-free atmosphere prior to introduction of hydrogen. Upon completion of hydrogen use, the system is again purged with helium until no indication of hydrogen is present. The system may then be disconnected and the liquid-hydrogen trailer removed. Liquid-level control of liquid hydrogen in the test hardware is accomplished in the same manner as that of the liquid nitrogen and uses the same equipment.

The entire liquid-hydrogen circuit and the test facility are continuously monitored for indications of the presence of an explosive gas mixture. Should such a condition develop, all power and liquid-hydrogen flow are terminated until such time as the condition is remedied.

Table 3.1
Irradiation Schedule

Run No.	Irradiation Date	Irradiation Position	Irradiation Test Hardware	Specified Gamma Dose [ergs/gm(C)]	Total Mw-Hours	Remarks
1	25 Mar 65	N E W	(NERVA) (NERVA) 2 Static Air Racks	-- -- 3(10),1(11)	 470	3-Mw Power Level - 2" H_2O Shield at N. Position
2a	3 Aug 65	N E W	3 Static Air Racks 2 Static Air Racks Open	2(8),5(8),1(9) 1(7),5(7) --	0.2	500-kw Power Level - 4" H_2O Shield at N. Position
2b	3 Aug 65	N E W	3 Static Air Racks Open Open	2(8),5(8),1(9) --	1.3	1-Mw Power Level - 4" H_2O Shield at N. Position
3a	16 Aug 65	N E W	2 Static Air Racks Open LFT[a] in Vac.	5(9),1(10) -- 3(9)	18.0 -- 18.0	3-Mw Power Level - 4" H_2O Shield at N. Position
3b	18 Aug 65	N E W	CTT[a] - LN_2 TCT[a] - LN_2 HFT[a] - Vac. (with static spec.)	5(9),1(10),3(10) 5(9),1(10),3(10) 1(10)	61.2	3-Mw Power Level - 4" H_2O Shield at N. Position. Doses Obtained by Intermittent Reactor Operation and Testing.
4a	29 Nov 65	N E W	Open LFT - Vacuum Static Vacuum Spec.	-- 5(8) 5(8),1(9)	2.0	2-Mw Power Level - 4" H_2O Shield at N. Position
4b	29 Nov 65	N E W	Open Open Static Vacuum Spec.	-- -- 5(8),1(9)	4.6	3-Mw Power Level - 4" H_2O Shield at N. Position
4c	1 Dec 65	N E W	BLT[a] - Air DT[a] - LN_2 - Vac. CMT[a] - LN_2 - Vac.	1(7),1(8),1(9),1(10) 1(10)	30.2 88.1 88.1	500-kw and 3-Mw Power Levels - 4" H_2O Shield at N. Position. Bearing Tester Was Retracted During Run Without Changing Reactor Power Level.
4d	9 Dec 65	N E W	CTT - LH_2 TCT - Air Open	1(9),5(9),1(10) 5(9),1(10),3(10) --	34.2 34.2	3-Mw Power Level - 2" H_2O Shield at N. Position. This Run Was Stopped Prematurely Because of Indicated Hydrogen Leak.
4e	15 Dec 65	N E W	CTT - LH_2 TCT - LH_2 Open	1(10),3(10) 5(9),1(10),3(10) --	54.5	3-Mw Power Level - 2" H_2O Shield at N. Position
5a	6 Jan 66	N E W	Open LFT - Vacuum Open	-- 5(9) --	-- 44.4 --	3-Mw Power Level - 4" H_2O Shield at N. Position
5b	10 Jan 66	N E W	Open Open Static Vacuum Spec.	-- -- 5(7),1(8)	-- -- 0.8	1-Mw Power Level - 4" H_2O Shield at N. Position
5c	11 Jan 66	N E W	DT - Air DT - Vac. - LN_2 BLT - Vac.	1(7),1(8),1(9),1(10) 1(7),1(8),1(9),1(10) 1(7),1(8),1(9),1(10)	61.3 61.3 61.3	500-kw and 3-Mw Power Level - 4" H_2O, Shield at N. Position

[a] **Abbreviations**

LFT - Low-Force Tester
CTT - Cryotensile Tester
TCT - Thermal Conductivity Tester
HFT - High-Force Tester
BLT - Bearing Lubricant Tester
DT - Dielectric Tester
CMT - Cryomechanical Tester

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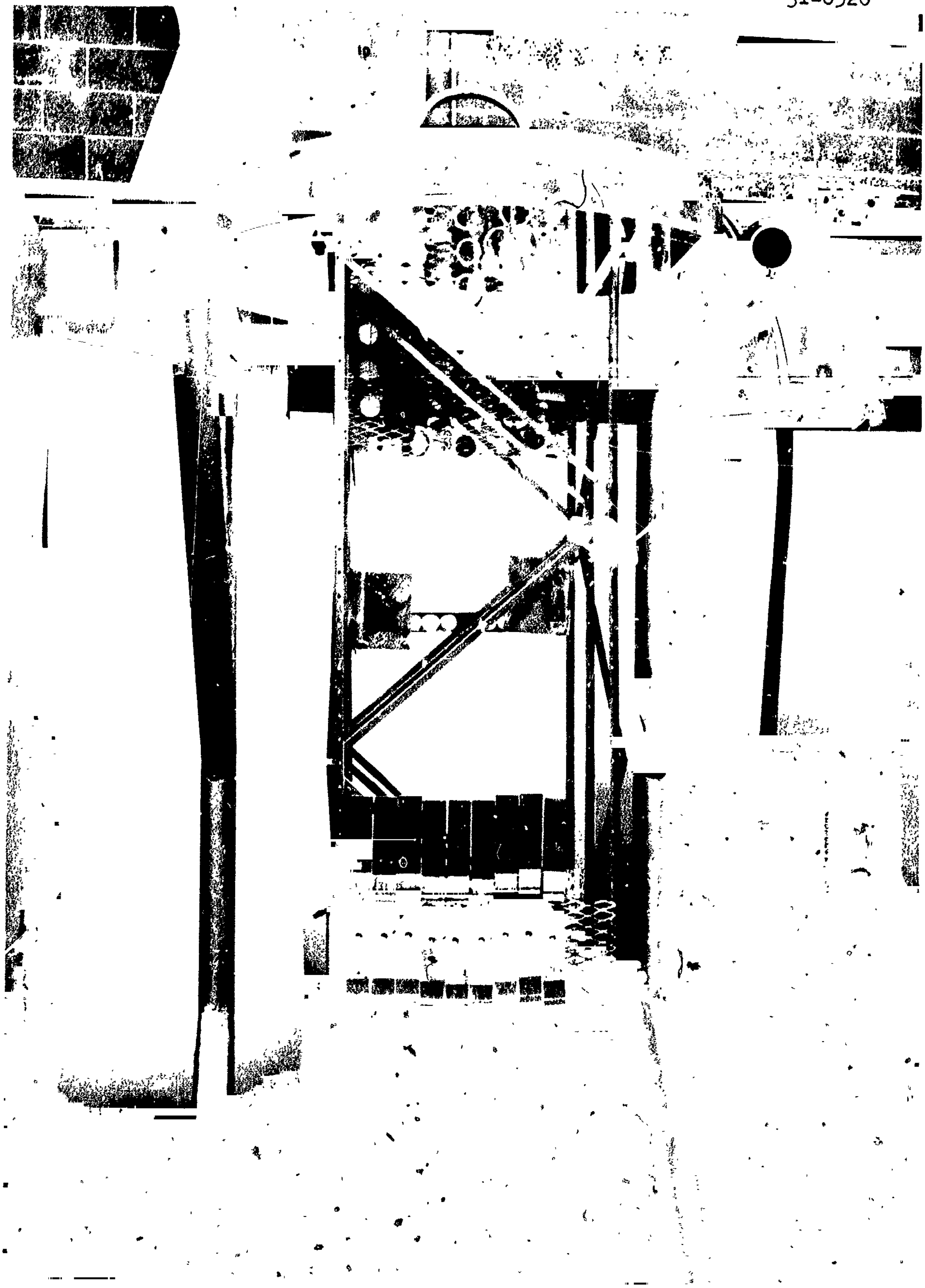

Figure 3.1 Static Samples on Rack for Vacuum Irradiation

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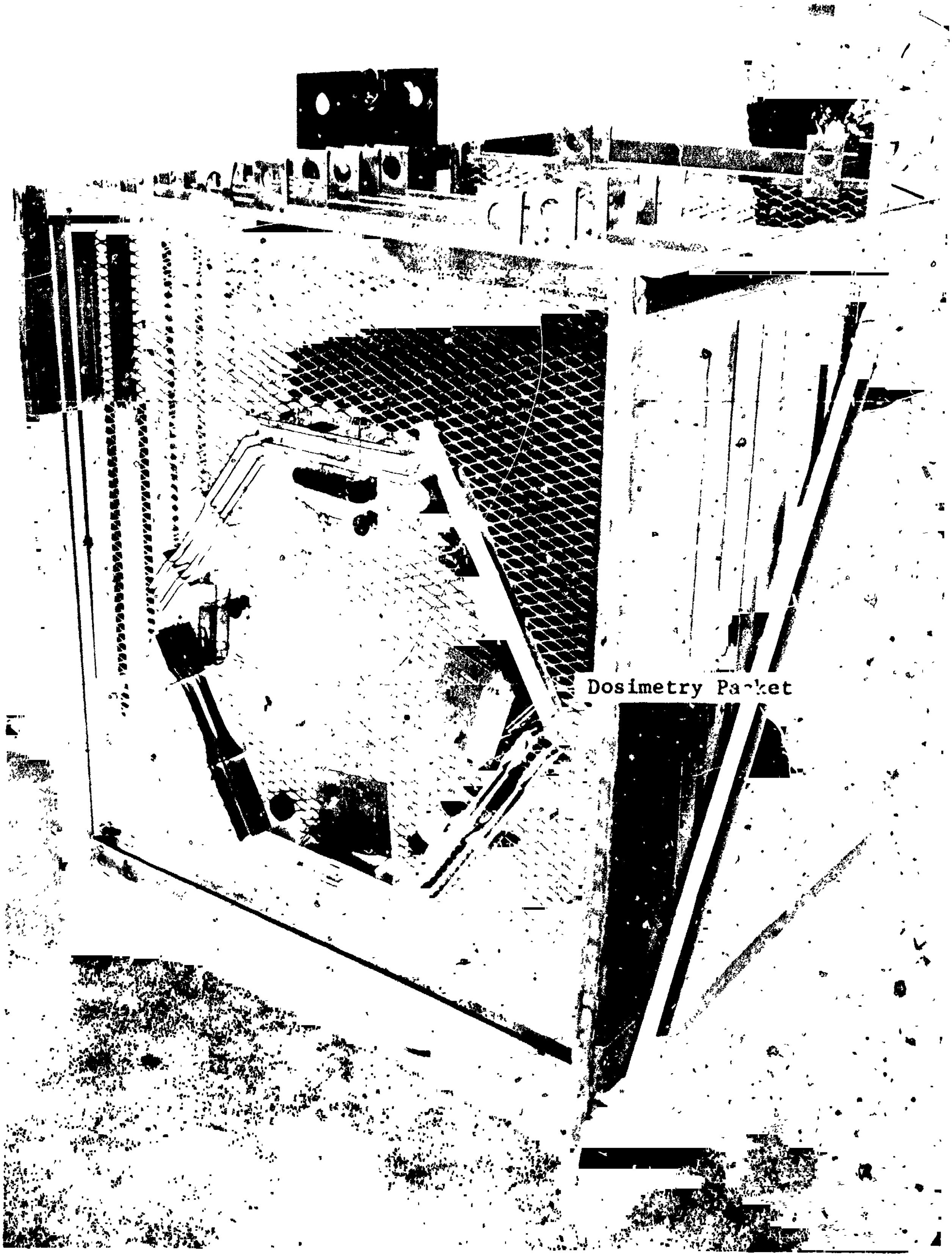

Figure 3.2 Static Samples on Rack for Ambient-Air Irradiation

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IV. SPECIMEN CONFIGURATIONS AND TESTING CHARACTERISTICS

In this test program, many different types of materials were subjected to a variety of environments and, as a consequence, several types of test specimens were required. When possible, ASTM standard test specimen configurations were used; however, in order to test materials in vacuum and at cryotemperatures it was necessary, in several instances, to design special test equipment and specimen configurations. Obviously, the prime consideration in the design of the test specimens was that they be as similar to the ASTM standard specimens as possible and still be compatible with the test equipment used to obtain the required environment.

The configurations and testing characteristics of all the types of specimens used in this period are described below. In addition, the specific type of specimen used with each dynamic tester is mentioned in the test-method section for each individual material (Sections V through XI).

4.1 Mechanical-Property Specimens

4.1.1 Dumbbell Specimens

All the tensile specimens tested during the current period which have a reduced section in the center are referred to as dumbbell specimens. Several types of dumbbell specimens were fabricated, but the reduced center sections were all shaped and sized in accordance with ASTM D-638 or D-412.

Figures 4.1 and 4.2 are drawings of typical tensile specimens that were tested in the dynamic testers. The dynamic testers incorporate a pin-type jaw arrangement, and sequential testing of the specimens is accomplished by one upward movement of the pin-type jaw applied to a parallel loading of specimens having varying-length pin slots.

The specimens tested in the Instron were either the same type as those tested in the dynamic testers or standard ASTM specimens. The particular specimen configuration used for each material is given in the appropriate material Test Methods and Results sections.

In testing tensile specimens in the dynamic testers in vacuum and at cryotemperatures, precise elongation measurements with an extensometer or strain gage, as required by ASTM methods, were not possible. At the time this program was planned, methods for using extensometers and strain gages in vacuum and cryogens and operating them remotely had not been sufficiently developed. Since the only extension measurement possible with the dynamic equipment used in this program was the crosshead travel (corrected for tester deflection), it was evident that some compensation should be made for the extension which occurs throughout the length of the specimen as contrasted to that which takes place in the gage-length section only.

It is possible to correlate total strain in the test specimen with the strain in the reduced section by using a standard extensometer, with its associated readout equipment, in the appropriate dynamic testers and thus establish a relation between the actual strain recorded by the extensometer and the crosshead travel. This could be done manually in the IML with all equipment exposed to the atmosphere, and would result in a specific relationship for each type of test material. However, this relationship could only be established under room-temperature conditions and would not be valid for LN_2 and LH_2 test conditions. It was therefore decided that a nominal gage length would be selected which would cover a portion of the specimen in which greater than 90% of the strain would occur. The nominal gage lengths established for Type I and Type II specimens (Figs. 4.1 and 4.2) were 3.5 and 4.0 in., respectively. Thus, by using the total strain as represented by total crosshead travel, and dividing this value by 3.5 (or 4), a very close value for strain in terms of inches-per-inch of gage length resulted. This method was used in all test procedures for dumbbell-type specimens and definitely provided means of showing relative changes due to the effects of radiation.

Visual examinations of the dumbbell specimens were made following testing, and the type of break exhibited by each specimen was classified according to the break code shown in Figure 4.3.

4.1.2 Lap-Shear Specimens

The structural adhesives were fabricated into lap-shear specimens according to ASTM D-1002-64. For testing lap-shear specimens in the dynamic testers, a modification was made to adapt the specimens to the pin-type jaws of the testers. Figure 4.4 is a drawing of a typical lap-shear specimen.

The silicone sealants were made into special lap-shear speciments by the Dow Corning Corporation.

4.1.3 Thin-Film Specimens

Specimens of all materials were fabricated in accordance with ASTM D-882-61T. The specimens were 1.0 in. wide by 6.0 in. long except for the H-Film specimens, which were 0.5 in. wide. The thickness of each material is given in its respective Test Method and Results section of the report.

4.1.4 Flexure Specimens

The flexure specimens were cut from plastic sheets into pieces 1.0 in wide by 4.0 in. long. The thickness of each specimen depended on the sheet of plastic from which it was cut and is given in Sections 9.5 and 9.8.

4.1.5 Compression Specimens

All of the compression specimens were cylinders which measured 0.5 in. in height and 1.129 in. in diameter.

4.2 Dielectric Specimens

The dielectric specimens were 4.5-in.-diam discs of test material ranging in thickness from approximately 0.10 to 0.15 in. With the exception of Epon 828/Z, the specimens were cut from the manufacturer's sheet stock. The Epon specimens were obtained by casting the resin and curing agent to the desired thickness in 4.5-in.-ID aluminum molds.

The dielectric specimens were cleaned thoroughly prior to placement in the dielectric test cells. A wash with methyl ethyl ketone, followed by acetone, was used for the Lamicoid, Kynar, Teflon, and Estane specimens. A toluene wash, followed by acetone, was used for the Sylgard and RTV-501 specimens. Alcohol only was used to clean the Lexan specimens. The Epon samples were washed with a solvent degreaser, followed by cleaning with methyl ethyl ketone and then acetone.

4.3 Thermal-Conductivity Specimens

Thermal-conductivity tests were performed on four rigid, cellular, organic foam materials. The raw material was foamed by the manufacturers and shipped to the Fort Worth Division in blocks which were, roughly, 4 in. by 4 in. by 18 in. in size. These blocks were then machined on a standard lathe into the size and shape required for their use in the thermal-conductivity test units. As can be seen in Figure 2.18, the test specimen consisted of a cylinder of foam 8 in. in length, having a 2.77-in. outside diameter and a 0.75-in. inside diameter. Tolerances of +0.001 in. and -0.005 in. were held in the machining operation, which allowed a press fit of the cylinder into its outer aluminum casing and also a press fit for the ceramic heater spool used in the center of the test specimen.

4.4 Bearing-Lubricant Specimens

Prior to application of the test lubricants, the motor bearings were subjected to standardized multiple wash processes to ensure cleanliness, followed by drying with pressurized, filtered air. Details on specimen preparation are outlined as follows:

Almasol SFD-238 is a MoS_2-base dry-film lubricant with organic binder that was applied to the inner and outer bearing races and retainer by the Almasol Corporation. The binder material and application process are proprietary.

DC-705, FS-1265, GE F-50, and OS-124 are oil-type lubricants that were applied to the bearings by Miniature Precision Bearing, Inc. The lubricants were applied to the bearings from a hypodermic syringe through a No. 26 needle. As an added precaution against contamination of the oil, a Millipore filter was mounted between the syringe and the needle. The lubricant quantity was determined by comparing the weight of the bearing before and after lubrication. A Model No. 1-910 Gramatic Balance was used for weighing the bearings.

Duroid bearing retainers were machined by Miniature Precision Bearing, Inc., from Teflon stock impregnated with MoS_2 and reinforced with fiberglass.

Electrofilm 66-C is a solid-film lubricant that was diluted with a solvent for spray application by Miniature Precision Bearing, Inc. The lubricant was kept under agitation at the time of application to avoid settling of the MoS_2. It was applied with an air brush to the rotating bearing component (inner and outer races), which was allowed to rotate after the spraying process until the film was air-dried. The coated races were then baked at 190°F for 1 hr to cure the film. The thickness of the baked film was held between 0.0002 and 0.0003 in.

ETR-H is a Shell Oil Company grease that was applied to the bearings by Miniature Precision Bearing, Inc. from a hypodermic syringe through a No. 18 needle. Application was made under a binocular microscope to ensure that an even pattern of grease was laid at the bore and outside diameter of the retainer in direct contact with the balls and ball grooves. Lubricant quantity was determined by comparing the bearing weight before and after the lubricant was applied.

Kynar (filled) bearing retainers were machined by Miniature Precision Bearing, Inc., from vinylidene fluoride stock containing a filler.

Minapure is a grease manufactured by Miniature Precision Bearing, Inc. It was applied to the bearings by the manufacturer.

MLF-5 is a solid-film lubricant with inorganic binder. Midwest Research Institute prepared and applied the lubricant to the bearings. After the standard bearing wash procedure, the MLF-5 (dispersed in distilled water by continuous stirring) was sprayed onto the races by an air brush utilizing pressurized dry nitrogen. The lubricant was dried at temperatures not exceeding 140°F and then cured in an air environment according to the following sequence: 1 hr at 65° to 100°F and 8 to 16 hr at 300°F, followed by cooling from 300° to 150°F for not less than 1 hr.

Polymer SP-F bearing retainers were machined by E. I. du Pont de Nemours and Co., Inc., from specifications supplied by Miniature Precision Bearing, Inc.

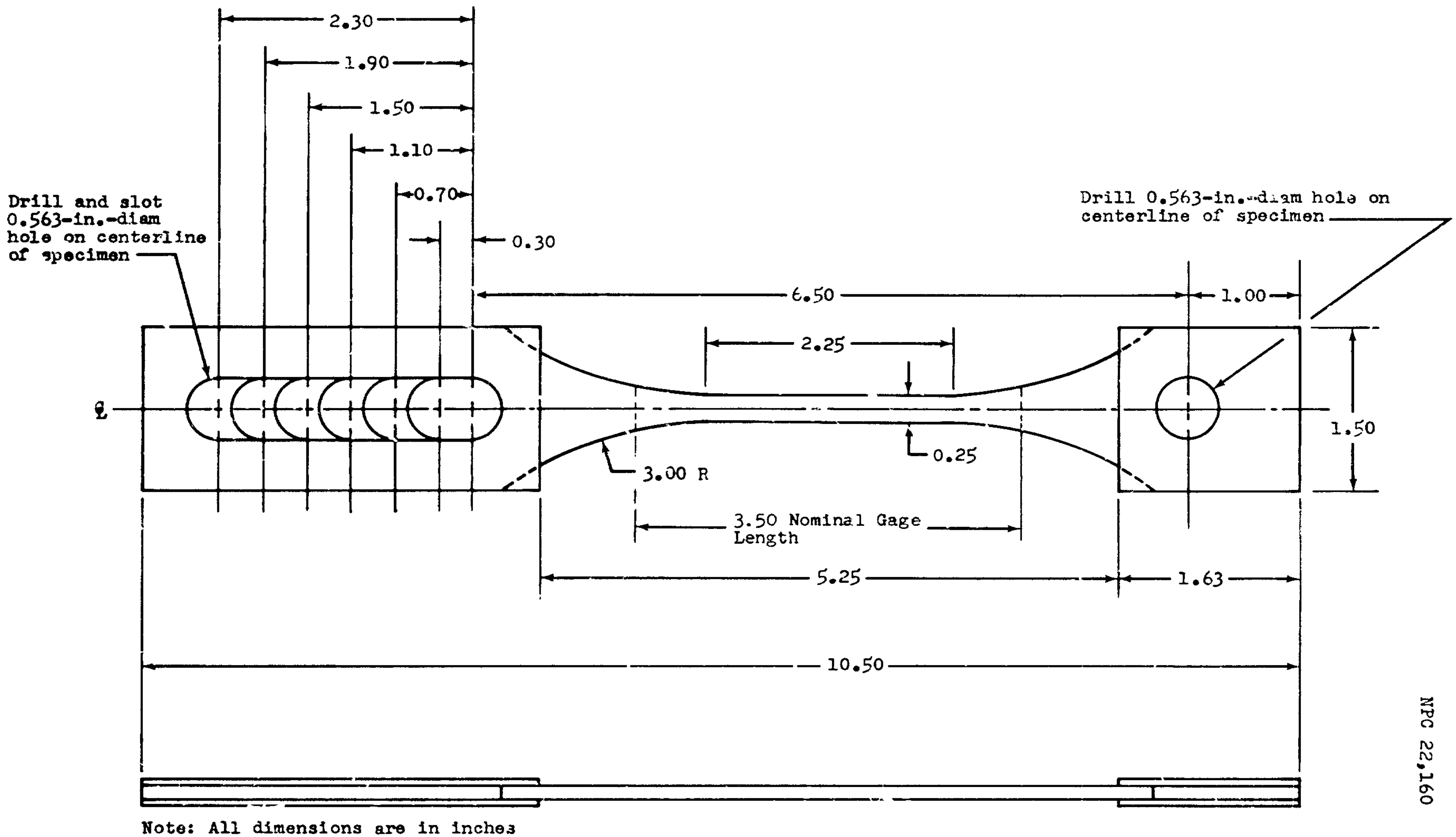

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Figure 4.1 Typical Narrow-Gage Tensile Specimen

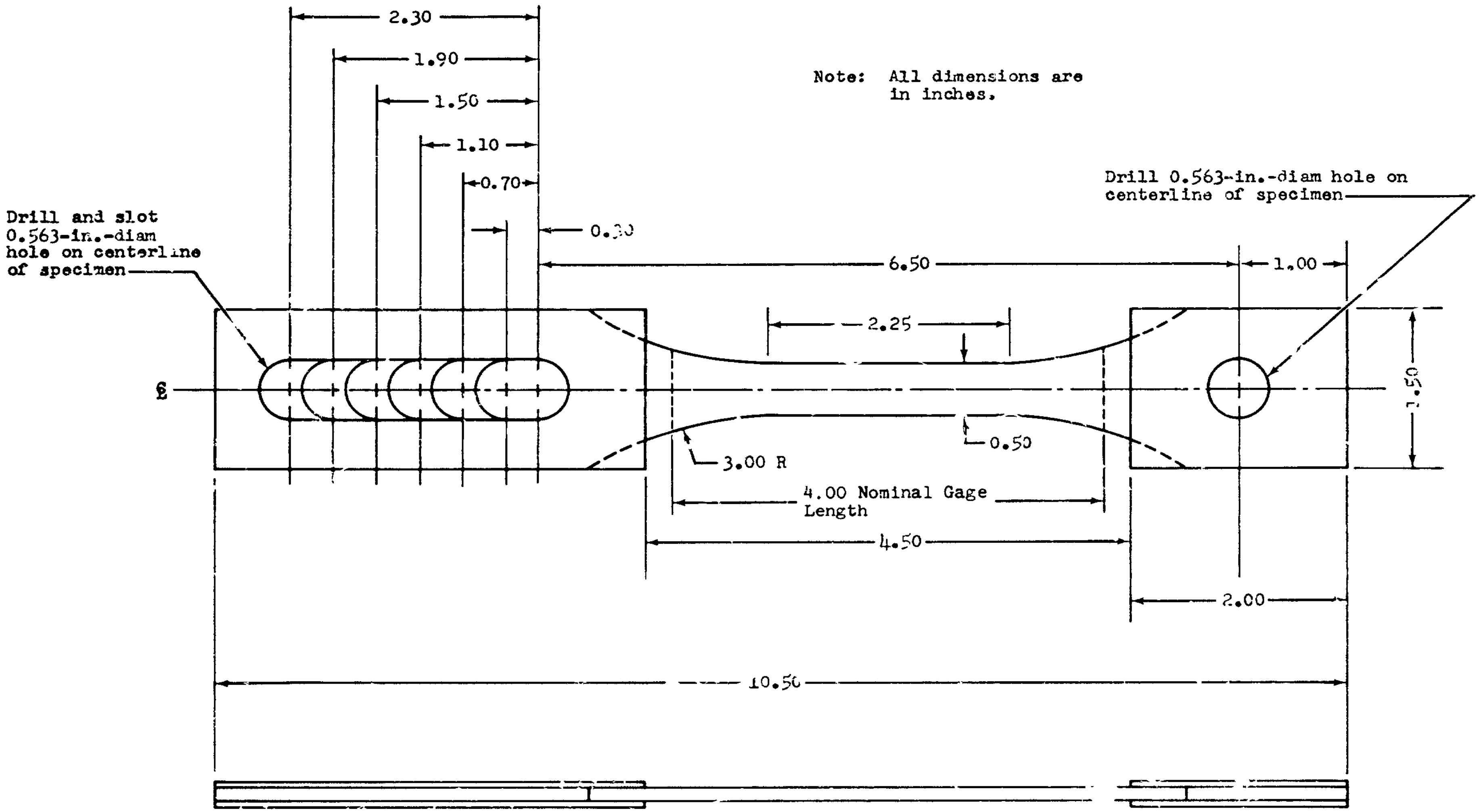
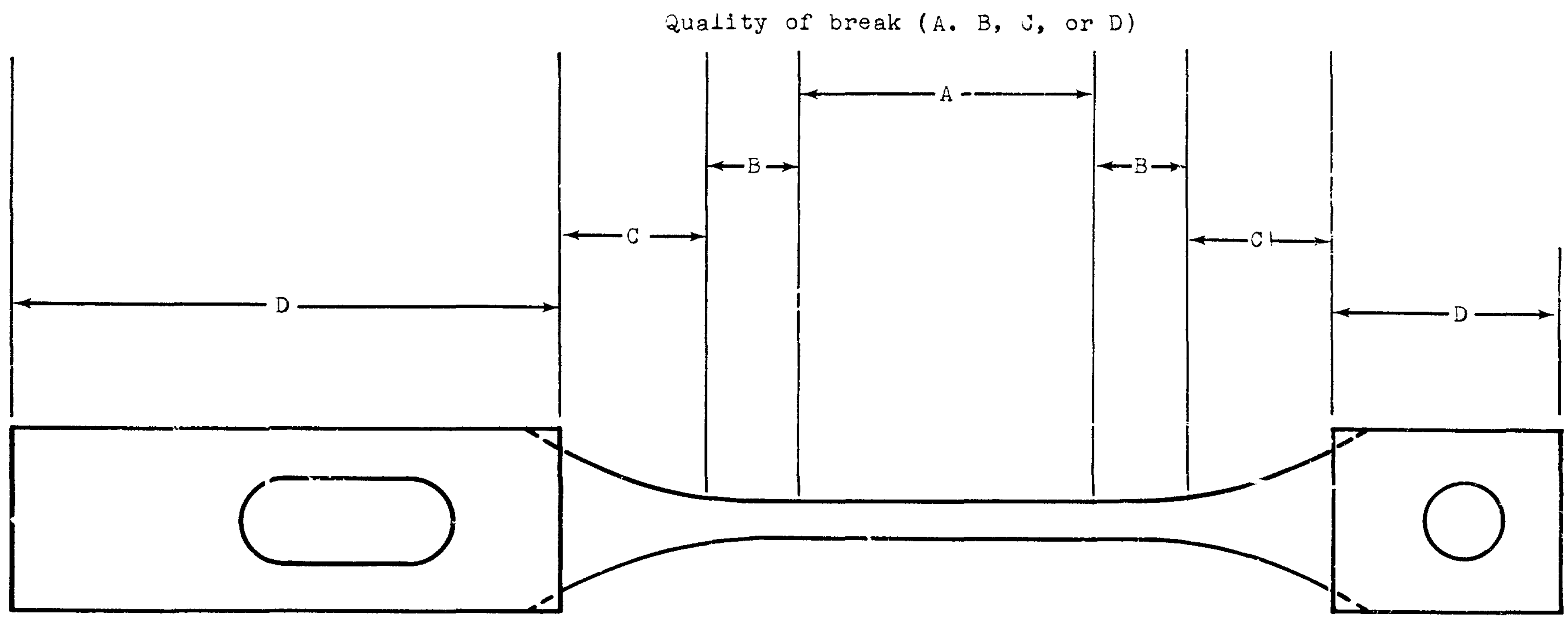
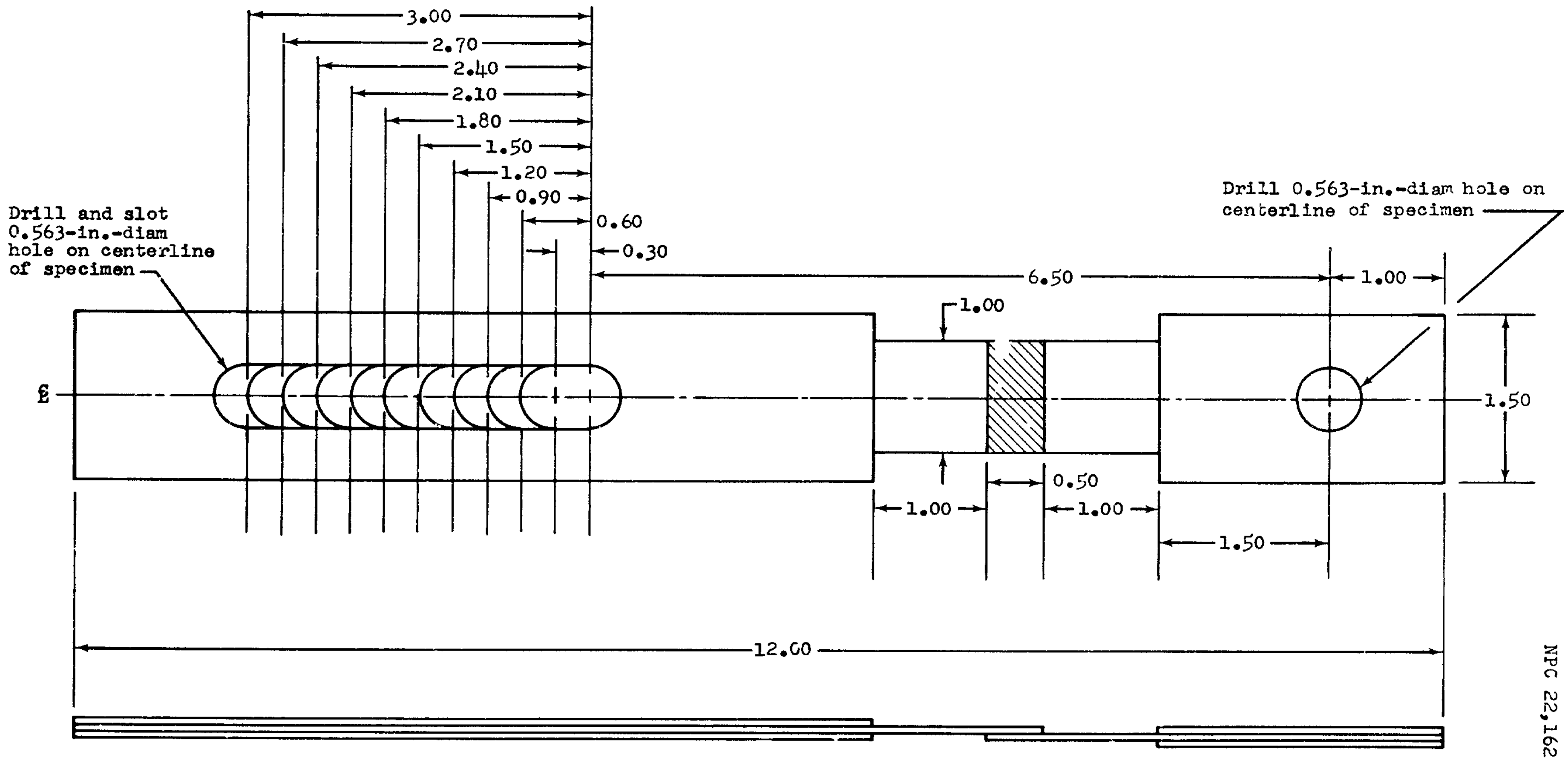


Figure 4.2 Typical Wide-Gage Tensile Specimen



Note: See Figures 4.1 and 4.2 for detailed specimen drawings, including dimensions.

Figure 4.3 **Specimen-Break Code Description**



Note: All dimensions are in inches

Figure 4.4 Typical Lap-Shear Adhesive Specimen

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V. STRUCTURAL ADHESIVE TEST METHODS AND RESULTS

Table 5.1

Outline of Structural Adhesive Tests[a]

Material	Type of Test	Irradiation Environment	Nominal Gamma Dose [ergs/gm(C)]	Materials Tester	ASTM Test Method
Aerobond 422J	Static	Air	1(11)	Instron	D-1002-64
	Dynamic	LH_2	1(10),3(10)	Cryotensile	D-1002-64, Mod.
Aerobond 430	Static	Air	3(10),1(11)	Instron	D-1002-64
		Vacuum	1(9),1(10)	Instron	D-1002-64
APCO 1252	Static	Air	3(10),1(11)	Instron	D-1002-64
	Dynamic	Vac-cryo	1(10)	Cryo-mechanical	D-1002-64, Mod.
Epon 934	Static	Air	1(10),3(10),1(11)	Instron	D-1002-64, Mod.
	Dynamic	LN_2	1(10),3(10)	Cryotensile	D-1002-64, Mod.
	Dynamic	LH_2	1(10),3(10)	Cryotensile	D-1002-64, Mod.
Epon 951	Static	Air	1(9),5(9),1(10)	Instron	D-1002-64, Mod.
FM-1000	Static	Air	1(10),3(10),1(11)	Instron	D-1002-64, Mod.
	Dynamic	LN_2	1(10),3(10)	Cryotensile	D-1002-64, Mod.
	Dynamic	LH_2	1(10),3(10)	Cryotensile	D-1002-64, Mod.
HT-424	Static	Air	1(10),3(10),1(11)	Instron	D-1002-64
	Dynamic	LN_2	1(10),3(10)	Cryotensile	D-1002-64, Mod.
	Dynamic	LH_2	1(10),3(10)	Cryotensile	D-1002-64, Mod.
Narmco A	Static	Air	1(10),3(10),1(11)	Instron	D-1002-64
	Dynamic	LH_2	1(10),3(10)	Cryotensile	D-1002-64, Mod.

[a]Ultimate Tensile Shear Strength and Percent Adhesive Failure data presented.

V. STRUCTURAL ADHESIVE TEST METHODS AND RESULTS

This section of the report contains all of the data obtained on structural adhesives tested during the current period. The ultimate tensile-shear strength of each adhesive listed in Table 5.1 (facing page) was measured under the conditions shown. Table A-1 (App. A) lists the manufacturers of the materials and gives a description of how each test panel was prepared.

The Program Summary table in this report lists all of the adhesive materials tested during the three major contractual periods and references the corresponding reports containing the data. In most cases, the current test data were required to fill remaining gaps in the data compilation.

All of the materials tested in the current period were irradiated statically in an air environment to two relatively high doses. Several days after completion of the irradiations, the specimens were tested at room temperature and pressure in an Instron machine at a crosshead speed of 0.05 in./min. In addition to the static tests, dynamic tests were performed with the Cryotensile Tester on three materials in LN_2 and LH_2. These materials were Epon 934, FM-1000, and HT 424. Two additional materials were subjected to an LH_2 test only, LN_2 tests having been performed in a previous period. These were Aerobond 422J and Narmco A. Both control and irradiation tests were performed on all materials. Tabulated data for each material are located at the end of this section.

The static test specimens were fabricated and tested in accordance with ASTM D-1002-53T. The test specimens which were subjected to LN_2 and LH_2 irradiations and tested in the Cryotensile Tester were modified lap-shear type as described in detail in Section 4.1.2. The 1/2- by 1-in. bonded area was in accordance with the ASTM designation, and the spacing between top and bottom doublers was the same as the jaw-grip spacing specified by ASTM. Doublers were used for reinforcement on the ends of the dynamic test specimens.

5.1 Aerobond 422J

The test specimens for this material were cut from the same batch of material used in a previous period (Ref. 4). The results from current tests on Aerobond 422J are given in Table 5.2 for both the static and dynamic conditions.

The Aerobond 422J specimens were inspected after completion of all tests for color change and percent adhesive failure. The original dark olive color yellowed slightly during the air irradiation, but no color change was apparent after the LH_2 irradiations. Definite contrasts in the type of failure were obvious. A 10% adhesive failure was noted for control and high-dose air-irradiated specimens, but specimens tested in LH_2 (both control and irradiated) showed a 90 to 95% adhesive failure. However, a visual inspection of the specimens and a study of the ultimate shear strength data revealed no significant damage to this material, either from cryotemperature or radiation effects.

5.2 Aerobond 430

Aerobond 430 was the only adhesive material irradiated in vacuum during this current test period. All of the other adhesives were irradiated in vacuum previously and reported in Reference 3. The test specimens for the current period were taken from the same batch of specimens as those used in the previous period. Postirradiation testing of all specimens irradiated in either vacuum or air was accomplished in the Instron Tester in ambient air. The results from current tests on Aerobond 430 are given in Table 5.3.

No significant color change from the original olive-green color was noted in any of the irradiated specimens. However, there was an increasing percent of adhesive failure as a function of radiation dose, ranging, for those irradiated and tested in air, from 10% on controls to 90% after irradiation to

1.7×10^{11} ergs/gm(C). For those irradiated in vacuum and tested in air, the percent of adhesive failure increased from 10% for controls to 40% for those irradiated to the high dose.

5.3 APCO 1252

This material was tested previously in ambient air, LN_2, and LH_2, and the data were reported and discussed in Reference 2. The test specimens used in the current program were from the same batch of materials used for specimens tested in vacuum and reported in Reference 3. As shown in Table 5.4, lap-shear specimens of APCO 1252 were subjected to two radiation exposures in air and one radiation exposure in vacuum while at cryotemperature. The test specimens used in both the vacuum-LN_2 control test and the vacuum-LN_2 irradiation test were lap-shear type as described in Section 4.2.

Inspection of the APCO 1252 specimens after irradiation in air showed a change in color from light cream to yellow. There was no color change in specimens that were irradiated in the vacuum-cryotemperature environment. Adhesive failure for air-tested specimens varied from 85% for the controls to 90% for the irradiated specimens. In contrast, for the vacuum-cryotemperature conditions, the controls had a 95% adhesive failure and irradiated specimens only 72%, a reversal in trend.

5.4 Epon 934

As shown in Table 5.5 this material was subjected to two complete radiation exposures in air, two radiation exposures in LN_2, and two radiation exposures in LH_2. The test specimens for the current program were fabricated from a new batch of material.

Specimens irradiated in air and LN_2 showed a color change from grey to brown, with a yellow cast evident in thin sections, but specimens irradiated in LH_2 showed a slight brownish cast as the only change. Adhesive failure of control and irradiated specimens in air, LN_2, and LH_2 tests ranged from 90 to 100%, with no trend being noted for any of the environmental conditions. This uniformity in percent of adhesive failure for all test conditions suggests a high degree of reliability for this adhesive under the various environments involved.

It should be noted that this is the material that was selected previously by the Fort Worth Division as a bonding agent for specimen doublers. This added experience with the material showed it to be an adequate adhesive for use in bonding plastic to plastic, plastic to aluminum, and aluminum to aluminum for use in environments encountered in this program. This material was not used on silicone elastomers but was used to bond silicone-resin laminates, polyethylene, and Teflon to aluminum.

5.5 Epon 951

This material had not been tested previously in the overall program. It was tested in the current period for a comparison with similar epoxy-nylon materials tested during the first two annual contractual periods. It was irradiated and tested under ambient-air conditions only. The static-air irradiation results are shown in Table 5.6.

The following color progression was noted for this material: control specimens, grey; low-dose specimens, light grey; high-dose specimens, light green. This color change with irradiation dose seems to be typical of the epoxy-nylon adhesives, as will be noted for FM-1000 (below). Adhesive failure varied from about 50% to 80%, with no specific trend for any test condition being discernible. It should be noted that specimens for this particular material, as prepared by the manufacturer, were made up with a very thin layer of Epon 951. This method may be proper, but it is noted.

5.6 FM-1000

This material is also an epoxy-nylon adhesive that has shown good retention of adhesive properties in previous testing. The specimens tested and reported in the current period were taken from a new batch of material. The air-irradiation tests were repeated for comparison with previously reported data. As can be seen in Table 5.7, FM-1000 was subjected to several test conditions in environments of air, LN_2, and LH_2, and significant differences in properties were measured as a function of exposure to these environments. There was a definite progressive change in the color of the FM-1000 as it was irradiated in air. Furthermore, the type of failure during postirradiation tests was gradually more adhesive than cohesive with higher and higher doses. Adhesive failure for air tests progressed from 10% for the controls to 55% at the high dose of 1×10^{11} ergs/gm(C). The following color progression was noted: control specimens, light cream; specimens irradiated to 9.7×10^{9} ergs/gm(C), light tan; specimens irradiated to 3.3×10^{10} ergs/gm(C), tan; specimens irradiated to 1.7×10^{11} ergs/gm(C), dark brown. In the LN_2 irradiation, a color change was again noted, but it was not as pronounced as in the air test. Specimens irradiated to 3×10^{10} ergs/gm(C) were a light tan, considerably lighter than those irradiated to the same dose level in air. Again, the degree of adhesive failure was typical for a cryotemperature test, being in the range of 90 to 95%. In the LH_2 irradiations, virtually no color change was apparent between the original material and the irradiated specimens and, here again, a typical adhesive failure of 90 to 100% was noted.

5.7 HT 424

The test specimens were taken from the same batch of material used for specimens tested in a previous period (Ref. 3). As can be seen in Table 5.8, this material was tested after a high radiation exposure in air and after two radiation exposures each in LN_2 and LH_2.

Inspection of this material showed very little color change after irradiation in both air and LN_2. All specimens in the air irradiation demonstrated an adhesive failure of about 5%. All specimens tested in LN_2 (both control and irradiated) showed an adhesive failure of about 80%. With the addition of these data to the data reported in Reference 3, a complete picture of the irradiation and testing history of this material is available.

5.8 Narmco A

The test specimens used in the current period were taken from the same batch of material used for specimens tested and reported on in Reference 3. As can be seen from the data contained in Table 5.9, LH_2 tests only were conducted during the current program.

Inspection of the specimens showed a trend in both color change and percent of adhesive failure as a function of irradiation time. The following color progression was noted for the

LH_2 test. control specimens, light cream; specimens irradiated to 1 x 10^{10} ergs/gm(C), yellow; specimens irradiated to 3 x 10^{10} ergs/gm(C), bright yellow; specimens irradiated to 1 x 10^{11} ergs/gm(C), yellowish brown. Adhesive failure changed from about 30% for control specimens to almost 100% for those irradiated to the maximum dose.

5.9 General Discussion of Results

This current testing work on adhesives is essentially a continuation of the program originated in the previous contractual period. Only Epon 951, a new epoxy-nylon material, was added to the current program for a comparison with the FM-1000, which had a very high initial tensile shear strength. A comparison of the control values given in Table 5.10 shows that these high tensile values are reproducible between vendors and that the values are retained to 1 x 10^{10} ergs/gm(C). But for the higher doses, epoxy material such as Epon 934 would be more predictable and reliable, since no change in tensile shear properties was noted for the material.

Table 5.10 gives a few of the test values obtained during this program and presents a comparison between the LH_2 and air environmental effects.

The adhesives showed a general trend toward increased percentage of adhesive failure when tested at cryotemperatures, being 90 to 100% adhesive at the high doses in LH_2.

Table 5.2

Aerobond 422J Structural Adhesive
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)							
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
1-11 1-12 1-13 1-14 1-15	-	Air	Instron at 0.05 in./min	0	0	0	0	-	2464 2437 2344 2215 2312 2354/107	10 avg	75	760
1-6 1-7 1-8 1-9 1-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	15	2319 2435 2569 2181 2303 2361/167	10 avg	240	760
1-111 1-112 1-113 1-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	2396 2597 2521 2228 2436/179	92 avg	-423	760
1-126 1-127 1-128 1-129	LH_2	LH_2	CTT at 0.05 in./min	7.5(9)	-	1.3(15)	-	-	2278 2245 2454 2000 2244/220	92 avg	-423	760
1-131 1-132 1-133 1-134	LH_2	LH_2	CTT at 0.05 in./min	2.4(10)	-	4.4(10)	-	-	2456 2167 2195 2020 2209/212	92 avg	-423	760

[a]Values given as: average value/standard deviation on an individual basis.

Table 5.3

Aerobond 430 Structural Adhesive
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
2-11 2-12 2-13 2-14 2-15	-	Air	Instron at 0.05 in./min	0	0	0	0	-	3198 3221 3211 3152 3133 3183/38	10 avg	75	760
2-1 2-2 2-3 2-4 2-5	Air	Air	Instron at 0.05 in./min	3.3(10)	-	5.4(15)	-	15	2666 2624 2678 2788 2671 2685/71	7) avg	200	760
2-6 2-7 2-8 2-9 2-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	15	2086 2253 2267 2181 2279 2213/83	90 avg	240	760
2-66 2-67 2-68 2-69 2-70	Vac	Air	Instron at 0.05 in./min	1.2(9)	1.6(13)	1.8(14)	6.7(13)	45	3190 3140 3200 3440 3060 3206/163	10 avg	145	4.6(-6)
2-76 2-77 2-78 2-79 2-80	Vac	Air	Instron at 0.05 in./min	8.7(9)	7.6(13)	-	-	-	2895 2921 2909 2923 2800 2890/53	40 avg	160	2.0(-6)

[a]Values given as: average value/standard deviation on an individual basis.

Table 5.4

APCO 1252 Structural Adhesive
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)							
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
7-11 7-12 7-13 7-14 7-15	-	Air	Instron at 0.05 in./min	0	0	0	0	-	3469 3398 3177 3127 2969 3228/215	88 avg	75	760
7-1 7-2 7-3 7-4 7-5	Air	Air	Instron at 0.05 in./min	3.3(10)	-	5.4(15)	-	15	3559 3741 3416 3309 3020 3409/310	95 avg	200	760
7-6 7-7 7-8 7-9 7-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	15	2877 3242 2836 2421 2373 2750/374	95 avg	240	760
7-136 7-137 7-138 7-139	-	Vac-LN_2	CMT at 0.05 in./min	0	0	0	0	-	4139 4347 5012 3780 4329/598	95 avg	-250	.2 to .02
7-141 7-142 7-143 7-144	Vac-LN_2	Vac-LN_2	CMT at 0.05 in./min	1.2(10)	5.9(13)	1.1(15)	-	-	3802 -- 4248 3041 3697/713	72 avg	-290	.13 to .07

[a]Values given as: average value/standard deviation on an individual basis.

Table 5.5

Epon 934 Structural Adhesive
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
18A-11 18A-12 18A-13 18A-14 18A-15	-	Air	Instron at 0.05 in./min	0	0	0	0	-	2920 2598 2842 2531 2561 2690/167	90 avg	75	760
18A-46 18A-47 18A-48 18A-49 18A-50	Air	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	3	2158 2919 2153 2811 2839 2576/334	90 avg	160	760
18A-1 18A-2 18A-3 18A-4 18A-5	Air	Air	Instron at 0.05 in./min	3.3(10)	-	5.4(15)	-	15	3066 2882 2824 2799 3098 2934/129	90 avg	200	760
18A-6 18A-7 18A-8 18A-9 18A-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	15	2818 2739 2450 2846 2977 2766/227	90 avg	240	760
18A-91 18A-92 18A-93 18A-94	-	LN_2	CTT at 0.05 in./min	0	0	0	0	-	2019 2016 1957 1942 1983/37	90 avg	-320	760

[a]Values given as: average value/standard deviation on an individual basis.

Table 5.5 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)							
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
18A-101 18A-102 18A-103 18A-104	LN_2	LN_2	CTT at 0.05 in./min	4.8(9)	-	8.5(14)	-	-	2034 2065 2023 1969 2023/47	90 avg	-320	760
18A-106 18A-107 18A-108 18A-109	LN_2	LN_2	CTT at 0.05 in./min	1.4(10)	-	2.4(15)	-	-	2060 1520 2219 1835 1908/339	90 avg	-320	760
18A-111 18A-112 18A-113 18A-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	1880 1861 1874 1984 1899/60	90 avg	-423	760
18A-126 18A-127 18A-128 18A-129	LH_2	LH_2	CTT at 0.05 in./min	7.5(9)	-	1.3(15)	-	-	1815 1842 1859 1768 1821/44	90 avg	-423	760
18A-131 18A-132 18A-133 18A-134	LH_2	LH_2	CTT at 0.05 in./min	2.4(10)	-	4.4(15)	-	-	1704 1874 1383 1802 1684/238	90 avg	-423	760

Table 5.6

Epon 951 Structural Adhesive
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm2)							
					E < 0.48 ev	E > 2.9 Mev	E > 3.1 Mev					
102-11 102-12 102-13 102-14	-	Air	Instron at 0.05 in./min	0	0	0	0	-	6605 6532 6592 6582 6578/35	65 avg	75	760
102-36 102-37 102-38 102-39	Air	Air	Instron at 0.05 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	6868 6508 6390 6052 6455/396	65 avg	75	760
102-41 102-42 102-43 102-44	Air	Air	Instron at 0.05 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	3	7042 6911 5793 6202 6487/607	65 avg	125	760
102-46 102-47 102-48 102-49	Air	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	3	6303 5857 6463 6807 6358/461	65 avg	160	760

[a] Values given as: average value/standard deviation on an individual basis.

Table 5.7

FM 1000 Structural Adhesive
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm2) E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
6A-11 6A-12 6A-13 6A-14 6A-15	-	Air	Instron at 0.05 in./min	0	0	0	0	-	6770 6587 6318 6517 6531 6545/194	10 avg	75	760
6A-46 6A-47 6A-48 6A-49 6A-50	Air	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	3	6741 6155 6155 6016 6250 6263/312	25 avg	160	760
6A-1 6A-2 6A-3 6A-4 6A-5	Air	Air	Instron at 0.05 in./min	3.3(10)	-	5.4(15)	-	15	5331 5918 5909 6093 5839 5818/328	40 avg	200	760
6A-6 6A-7 6A-8 6A-9 6A-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	15	2068 2549 2152 2146 2090 2201/207	[illegible]5 avg	240	760
6A-91 6A-92 6A-93 6A-94	-	LN_2	CTT at 0.05 in./min	0	0	0	0	-	3560 5214 4784 5118 4669/803	90 avg	-320	760

[a]Values given as: average value/standard deviation on an individual basis.

Table 5.7 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)							
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
6A-101 6A-102 6A-103 6A-104	LN_2	LN_2	CTT at 0.05 in./min	4.8(9)	-	8.5(14)	-	-	5360 3278 5635 3761 4508/1145	92 avg	-320	760
6A-106 6A-107 6A-108 6A-109	LN_2	LN_2	CTT at 0.05 in./min	1.4(10)	-	2.4(15)	-	-	1439 2951 2746 1250 2096/826	95 avg	-320	760
6A-111 6A-112 6A-113 6A-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	3397 2675 2732 3080 2971/324	95 avg	-423	760
6A-126 6A-127 6A-128 6A-129	LH_2	LH_2	CTT at 0.05 in./min	7.5(9)	-	4.4(15)	-	-	1891 2585 2243 1920 2159/337	97 avg	-423	760
6A-131 6A-132 6A-133 5A-134	LH_2	LH_2	CTT at 0.05 in./min	2.4(10)	-	4.4(15)	-	-	2064 1684 1708 1446 1726/170	98 avg	-423	760

Table 5.8

HT-424 Structural Adhesive
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)							
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
8-11 8-12 8-13 8-14 8-15	-	Air	Instron at 0.05 in./min	0	0	0	0	-	3399 3439 3465 3658 3340 3460/137	5 avg	75	760
8-46 8-47 8-48 8-49 8-50	Air	Air	Instron at 0.05 in./min	9.7(9)	3.5(15)	2.0(15)	6.3(13)	3	3082 3062 2959 2966 3068 3027/53	5 avg	160	760
8-1 8-2 8-3 8-4 8-5	Air	Air	Instron at 0.05 in./min	3.3(10)	-	5.4(15)	-	14	2613 2650 2591 2795 2545 2639/107	5 avg	200	760
8-6 8-7 8-[illegible] 8-9 8-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	14	2150 2198 2184 2275 2156 2193/54	5 avg	240	760
8-91 8-92 8-93 8-94	-	LN_2	CTT at 0.05 in./min	0	0	0	0	-	4684 4482 4212 4506 4471/229	80 avg	-320	760

[a]Values given as: average value/standard deviation on an individual basis.

Table 5.8 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)							
					E < 0.48 ev	F > 2.9 Mev	E > 8.1 Mev					
8-101 8-102 8-103 8-104	LN_2	LN_2	CTT at 0.05 in./min	4.8(9)	-	8.5(14)	-	-	4315 4110 3801 3878 4026/250	80 avg	-320	760
8-106 8-107 8-108 8-109	LN_2	LN_2	CTT at 0.05 in./min	2.5(10)	-	4.3(15)	-	-	3124 3486 3247 3498 3339/182	80 avg	-320	760
8-111 8-112 8-113 8-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	3603 3559 3454 3760 3593/149	90 avg	-423	760
8-126 8-127 8-128 8-129	LH_2	LH_2	CTT at 0.05 in./min	7.5(9)	-	1.3(15)	-	-	2868 2793 3359 3479 3125/333	90 avg	-423	760
8-131 8-132 8-133 8-134	LH_2	LH_2	CTT at 0.05 in./min	2.4(10)	-	4.4(15)	-	-	3118 2743 2982 2727 2893/190	90 avg	-423	760

Table 5.9

Narmco-A Structural Adhesive
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)							
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
13-11 13-12 13-13 13-14 13-15	-	Air	Instron at 0.05 in./min	0	0	0	0	-	3945 3683 3695 3718 3926 3793/113	30 avg	75	760
13-46 13-47 13-48 13-49 13-50	Air	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	3	3380 2960 3471 4019 3623 3491/455	50 avg	160	760
13-1 13-2 13-3 13-4 13-5	Air	Air	Instron at 0.05 in./min	3.3(10)	-	5.4(15)	-	14	3814 4011 4150 4185 4541 4140/313	70 avg	200	760
13-6 13-7 13-8 13-9 13-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	14	1277 1225 775 1603 1686 1313/392	95 avg	240	760

[a]Values given as: average value/standard deviation on an individual basis.

Table 5.9 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)							
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
13-111 13-112 13-113 13-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	2375 1963 1771 2081 2048/293	96 avg	-423	760
13-126 13-127 13-128 13-129	LH_2	LH_2	CTT at 0.05 in./min	7.5(9)	-	1.3(15)	-	-	1895 1638 1388 1498 1605/246	96 avg	-423	760
13-131 13-132 13-133 13-134	LH_2	LH_2	CTT at 0.05 in./min	2.4(10)	-	4.4(15)	-	-	1921 1705 1665 1412 1676/247	98 avg	-423	760

Table 5.10

Summary Table of Ultimate Tensile Shear Strength for Adhesives (psi)

Adhesive Material	Air Environment			LH_2 Environment	
	Control	1.0(10) [ergs/gm(C)]	1.7(10) [ergs/gm(C)]	Control	8.0(10) [ergs/gm(C)]
Aerobond 422J	2354	-	2361	2436	2244
Aerobond 430	3183	2450	2213	-	-
APCO 1252	3228	3416	2750	-	-
Epon 934	2960	2576	2766	1899	1821
Epon 951	6578	6358	-	-	-
FM-1000	6545	6263	2201	2971	2159
HT 424	3460	3027	2193	3593	3125
Narmco A	3800	3491	1313	2048	1605

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VI. STRUCTURAL LAMINATE TEST METHODS AND RESULTS

Table 6.1

Outline of Structural Laminate Tests[a]

Material	Type of Test	Irradiation Environment	Nominal Gamma Dose [ergs/gm(C)]	Materials Tester
Conolon 506	Dynamic	Vac-cryo	1(10)	Cryomechanical
CTL 91-LD	Static	Air	1(11)	Instron
	Dynamic	LH_2	1(10),3(10)	Cryotensile
DC-2104	Static	Air	1(11)	Instron
	Dynamic	LH_2	1(10),3(10)	Cryotensile
Epon 828/A	Static	Air	1(10),3(10),1(11)	Instron
	Dynamic	LN_2	1(10),3(10)	Cryotensile
	Dynamic	LH_2	1(10),3(10)	Cryotensile
Mobaloy 81-AH7	Static	Air	1(10),3(10),1(11)	Instron
	Dynamic	LN_2	1(10),3(10)	Cryotensile
	Dynamic	LH_2	1(10),3(10)	Cryotensile
Paraplex P-43	Static	Air	1(11)	Instron
	Static	Vacuum	1(10)	Instron
	Dynamic	Vacuum	1(10)	High-Force
Selectron 5003	Static	Air	1(10),3(10),1(11)	Instron
	Dynamic	LN_2	1(10),3(10)	Cryotensile
	Dynamic	LH_2	1(10),3(10)	Cryotensile

[a]ASTM Test Method D638-61T(Mod) was used to obtain the following data: Tensile Strength at Rupture, Elongation at Rupture, and Stress-Strain Curves.

VI. STRUCTURAL LAMINATE TEST METHODS AND RESULTS

This section of the report contains a tabulation and discussion of data obtained on structural laminates tested during the current period. Materials tested were selected on a continuing basis with those tested in previous periods. The Program Summary table shown at the beginning of this report lists all of the structural laminate materials tested during the two annual and final biennial contractual periods in the program, and applicable reports covering each material are referenced.

Six of the seven current materials were irradiated and tested in an air environment, and five were irradiated and tested while submerged in either LN_2 or LH_2. Some were exposed to both of these environments. One material was tested in a vacuum-cryotemperature environment and one material was tested in a vacuum environment to complete the data cycles required. The current data, along with the data contained in previous reports, provide a comprehensive picture of the various environmental effects on the mechanical properties of structural laminates.

Table 6.1 (facing page) contains a résumé of the test conditions, environments, doses, and materials tested under this category in the current period. Summary tabulations and plots of the data obtained on materials listed in Table 6.1 are shown at the end of this section and are organized according to individual materials tested. Both static and dynamic tests were conducted in the program. Static tests consisted of irradiating specimens in an air environment and subsequently testing them in an Instron machine at a crosshead speed of 0.05 in./min. The dynamic tests involved the use of a cryotemperature or vacuum environment for both the irradiation and subsequent tests, without intervening removal of the specimens from the environment.

The ASTM D-638 test method was modified slightly for the dynamic tests. The modification involved the use of pinned specimens with doublers bonded onto each end. In the static tests the specimens had the same configuration, but no doublers were used. The latter were tested in the Instron machine with standard jaws. No significant differences were detected between data received from tests using the two types of specimens and jaws. Specimen configuration details are given in Section 4.1.

6.1 Conolon 506

A new batch of this material, which is presently designated Narmco 506, was ordered for this test program. The material was subjected to vacuum-LN_2 control and vacuum-LN_2 irradiation tests in the Cryomechanical Tester, which is described in Section 2.5.

Except for the specimen modification described above, the tests were conducted in accordance with ASTM D-638-61T at a testing speed of 0.05 in./min. Average stress-strain curves of the four specimens tested in each condition are shown in Figure 6.1. Table 6.2 is a tabulation of the environmental conditions and test results.

This material, being a phenolic laminate, demonstrated exceptional resistance to deterioration from both the radiation and cryogenic environments. The breaks, both for the control and irradiated specimens, were all "A" type (or good). Some delamination occurred during the fracture process, but this was very slight compared to other laminates tested under cryogenic conditions.

6.2 CTL 91-LD

This material has been tested extensively throughout the overall program, as is shown in the references in the Program Summary New test panels were ordered for current tests in ambient air and LH_2, and the specimens were subjected to the irradiation exposures and environments given in Table 6.1. The test specimens subjected to the air irradiation were slotted specimens and were subsequently tested in the Instron with pin-type jaws. The test specimens subjected to LH_2 irradiation exposures were tested in the Cryotensile Tester in the specimen configuration described in Section 4.1. Average stress-strain curves for the specimens tested under various environmental conditions are shown in Figure 6.2. Table 6.3 is a tabulation of the environmental conditions and test results.

This material demonstrated excellent resistance to deterioration in mechanical properties under the influence of either cryotemperature or radiation environments, or both environments in combination. Most specimens had good "A"-type breaks in all environments after irradiation to 3 x 10^{10} ergs/gm(C).

6.3 DC-2104

This material has been tested extensively in vacuum, air, and LN_2, as can be seen from the references in the Program Summary table. It was tested this year in LH_2 to complete the data cycle begun in previous test periods. Specimens and material for current tests were chosen from that remaining from the previous periods. The specimens tested in the Instron machine were of the same configuration as the pin-type specimens, but were minus the doublers and pin holes. Dynamic tests in cryotemperature environments were similar to those reported for the previous tests. The test results are presented in Table 6.4, and stress-strain curves are presented in Figures 6.3 and 6.4.

Good breaks resulted for all statically tested control specimens. The data were statistically satisfactory and there was no delaminating. Data from specimens irradiated to the high dose and tested statically were also good. Most breaks were "A" type. Generally good data, "A"-type breaks, and only minor delaminations resulted in LH_2 control and postirradiation tests.

6.4 Epon 828/A

A new batch of this material was ordered for the extensive testing planned for the current period. The material was subjected to three air irradiations, two LN_2 irradiations, and two LH_2 irradiations. Data from the tests are given in Table 6.5. Data for individual specimens tested in the various irradiation configurations are included. Stress-strain plots for specimens tested under each of the environmental conditions are given in Figures 6.5, 6.6, and 6.7. Each of the curves shown represents an average of data from four or five specimens.

Inspection of Epon 828/A showed that in air-irradiation conditions all specimens had good "A" breaks, which ensured statistically good data. However, there was a definite color change in the material as a result of the irradiation. This change was from an original greenish yellow to a light brown, and ultimately, to a dark brown. Cryotemperature test results were satisfactory, with all specimens breaking in the gage length. The color changed in the LN_2 test conditions from a green to a dark yellowish brown. The Shell Epon 934 adhesive used to bond the aluminum doublers to this material failed during all of the LN_2 tests; however, the rivets held to a satisfactory completion of the tests.

In the LH_2 tests, all of the doublers remained bonded to the test specimens. The color changed from a green to a light yellowish brown. Data were quite good, however, even to the high dose of 3×10^{10} ergs/gm(C).

6.5 Mobaloy 81-AH7

A new batch of test material was obtained for this year's tests at the high dose in air and for the LN_2 and LH_2 tests. The cryotemperature irradiation and postirradiation tests were made in the Cryotensile Tester. Table 6.6 presents the complete environmental test conditions and test results for this material, and Figures 6.8, 6.9, and 6.10 present stress-strain curves for the material under each of the environmental conditions shown. Each curve represents an average curve for three or four specimens. The specimen configuration is shown in Section 4.1.

From a visual standpoint, Mobaloy tested quite satisfactorily. For the air, LN_2, and LH_2 tests, all breaks could be classed as "A" type. Some discoloration occurred during irradiation in air, but virtually none was evident under cryotemperature environments. All specimens showed some delaminating, but it was minimal. This material should be considered for use in high radiation fields, cryotemperature conditions, or both.

6.6 Paraplex P-43

Specimens for current tests on this material were taken from the same batch of specimens that were used in a previous period (Ref. 3). During the current testing period, the material was subjected to one air irradiation and two vacuum irradiations. Both the vacuum control specimens and the specimens that were irradiated in vacuum were subsequently tested in vacuum in the High-Force Tester. All the other specimens were tested in the Instron using wedge-action jaws, with the exception of three air controls which were tested using the pin-type jaws. ASTM Designation D-638-61T was followed during all tests. Table 6.7 is a tabulation of the environmental conditions and test results. Figures 6.11 and 6.12 present stress-strain curves plotted from average values obtained for all test conditions.

An inspection of Paraplex P-43 specimens showed some discoloration after irradiation. There was also some delamination noted in tested specimens, but 90% of the breaks could be classed as either "A" or "B" type.

The vacuum controls had ply separations in the entire gage section; this produced ragged fiberglass breaks, which indicated resin weakness. In vacuum there was no color change, while in air the specimens changed from green to yellow. The test results for this material are not as consistent as they are for other laminates tested.

6.7 Selectron 5003

A new batch of this material was ordered from the vendor for the current testing period. The results of the tests are given in Table 6.8. Individual specimen values and averages of data obtained from tests under each of the environmental conditions shown in Table 6.1 are included. Stress-strain curves for the dynamic tests are presented in Figures 6.13, 6.14, and 6.15 for the air, LN_2, and LH_2 irradiations, respectively. The stress-strain curves are average curves for data obtained for three or four specimens.

In air control tests, and tests in air after irradiation in air, all specimens showed "A"-type breaks. Some discoloration was observed in specimens irradiated in air, but very little delaminating occurred in the air tests. Significant delaminating occurred in the cryotemperature tests.

This material evidently had a cryotemperature failure independent of any irradiation failure, since there was a separation of the resin from the fiberglass plies even in the cryotemperature controls. The separations extended beyond the narrow gage section into the doubler section. This indicates the stress-relief pattern of these specimens as they are pulled and gives a visible indication of the pull-outs at the pin holes in some materials.

6.8 General Discussion of Results

The four basic types of structural laminates tested both in air and in LH_2 are represented in Table 6.9. Air irradiation produced only moderate changes in the tensile strength at rupture. Cryotemperatures greatly increased the tensile strength at rupture for the controls, with the only significant cryotemperature-irradiation change being noted in the polyester, Selectron 5003.

A general trend was noted in all test-specimen color changes. They were most pronounced in the air irradiations. The discolorations for specimens in LN_2 were less pronounced at the same doses, while in LH_2 the specimen color changes were very slight.

Table 6.2

Conolon 506 Structural Laminate
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
41A-136 41A-137 41A-138 41A-139	-	Vac-LN_2	CMT at 0.05 in./min	0	0	0	0	-	59,171 59,896 61,221 60,813 60,275/996	3.15 3.48 3.20 3.01 3.21/.23	-250	.2-.02
41A-141 41A-142 41A-143 41A-144	Vac-LN_2	Vac-LN_2	CMT at 0.05 in./min	6.1(9)	1.7(14)	9.1(14)	-	-	51,708 58,752 30,926 43,926 46,328/13,514	2.89 3.18 2.56 3.51 3.04/.46	-290	.13-.07

[a]Values given as: average value/standard deviation on an individual basis.

Table 6.3

CTL-91LD Structural Laminate
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
42-6* 42-7* 42-8*	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	17	36,820 33,020 34,850 34,897/2245	1.15 1.15 1.17 1.16/0.12	200	760
42-111 42-112 42-113 42-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	40,762 35,920 41,390 28,040 36,528/648	3.50 2.28 1.99 1.90 2.42/.78	-423	760
42-126 42-127 42-128 42-129	LH_2	LH_2	CTT at 0.05 in./min	6.2(9)	-	1.1(15)	-	-	51,078 54,982 47,922 43,186 49,292/5728	2.15 2.64 3.19 2.79 2.69/.51	-423	760
42-131 42-132 42-133 42-134	LH_2	LH_2	CTT at 0.05 in./min	2.3(10)	-	4.1(15)	-	-	53,909 51,939 44,873 49,044 49,941/4389	3.74 2.73 3.35 2.96 3.25/.49	-423	760

[a]Values given as: average value/standard deviation on an individual basis. *Slotted specimen

Table 6.4

DC-2104 Structural Laminate
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
43-11* 43-12* 43-13*	-	Air	Instron at 0.05 in./min	0	0	0	0	-	18,990 19,100 19,260 19,117/159	0.98 0.97 0.94 0.96/0.02	75	760
43-14 43-15									24,770 23,620 24,195/1019	0.91 1.00 0.96/0.08		
43-6* 43-7* 43-8*	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(11)	-	16	19,740 20,880 21,120 20,580/815	0.96 0.99 0.95 0.97/0.02	200	760
43-9 43-10A 43-10B									32,870 31,290 31,710 31,957/685	1.56 1.76 1.74 1.69/0.12		
43-111 43-112 43-113 43-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	57,322 56,822 53,318 52,623 55,021/2282	4.61 4.69 4.30 4.48 4.52/.15	-423	760
43-126 43-127 43-128 43-129	LH_2	LH_2	CTT at 0.05 in./min	6.2(9)	-	1.1(15)	-	-	61,169 63,066 58,211 61,770 61,054/2358	4.56 5.74 4.43 4.91 4.91/.64	-423	760
43-131 43-132 43-133 43-134	LH_2	LH_2	CTT at 0.05 in./min	2.3(10)	-	4.1(15)	-	-	53,218 56,010 64,250 51,543 56,255/6171	4.23 3.99 4.39 4.50 4.28/.25	-423	760

[a]Values given as: average value/standard deviation on an individual basis.

*Specimens from different batch of material

Table 6.5

Epon 828/A Structural Laminate
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
45A-11 45A-12 45A-13 45A-14 45A-15	-	Air	Instron at 0.05 in./min	0	0	0	0	-	39,910 43,490 41,420 36,280 37,890 39,798/3100	2.13 2.13 1.95 2.08 2.21 2.10/0.11	75	760
45A-46 45A-47 45A-48 45A-49 45A-50	Air	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	4	38,863 39,066 36,390 37,592 38,144 38,011/1150	1.89 1.91 1.65 1.64 1.79 1.78/0.12	140	760
45A-1 45A-2 45A-3 45A-4 45A-5	Air	Air	Instron at 0.05 in./min	3.3(10)	-	5.4(15)	-	16	39,830 40,860 39,030 38,850 37,460 39,206/1462	1.81 1.87 2.06 2.20 1.74 1.94/0.20	170	760
45A-6 45A-7 45A-8 45A-9 45A-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	16	39,380 36,230 40,200 37,790 34,760 37,672/2339	1.71 1.98 1.88 1.85 1.82 1.85/0.12	200	760
45A-91 45A-92 45A-93 45A-94	-	LN_2	CTT at 0.05 in./min	0	0	0	0	-	83,385 85,139 84,194 85,478 84,549/1017	5.17 5.26 5.34 5.30 5.27/0.08	-320	760

[a]Values given as: average value/standard deviation on an individual basis.

Table 6.5 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48 ev	E>2.9 Mev	E>8.1 Mev		Tensile Strength (psi)	Elongation (%)		
45A-101 45A-102 45A-103	LN_2	LN_2	CTT at 0.05 in./min	5.2(9)	-	9.4(14)	-	-	75,930 83,918 84,282 81,377/4904	4.43 5.94 5.91 5.43/0.89	-320	760
45A-106 45A-107 45A-108	LN_2	LN_2	CTT at 0.05 in./min	1.5(10)	-	2.6(15)	-	-	86,543 88,446 74,406 83,132/8293	5.46 5.74 5.89 5.70/0.25	-320	760
45A-111 45A-112 45A-113 45A-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	94,424 87,362 88,913 78,676 87,344/7648	5.31 5.29 5.47 5.50 5.44/.10	-423	760
45A-126 45A-127 45A-128 45A-129	LH_2	LH_2	CTT at 0.05 in./min	8.4(9)	-	1.5(15)	-	-	89/528 63,306 83,936 42,764[a] 78,923/15,488	4.99 3.27 4.61 5.42[a] 4.29/.43	-423	760
45A-131 45A-132 45A-133 45A-134	LH_2	LH_2	CTT at 0.05 in./min	1.1(10)	-	2.0(15)	-	-	60,292[b] 57,126[b] 81,898 87,453 84,675/49,250	3.60[b] 3.35[b] 5.51 5.48 5.49/.026	-423	760

[a] Double failure - data not included in average or standard deviation.
[b] Tested at +20°F - data not included in average or standard deviation.

Table 6.6

Mobaloy 81-AH7 Structural Laminate
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm²)				Tensile Strength (psi)	Elongation (%)		
					E<0.45 ev	E>2.9 Mev	E>8.1 Mev					
47A-11	-	Air	Instron at 0.05 in./min	0	0	0	0	-	33,620	1.17	75	760
47A-12									35,100	1.24		
47A-13									40,330	1.56		
47A-14									35,660	1.15		
47A-15									35,800	1.16		
									36,102/2885	1.26/0.18		
47A-46	Air	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	4	43,777	1.28	140	760
47A-47									38,763	1.17		
47A-48									39,53[illegible]	1.14		
47A-49									36,492	1.04		
47A-50									39,209	1.21		
									39,551/3132	1.17/0.10		
47A-1	Air	Air	Instron at 0.05 in./min	3.3(10)	-	5.4(15)	-	15	46,080	1.42	170	760
47A-2									44,650	1.29		
47A-3									34,370	0.97		
47A-4									36,060	1.10		
47A-5									32,740	1.04		
									38,780/5735	1.1[illegible]/0.19		
47A-6	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	15	38,440	1.20	200	760
47A-7									37,910	1.21		
47A-8									38,970	1.09		
47A-9									35,810	1.04		
47A-10									32,770	1.09		
									36,780/2438	1.13/0.07		
47A-91	-	LN_2	CTT at 0.05 in./min	0	0	0	0	-	61,604	2.90	-320	760
47A-92									62,791	3.02		
47A-93									59,495	2.61		
47A-94									56,992	2.53		
									60,221/2816	2.77/0.24		

[a] Values given as: average value/standard deviation on an individual basis.

Table 6.6 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
47A-101 47A-102 47A-103	LN_2	LN_2	CTT at 0.05 in./min	8.4(9)	-	1.5(15)	-	-	65,673 55,484 61,913 61,023/6018	3.37 2.86 3.11 3.11/0.30	-320	760
47A-106 47A-107 47A-108	LN_2	LN_2	CTT at 0.05 in./min	2.7(10)	-	4.7(15)	-	-	52,759 54,381 66,598 57,913/8174	2.69 2.86 3.26 2.94/0.34	-320	760
47A-111 47A-112 47A-113 47A-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	58,067 50,671 48,368 45,719 50,706/5997	2.71 2.31 2.25 2.47 2.44/.22	-423	760
47A-126 47A-127 47A-128 47A-129	LH_2	LH_2	CTT at 0.05 in./min	8.4(9)	-	1.5(15)	-	-	57,914[a] 41,257[a] 65,274 54,751 60,012/9328	2.72[a] 2.42[a] 3.13 4.01 3.07/.78	-423	760
47A-131 47A-132 47A-133 47A-134	LH_2	LH_2	CTT at 0.05 in./min	1.1(10)	-	2.0(15)	-	-	46,619[a] 46,429[a] 48,147 66,159 57,153/15,967	2.29[a] 2.35[a] 2.39 3.48 2.92/.97	-423	760

[a]Tested at +20°F - data not included in average or standard deviation.

Table 6.7

Paraplex P-43 Structural Laminate
Summary Table of Test Results

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48 ev	Neutrons (n/cm^2): E>2.9 Mev	Neutrons (n/cm^2): E>8.1 Mev	Time Until Test (days)	At Rupture[a]: Tensile Strength (psi)	At Rupture[a]: Elongation (%)	Avg. Temp. (F)	Avg. Press. (torr)
48-11[b]	-	Air	Instron at 0.05 in./min	0	0	0	0	-	45,000	1.87	75	760
48-12[b]									45,640	2.09		
48-13[b]									45,310	1.84		
									45,317/378	1.93/0.15		
48-14									42,400	1.99		
48-15A									43,270	1.85		
48-15C									42,640	1.79		
									42,270/514	1.89/0.12		
48-6	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	16	41,600	1.72	200	760
48-7									38,800	1.60		
48-8									41,500	1.67		
48-9									39,750	1.78		
48-10									38,420	1.61		
									40,014/1367	1.68/0.11		
48-76	Vac	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	8	46,255	1.88	140	2.0(-6)
48-77									46,712	1.60		
48-78									46,906	1.72		
48-79									44,300	1.96		
48-80									43,313	1.51		
									45,497/1545	1.73/0.19		
48-81	-	Vac	High-Force Tester at 0.05 in./min	0	0	0	0	-	45,460	3.71	75	1.0(-3)
48-82									42,013	3.48		
48-83									46,441	3.57		
48-84									46,995	3.55		
									45,227/2142	3.58/0.11		
48-86	Vac	Vac	High-Force Tester at 0.05 in./min	9.2(9)	1.1(14)	1.5(15)	-	-	47,273	4.07	140	2.0(-6)
48-87									49,327	4.35		
48-88									48,077	4.11		
48-89									48,920	3.90		
									48,399/998	4.10/0.22		

[a]Values given as: average value/standard deviation on an individual basis.
[b]Slotted specimen

Table 6.8

Selectron 5003 Structural Laminate
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.45 ev	E>2.9 Mev	E>8.1 Mev					
49A-11	-	Air	Instron at 0.05 in./min	0	0	0	0	-	41,340	1.47	75	760
49A-12									44,760	1.53		
49A-13									34,850	1.45		
49A-14									37,680	1.57		
49A-15									36,220	1.65		
									38,970/4,261	1.53/0.09		
49A-46	Air	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	4	46,346	1.60	140	760
49A-47									40,463	1.26		
49A-48									40,122	1.44		
49A-49									41,531	1.42		
49A-50									40,972	1.36		
									41,887/2676	1.42/0.15		
49A-1	Air	Air	Instron at 0.05 in./min	3.3(10)	-	5.4(15)	-	16	36,140	1.55	170	760
49A-2									36,780	1.43		
49A-3									44,930	1.82		
49A-4									36,640	1.51		
49A-5									36,960	1.57		
									38,290/3779	1.58/0.17		
49A-6	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	16	41,770	1.63	200	760
49A-7									41,800	1.70		
49A-8									46,850	1.81		
49A-9									44,640	1.70		
49A-10									44,580	1.82		
									43,928/2184	1.73/0.08		
49A-91	-	LN_2	CTT at 0.05 in./min	0	0	0	0	-	76,331	5.98	-320	760
49A-92									74,712	5.88		
49A-93									65,180	4.23		
49A-94									71,478	5.95		
									71,925/5416	5.51/0.85		

[a]Values given as: average value/standard deviation on an individual basis.

Table 6.8 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
49A-101 49A-102 49A-103	LN_2	LN_2	CTT at 0.05 in./min	7.8(9)	-	1.4(15)	-	-	70,647 76,176 No Data 73,412/4902	6.34 6.20 - 6.27/0.12	-320	760
49A-106 49A-107 49A-108	LN_2	LN_2	CTT at 0.05 in./min	2.2(10)	-	3.9(15)	-	-	73,177 63,207 70,753 69,046/5853	6.00 7.06 5.91 6.32/0.68	-320	760
49A-111 49A-112 49A-113 49A-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	73,511 72,881 69,796 66,851 70,760/3235	4.98 5.46 5.42 3.87 4.93/0.77	-423	760
49A-126 49A-127 49A-128 49A-129	LH_2	LH_2	CTT at 0.05 in./min	8.6(9)	-	1.5(15)	-	-	59,147 61,432 58,430 53,597 58,152/3805	4.10 4.39 4.61 4.77 4.47/0.33	-423	760
49A-131 49A-132 49A-133 49A-134	LH_2	LH_2	CTT at 0.05 in./min	1.4(10)	-	2.5(15)	-	-	56,620 45,277 58,929 52,120 53,237/6655	4.53 6.17 4.80 5.77 5.32/0.80	-423	760

Table 6.9

Summary Table of Tensile Strength at Rupture for Four Selected Laminates (psi)

Laminate Material	Air Environment		LH_2 Environment	
	Control	1.7(11) [ergs/gm(C)]	Control	1.5(10) [ergs/gm(C)]
Phenolic: Mobaloy 81-AH7	36,102	36,780	50,706	57,153
Silicone: DC 2104	24,195	31,957	55,021	56,255
Epoxy: Epon 828/A	39,798	37,672	87,344	84,675
Polyester: Selectron 5003	38,970	43,928	70,760	53,237

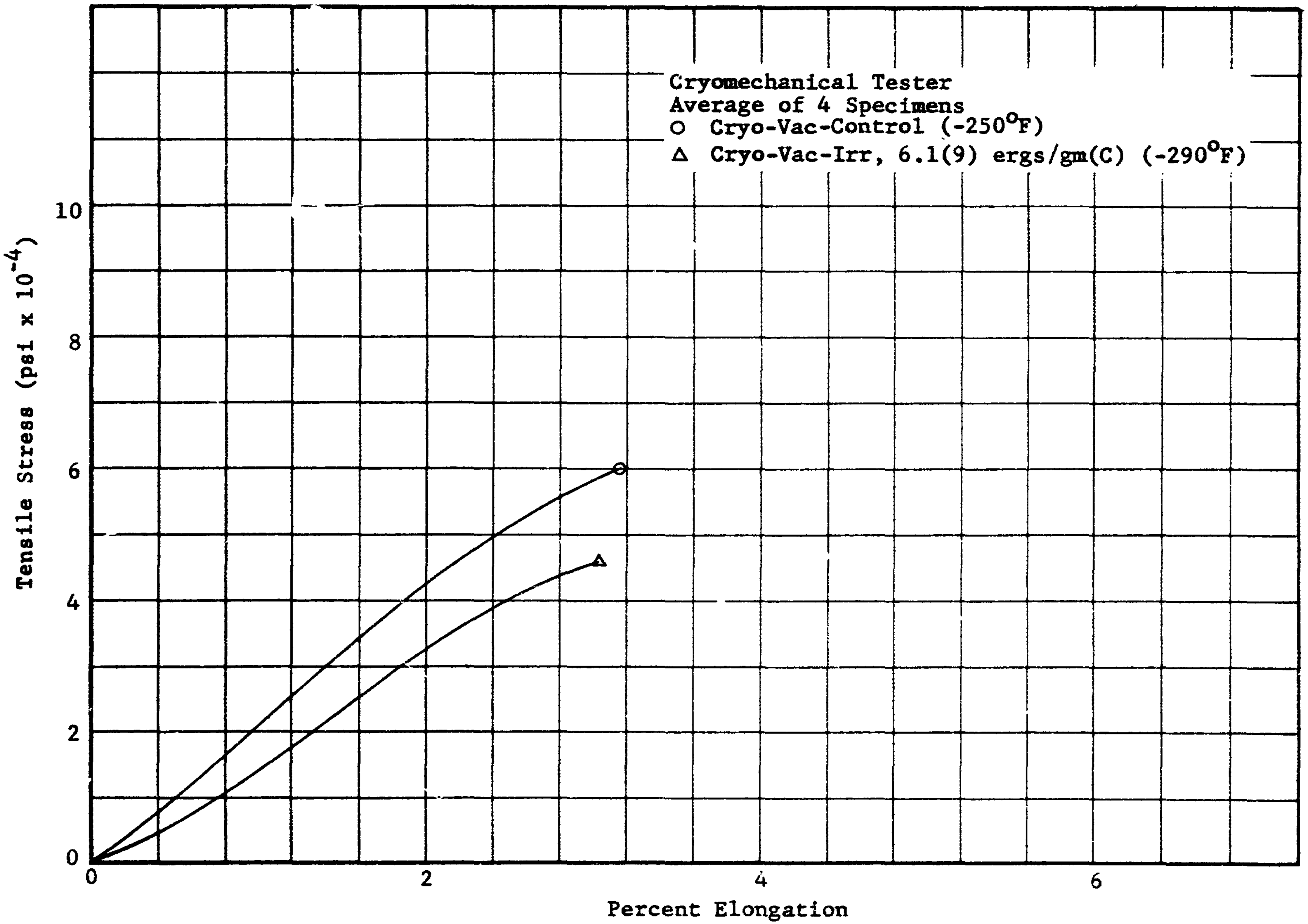

Figure 6.1 Conolon 506 Stress-Strain Curves: Vacuum/LN_2 Irradiation; Dynamic Tests

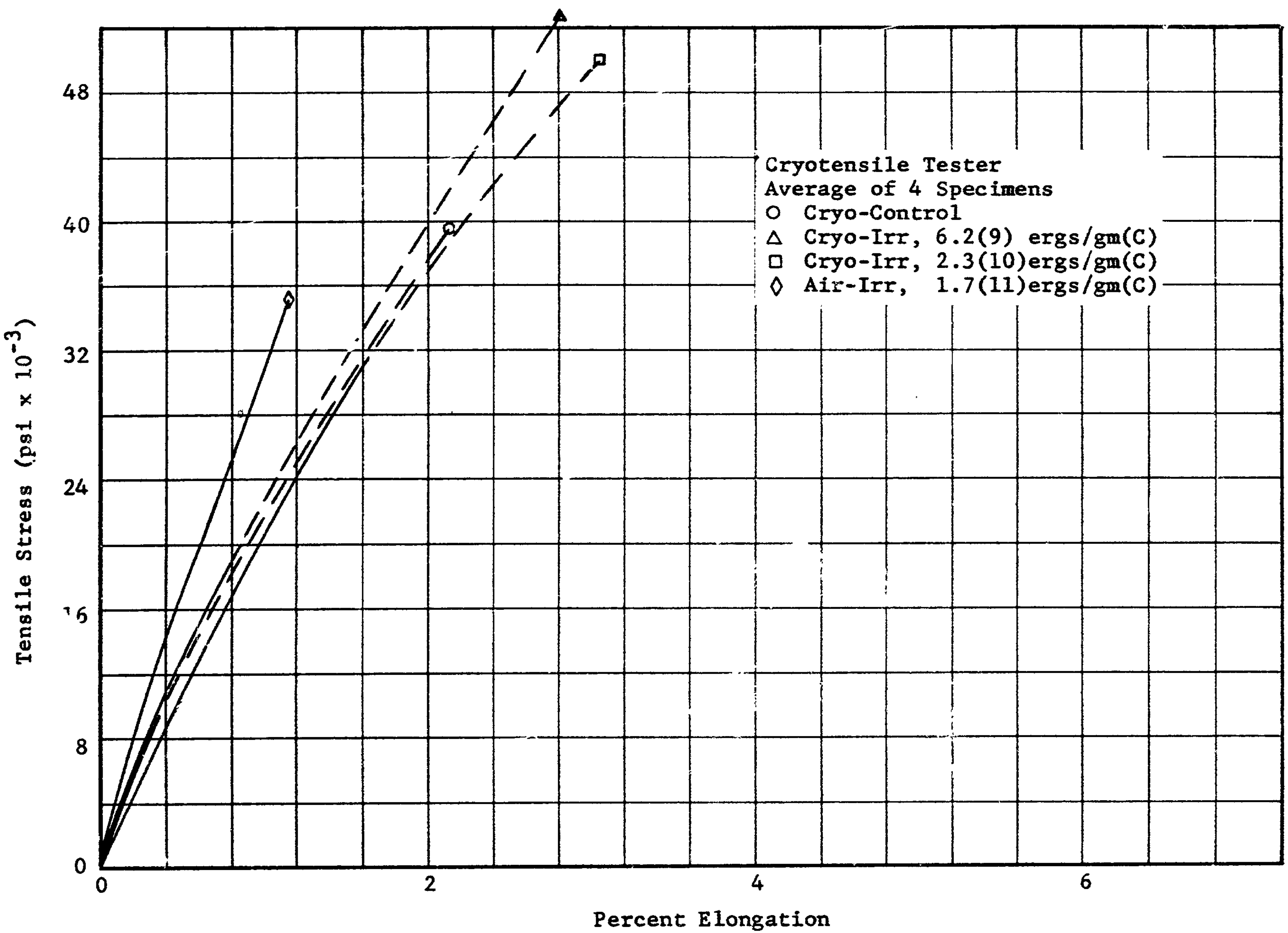

Figure 6.2 CTL-91LD Stress-Strain Curves: Air Irradiation; Static Test and LH_2 Dynamic Tests

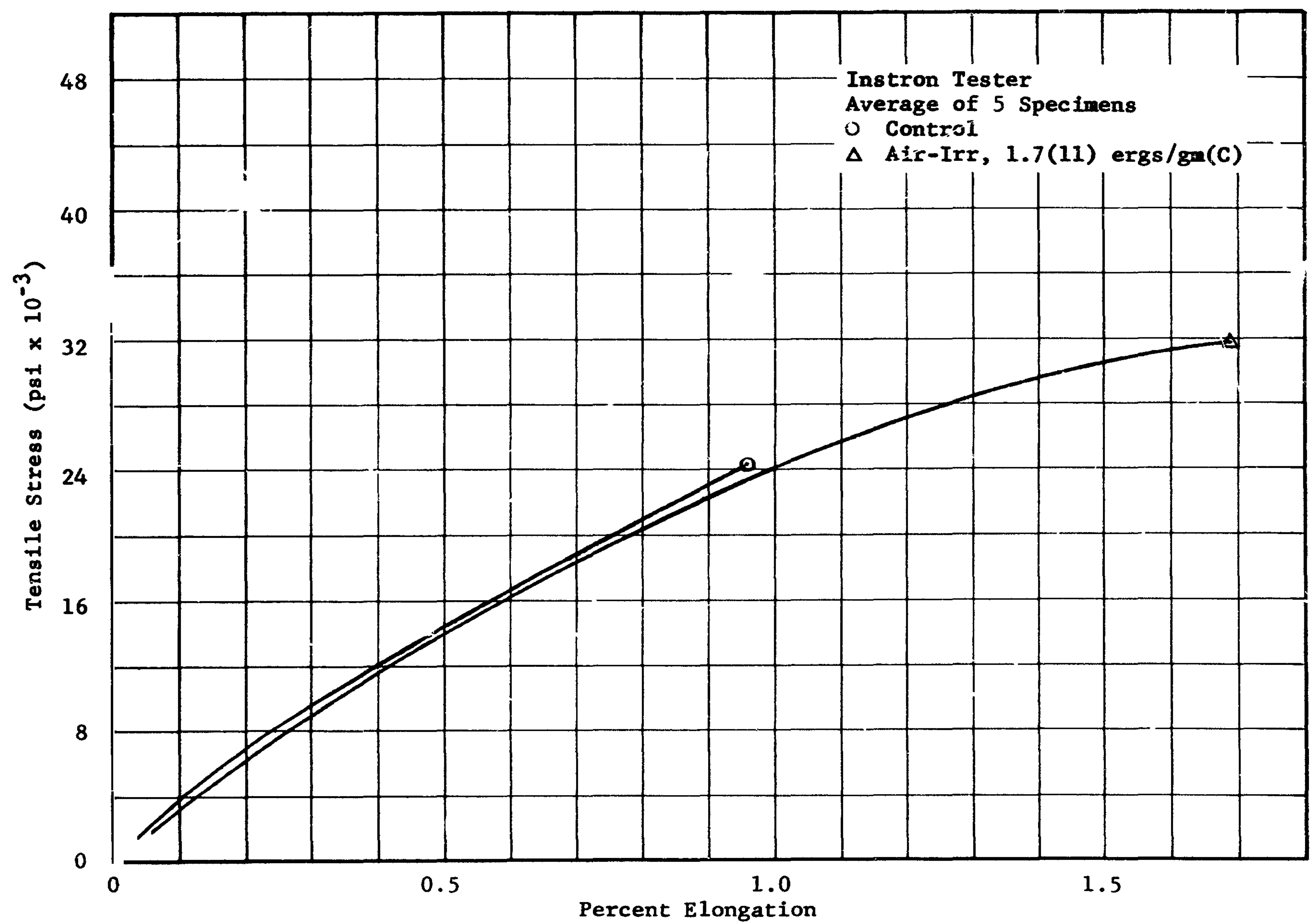

Figure 6.3 DC-2104 Stress-Strain Curves: Air Irradiation; Static Tests

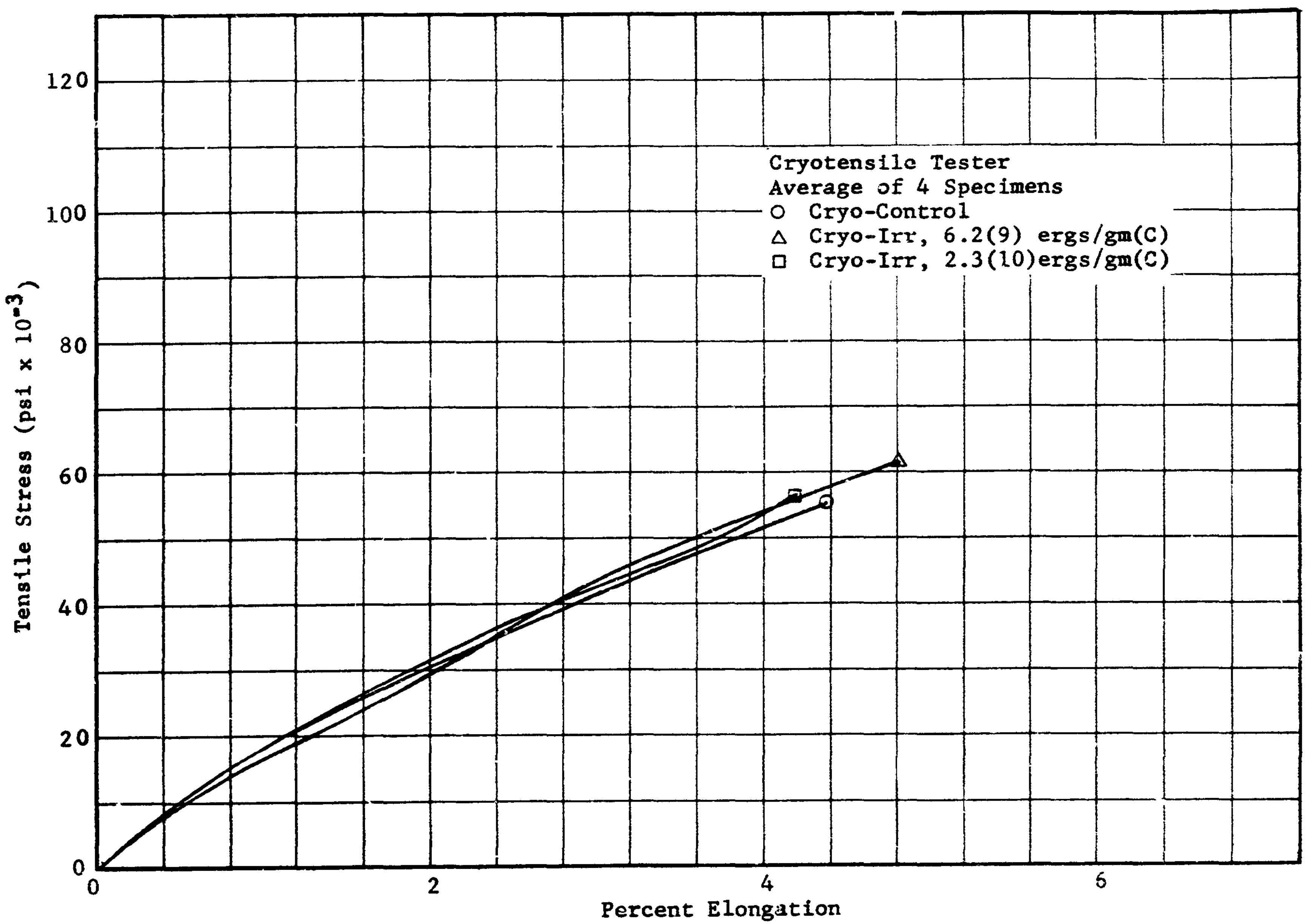

Figure 6.4 DC-2104 Stress-Strain Curves: LH_2 Irradiation; Dynamic Tests

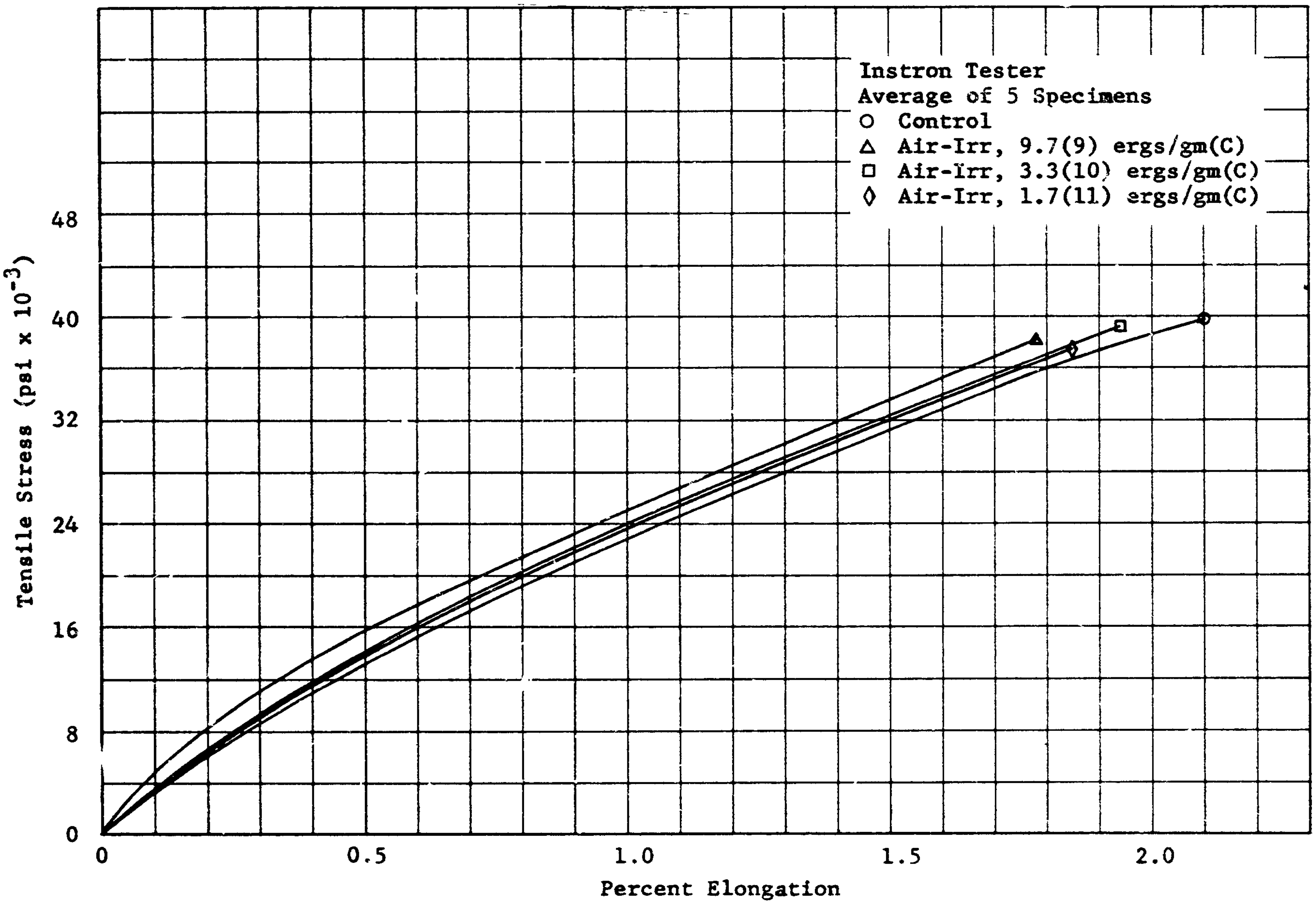

Figure 6.5 Epon 828/A Stress-Strain Curves: Air Irradiation; Static Test

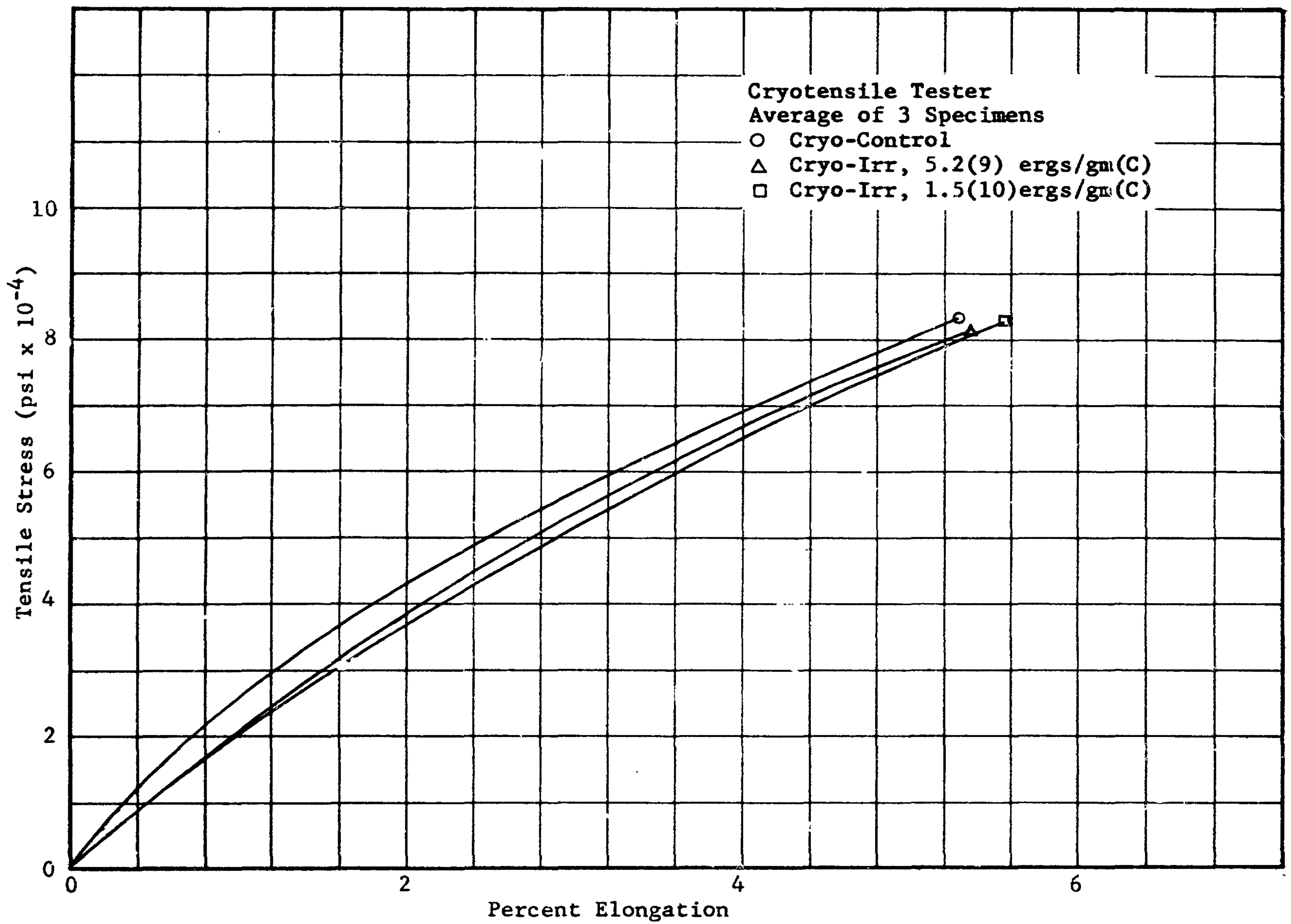

Figure 6.6 Epon 828/A Stress-Strain Curves: LN_2 Irradiation; Dynamic Tests

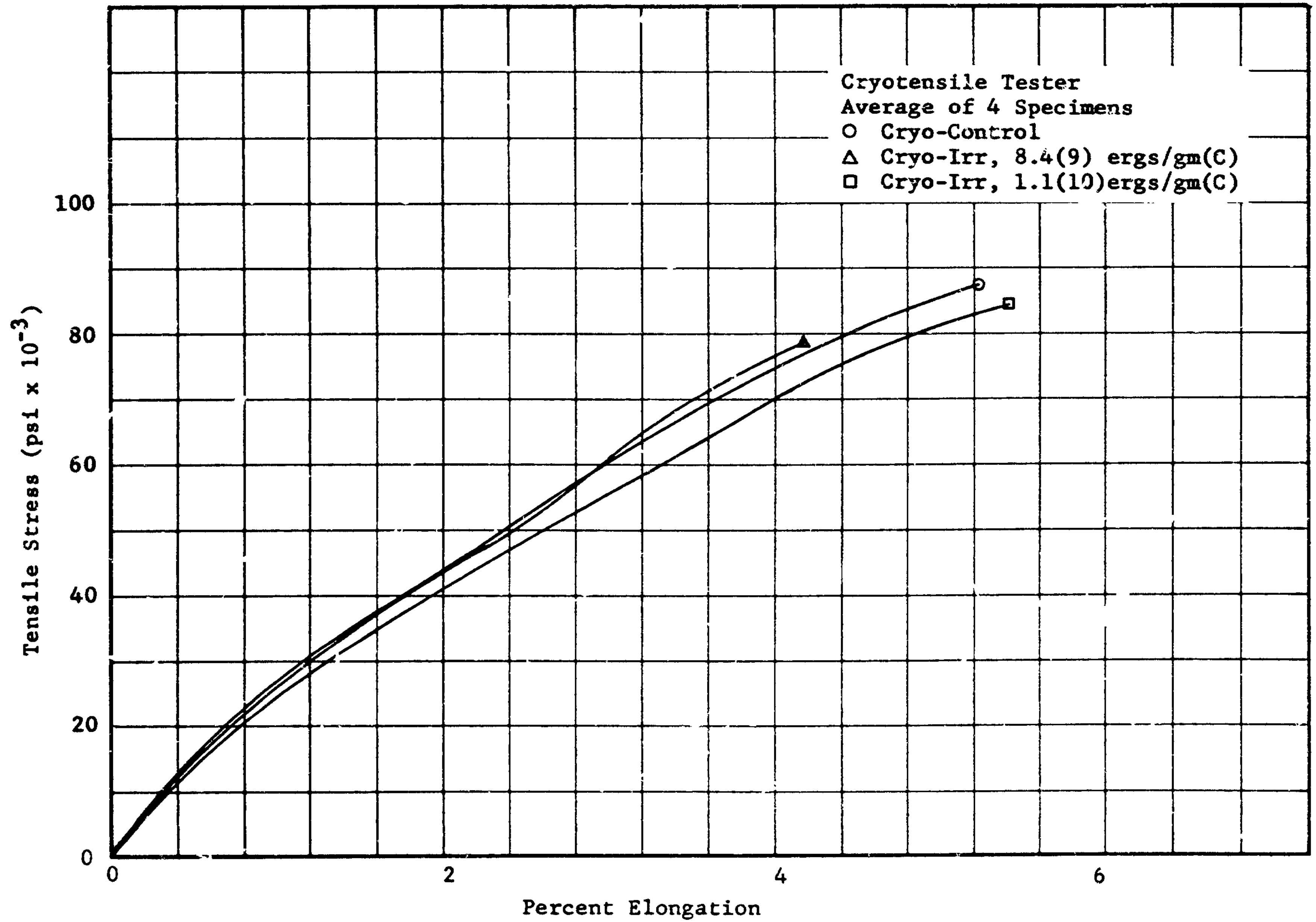

Figure 6.7 **Epon 828/A Stress-Strain Curves: LH_2 Irradiation; Dynamic Tests**

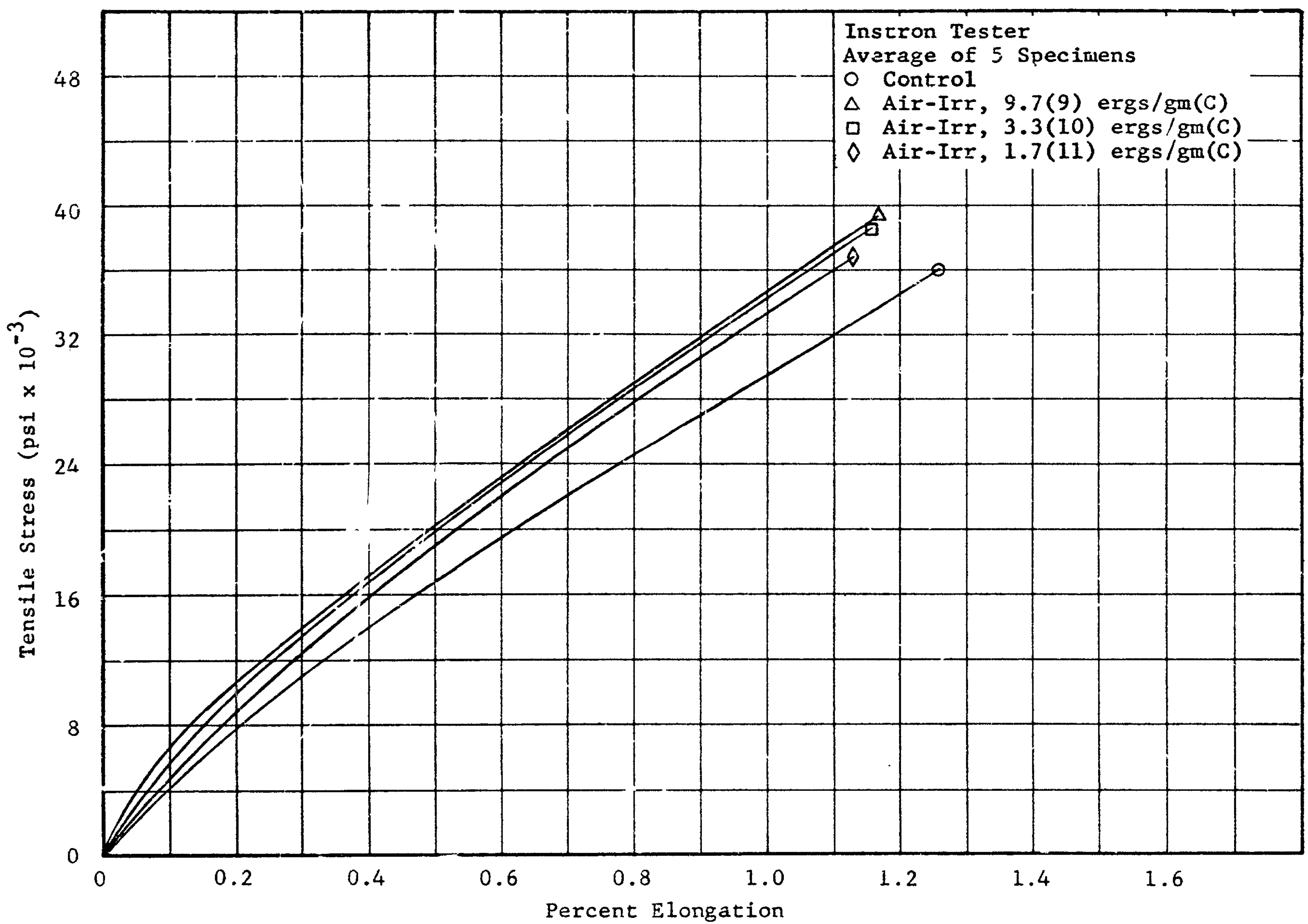

Figure 6.8 Mobaloy 81-AH7 Stress-Strain Curves: Air Irradiation; Static Tests

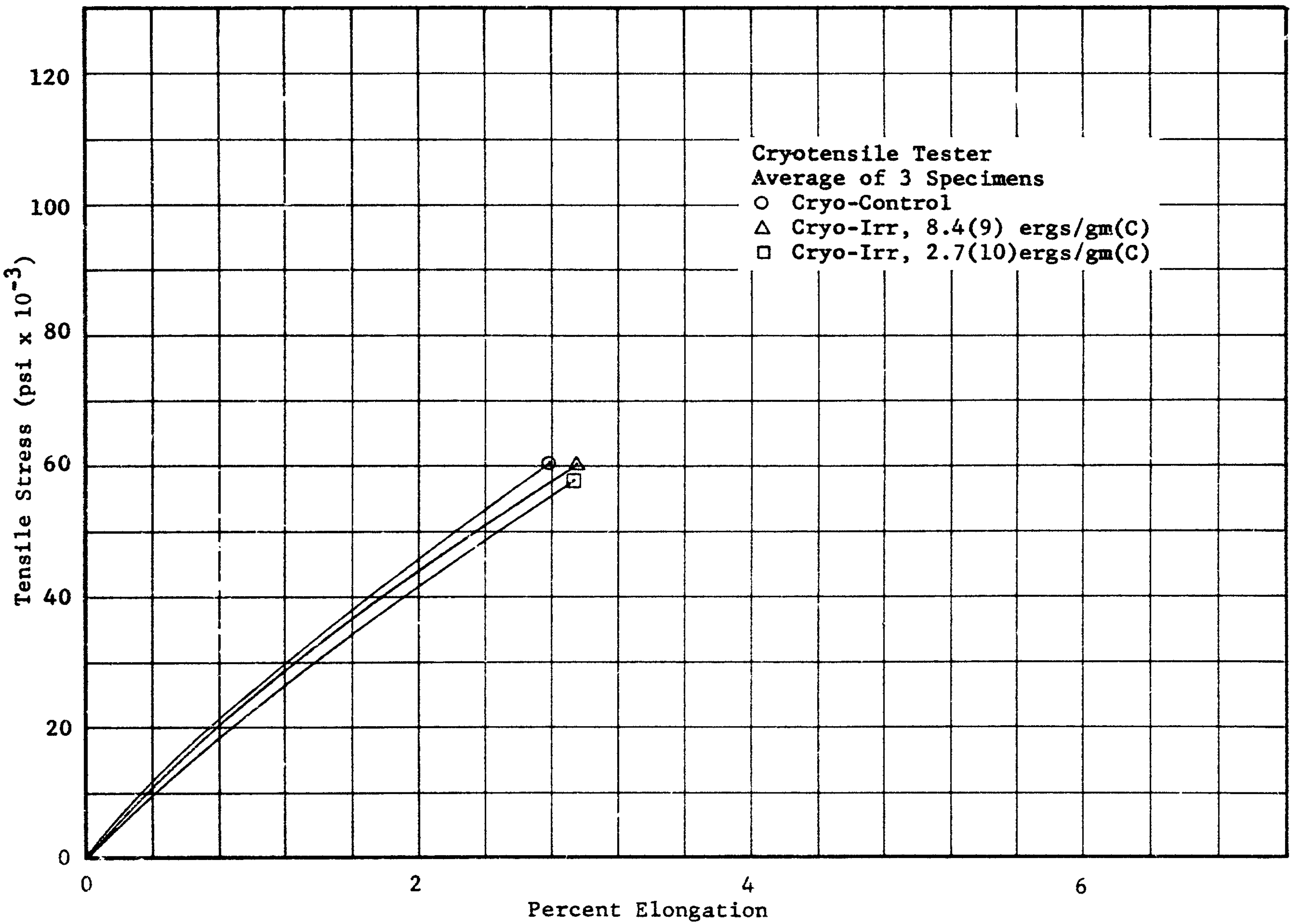

Figure 6.9 **Mobaloy 81-AH7 Stress-Strain Curves: LN_2 Irradiation; Dynamic Tests**

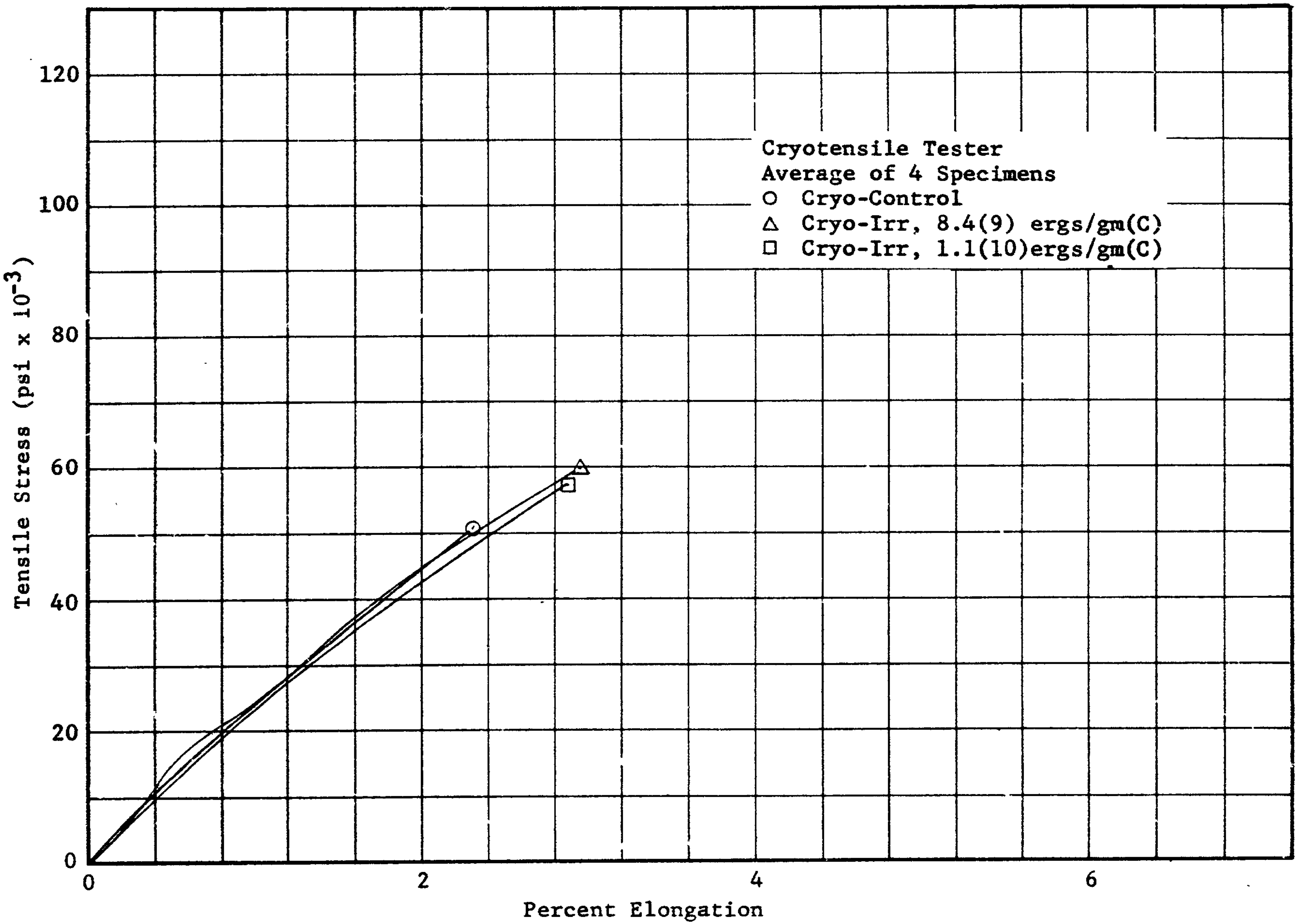

Figure 6.10 Mobaloy 81-AH7 Stress-Strain Curves: LH_2 Irradiation; Dynamic Tests

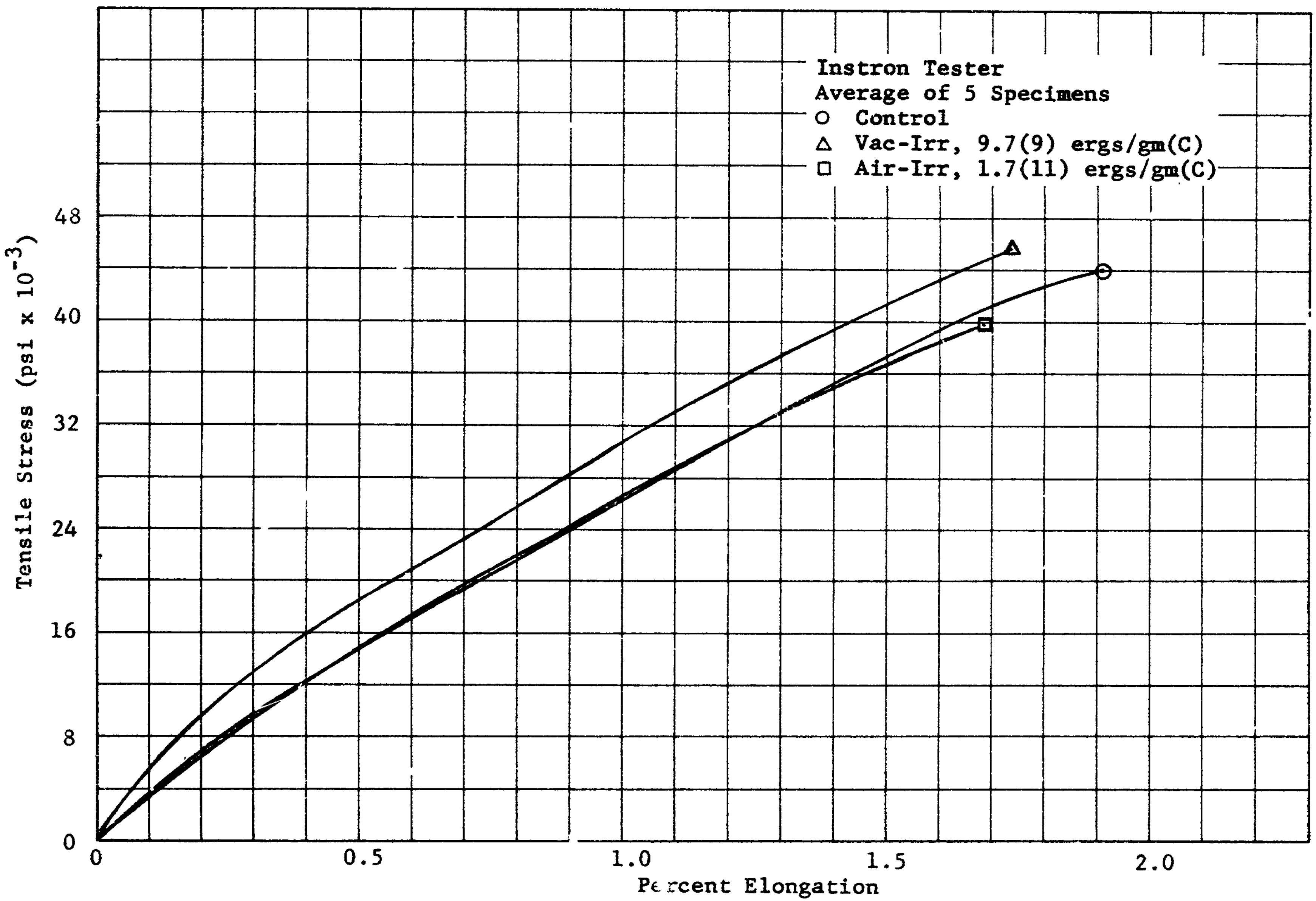

Figure 6.11 Paraplex P-43 Stress-Strain Curves: Air and Vacuum Irradiations; Static Tests

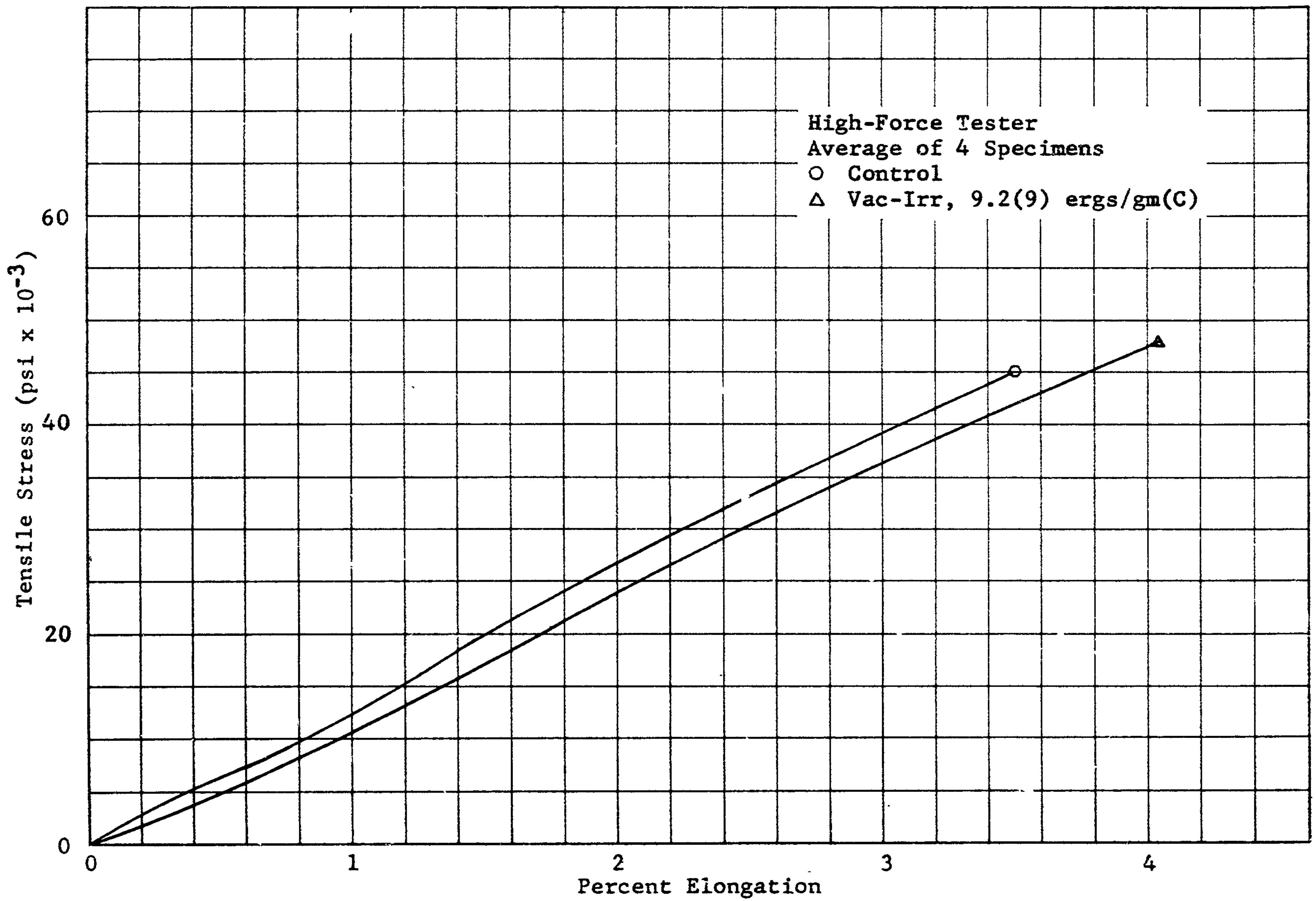

Figure 6.12 Paraplex P-43 Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

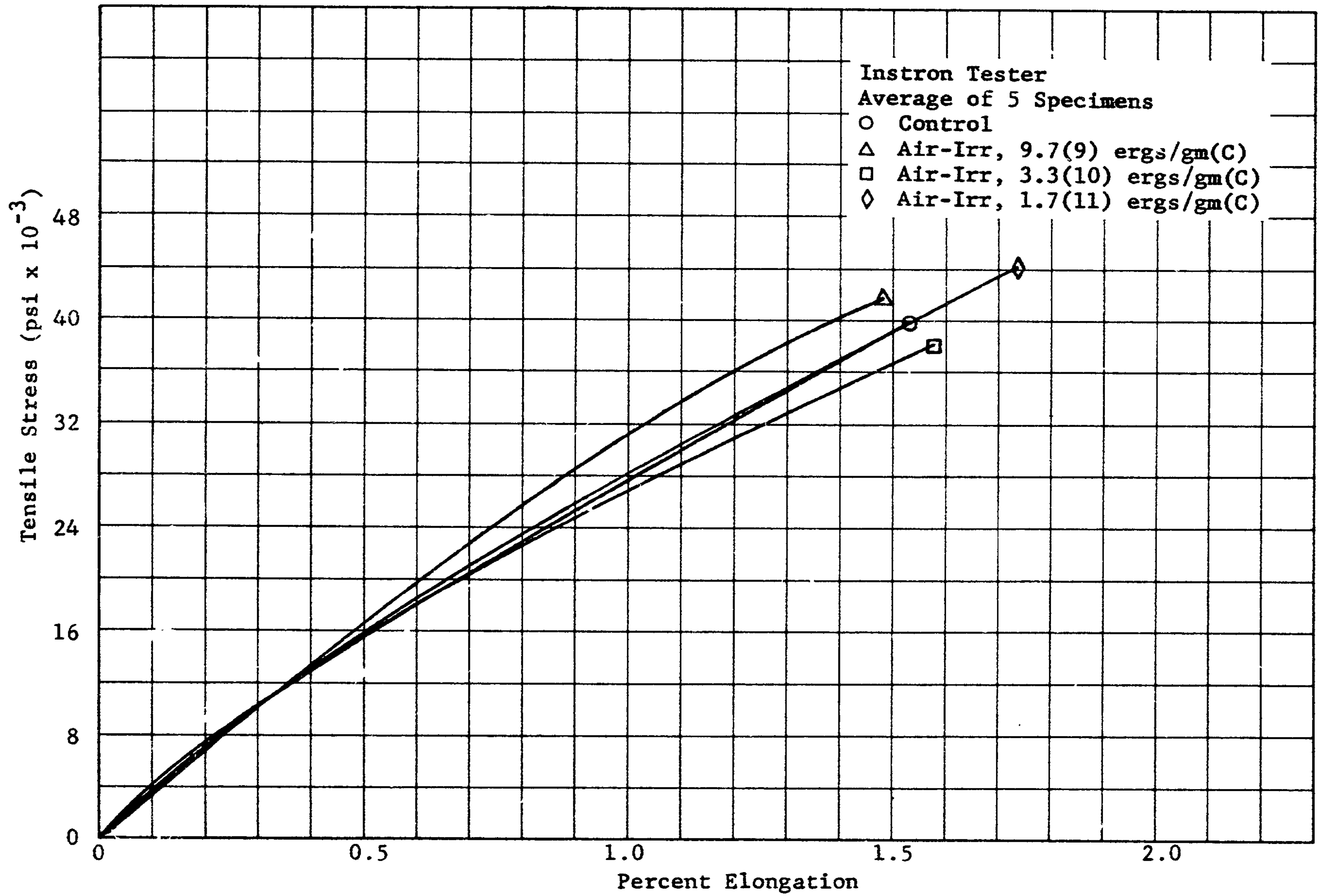

Figure 6.13 Selectron 5003 Stress-Strain Curves: Air Irradiation; Static Tests

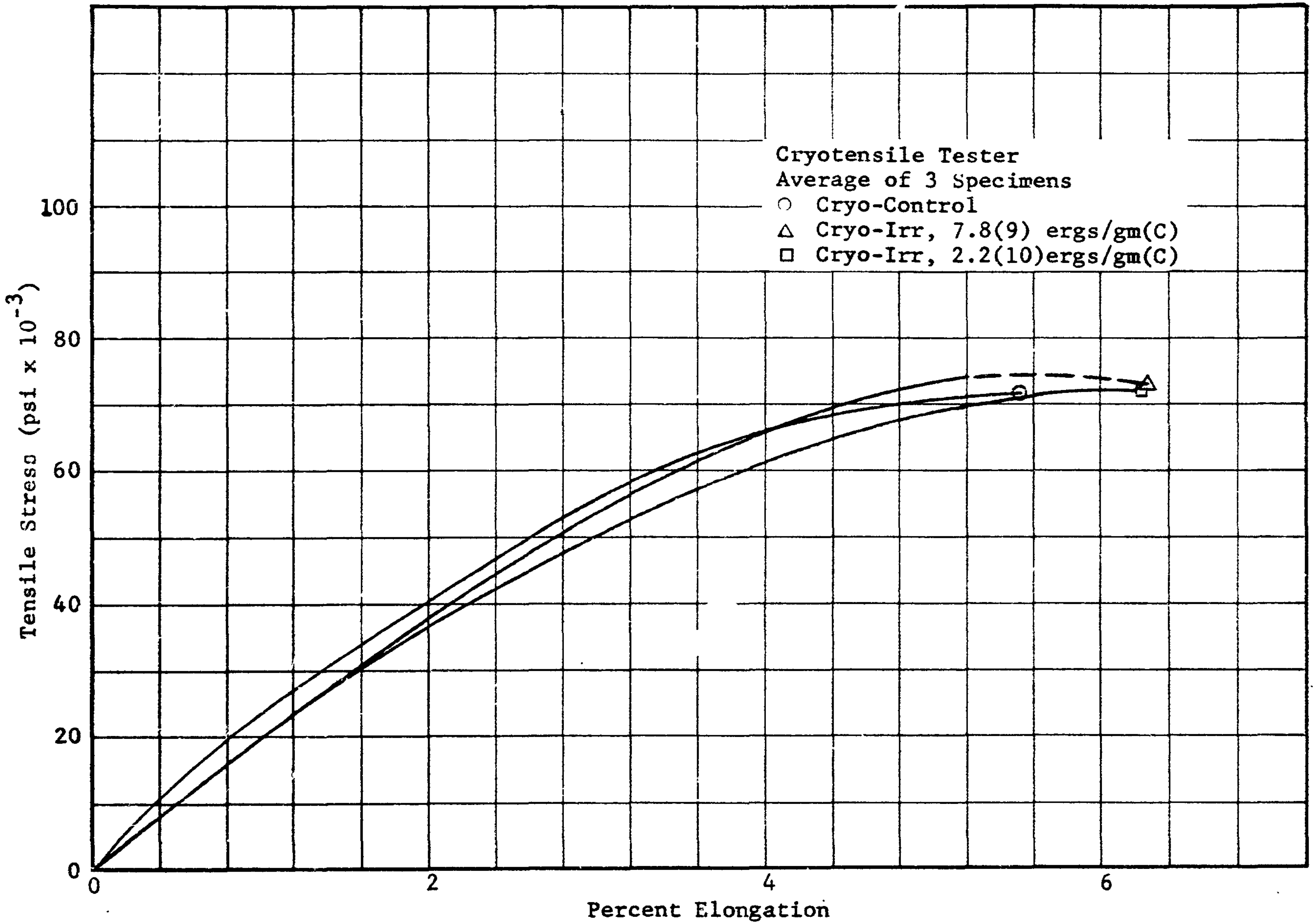

Figure 6.14 Selectron 5003 Stress-Strain Curves: LN_2 Irradiation; Dynamic Tests

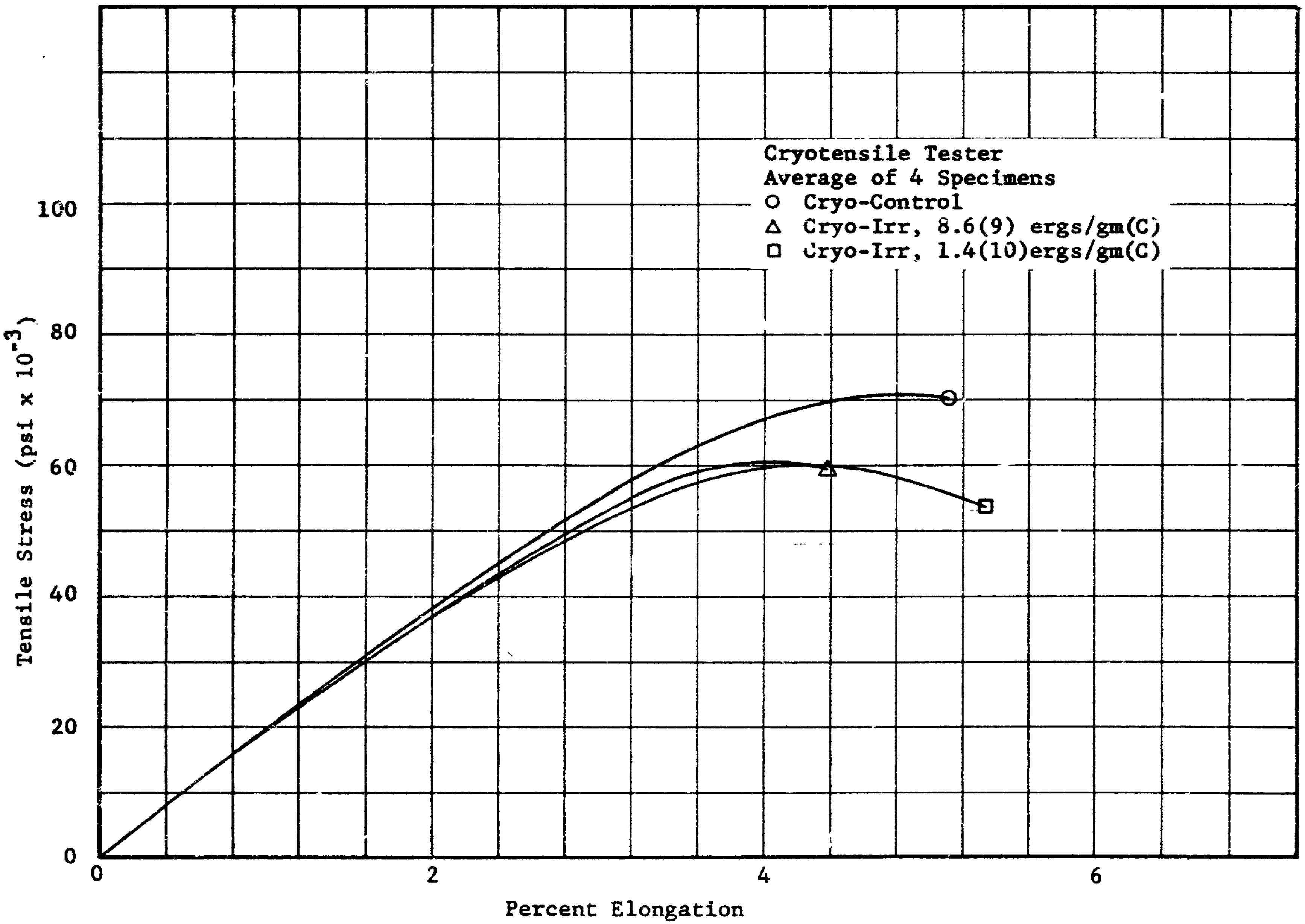

Figure 6.15 Selectron 5003 Stress-Strain Curves: LH_2 Irradiation; Dynamic Tests

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VII. SEAL TEST METHODS AND RESULTS

Table 7.1

Outline of Seal Tests

Material	Type of Test	Irradiation Environment	Nominal Gamma Dose [ergs/gm(C)]	Materials Tester	ASTM Test Method	Test Data
Buna N (PRP-737-70 FLX)	Static	Air	2(8),5(8),3(10),1(11)	Instron	D-1414-56T	Modulus Tensile Strength at Rupture Elongation at Rupture Stress-Strain Curves
	Static	Vacuum	1(9),5(9)	Instron	D-1414-56T	Modulus Tensile Strength at Rupture Elongation at Rupture Stress-Strain Curves
	Dynamic	Vacuum	3(9)	Low-Force	D-1414-56T, Mod.	Modulus Tensile Strength at Rupture Elongation at Rupture Stress-Strain Curves
	Static	Air	3(10),1(11)	Instron	D-575-46	Load-Deflection
Neoprene (PRP-2277)	Static	Air	5(9),1(10)	Instron	D-1414-56T	Modulus Tensile Strength at Rupture Elongation at Rupture
	Static	Vacuum	5(9),1(10)	Instron	D-1414-56T	Modulus Tensile Strength at Rupture Elongation at Rupture
	Static	Air	3(10),1(11)	Instron	D-575-46	Load-Deflection
Polymer SP-1	Static	Air	1(11)	Instron	D-638-61T, Mod.	Tensile Strength at Rupture Elongation at Rupture
	Dynamic	LH_2	1(10),3(10)	Cryotensile	D-638-61T, Mod.	Tensile Strength at Rupture Elongation at Rupture Stress-Strain Curves
Viton A (V495-7)	Static	Air	3(10),1(11)	Instron	D-1414-56T	Modulus Tensile Strength at Rupture Elongation at Rupture
Viton B (PRP-19007)	Static	Air	2(8),5(8),3(10),1(11)	Instron	D-1414-56T	Modulus Tensile Strength at Rupture Elongation at Rupture Stress-Strain Curves
	Static	Vacuum	1(9),5(9)	Instron	D-1414-56T	Modulus Tensile Strength at Rupture Elongation at Rupture Stress-Strain Curves
	Dynamic	Vacuum	5(8),5(9)	Low-Force	D-1414-56T, Mod.	Modulus Tensile Strength at Rupture Elongation at Rupture Stress-Strain Curves
	Static	Air	3(10),1(11)	Instron	D-575-46	Load-Deflection

VII. SEAL TEST METHODS AND RESULTS

This section of the report describes the test methods and results concerned with seal materials tested during the current period. The Program Summary table in the front of this report lists all of the seal materials tested during the two annual and one biennial contractual testing periods and references the applicable reports containing data.

Table 7.1 (facing page) lists the test conditions, environments, doses, and seal materials tested during the current period. All of the seal materials, with the exception of Polymer SP-1 and Viton A(V495-7), were tested in the form of O-rings and compression buttons. Viton A was tested in the form of O-rings only. Polymer SP-1 was tested for tensile properties and the test specimens were of the narrow-gage type described in Section 4.1.1. All of the static tests referred to in Table 7.1 are concerned with specimens that were irradiated statically in the environment shown, with postirradiation testing being performed on the Instron under room-air conditions. The dynamic tests were tests in which the postirradiation testing was conducted in the same environment as that used during the radiation exposure.

As shown in Table 7.1, Buna N and Viton B were tested in the Low-Force Tester in accordance with ASTM D-1414-56T, except for a change in crosshead speed from a specified 20 in./min to 0.5 in./min. This compromise in testing speed was made to prevent excessive hydraulic pressure in the Low-Force Tester. Polymer SP-1 is also shown as being tested under a modified test procedure. The modification entailed a change in specimen configuration in order to test the material in the Cryotensile Tester. The static specimens tested in the Instron were also made in the same configuration as the dynamic specimens so that comparable data would be obtained. The test specimens are described in Section 4.1.1. The materials in all seal specimens were from the same batch that was used in previous periods.

The summary tables containing the data and the summary stress-strain plots for the materials are presented at the end of this section and are listed by the material name. The names for these materials are based on chemical composition, which is different from the procedure used with other materials in this report.

7.1 Buna N (PRP-737-70 FLX)

The Buna N O-rings and compression buttons were selected from a supply on hand that had been submitted previously by the manufacturer for testing in this program. The material contains a special antirad agent.

Both static and dynamic irradiations were performed in air and vacuum. Static O-ring tests included air controls, four air irradiations with postirradiation tests in air, and two vacuum irradiations with postirradiation tests in air. Table 7.2 and Figure 7.1 summarize the static O-ring data. The elongation of Buna N decreased with increasing dose. Tensile strength varied very little but did increase slightly and then decreased. No discrepancies in elongation and tensile strength were apparent between air-irradiation and vacuum-irradiation conditions. At 1.7×10^{11} ergs/gm(C) the O-rings were too brittle to test. Even at 3.3×10^{10} ergs/gm(C) the elongation had dropped to an average of 16.5%.

A vacuum control and two dynamic irradiations were performed with this material in the Low-Force Tester. Results are presented in Table 7.2 and Figure 7.2. All specimens fractured, and after irradiation to a dose of 2.1×10^{9} ergs/gm(C) the elongation was 94%, having dropped from 177%.

Compression buttons showed the expected increase in hardness and reduced compressibility. These results are shown in Table 7.3.

7.2 Neoprene (PRP-2277)

Standard neoprene O-rings and compression buttons from stock previously supplied by the manufacturer for this program were irradiated in air and vacuum and tested in air. There were no dynamic tests on this seal material. Static data for the O-ring air controls plus two air and two vacuum irradiations are shown in Table 7.4.

Irradiation dose levels of up to 9.1×10^9 ergs/gm(C) in air and 8.5×10^9 ergs/gm(C) in vacuum reduced the tensile strength only slightly, but percent elongation diminished from 239% for controls to 57% for air irradiations and 39% for vacuum irradiations.

The compressive strength of compression buttons increased from 500 psi at 25% deflection for unirradiated specimens to over 7000 psi for only 10% deflection after irradiation to 3.3×10^{10} ergs/gm(C). Results are shown in Table 7.5.

7.3 Polymer SP-1

Polymer SP-1 is a rigid plastic seal material tested as dumbbell-type tensile specimens that were machined at NARF from slabs of the polyimide resin furnished by the manufacturer. In addition to an air irradiation to a high dose, performed to round out a data cycle started previously, an LH_2 control test and two LH_2 irradiations with LH_2 postirradiation tests were performed. Table 7.6 presents the air and LH_2 test data. The curves plotted in Figure 7.3 illustrate the stability and uniform performance of

Polymer SP-1 when irradiated in LH_2. Both the elongation and tensile strength at rupture increased when the specimens were submerged in LH_2, and nuclear radiation does not seem to have any effect on the polyimide up to a dose of 2.3×10^{10} ergs/gm(C). When inspected following the irradiations, no visible changes in color or structure of the Polymer SP-1 specimens were evident. Tensile breaks were mostly "A" type in the narrow gage section in both the air and LH_2 tests.

7.4 Viton A (V495-7)

The Viton O-rings were stock items available from the manufacturer and were included in the program in order to provide additional information on a material known for its good environmental characteristics. Irradiation space and scheduling allowed only one set of static air controls and two static air irradiations for this material during the test period.

It was evident from the test results that the Viton A received extensive radiation damage. Although they were brittle, the large diameter of these O-rings allowed them to be tested after the high radiation doses of 3.3×10^{10} and 1.7×10^{11} ergs/gm(C). The ultimate tensile strength at rupture changed from 1739 psi for the controls to 411 psi at the low dose and finally to 262 psi at the high dose. Elongation at break declined from 224% to 12.2% and finally to 3.8% at the high dose. The crosshead speed of the Instron was reduced to 10 in./min for the irradiated O-rings from the standard speed of 20 in./min used on the controls. This change allowed the stiff irradiated O-rings to be pulled on the Instron mandrel.

Since the Viton B could not be tested after these irradiation levels (see below, Sect. 7.5), Viton A, as formulated for these specimens, appears to have better radiation stability than the Viton B selected for these tests. Table 7.7 presents the test data.

7.5 Viton B (PRP-19007)

Standard O-rings and compression buttons of this Viton as supplied by the manufacturer were irradiated. The environmental conditions included air and vacuum with both static and dynamic irradiations.

Static O-ring tests included air controls, four air irradiations with postirradiation tests in air, and two vacuum irradiations with postirradiation tests in air. Table 7.8 and Figure 7.4 summarize the static O-ring data. The elongation of the Viton B decreased with increasing dose,but the tensile strength at rupture varied very little with dose for the O-rings that could be tested. Both elongation and tensile strength were independent of environment, as indicated by comparison of air and vacuum irradiations. At first, tensile strength increased slightly with dose but returned to a value near that of the controls at 5.3×10^9 ergs/gm(C). The two high dose levels of 3.1×10^{10} and 2.0×10^{11} ergs/gm(C) in air stiffened the O-rings until they were too hard and brittle to be tested on the Instron O-ring mandrel.

A vacuum control and two dynamic vacuum irradiations were performed in the Low-Force Tester on this material. Results are presented in Table 7.8 and Figure 7.5. The elongation for the control and low-dose specimens exceeded the travel of the pull mechanism; therefore, elongation and tensile strength at rupture are not available for these conditions. Furthermore, the relatively slow pull speed of the Low-Force Tester prevented any comparisons with the data from the vacuum-air static runs fo. any of the O-rings.

Compression buttons showed a definite, anticipated change to a harder, less compressible condition after static irradiation to 3.3×10^{10} ergs/gm(C) in air. Table 7.9 presents the compression data.

7.6 General Discussion of Results

All the elastomeric seal materials were stiffened by the irradiation, with effects of individual exposures noted for each component. Definite reductions in elongation were also noted and were more pronounced than noted changes in tensile strength.

Results of each O-ring test are discussed in more detail in the above sections covering specific compounds. The intended applications will determine the actual radiation limits for which O-rings can be specified. For instance, static O-ring seals should be more radiation resistant than dynamic seals because of the characteristic stiffening of elastomers.

Polymer SP-1 is an excellent material for seals and was determined to have outstanding radiation and cryotemperature stability.

Table 7.2

PRP-737-70 FLX Seal (O-Rings)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	165 168 198 185 188 181/14	336 330 362 346 353 345/14	890 896 923 906 896 902/14	1862 1944 1697 1812 1664 1796/120	181 196 159 174 160 174/16	75	760
	Air	Air	Instron at 20.0 in./min	1.8(8)	6.0(12)	3.8(13)	1.7(12)	2	185 188 185 191 191 188/3	362 362 362 372 372 366/4	906 906 893 926 926 911/14	1911 2106 1921 2063 1914 1983/84	183 200 186 194 176 188/10	75	760
	Air	Air	Instron at 20.0 in./min	5.7(8)	6.1(12)	1.4(14)	4.6(12)	2	214 204 201 204 198 204/7	422 395 399 412 395 405/12	1087 1054 1054 1071 1054 1064/14	1529 2135 2043 2010 2139 1971/262	127 190 178 170 186 170/27	75	760
	Air	Air	Instron (First spec. @ 20"/min, next 3 @ 10"/min)	3.3(10)	-	5.4(15)	-	14	- - - -	- - - -	- - - -	1648 1911 1087 1878 1631/400	18 18 13 17 16.5/2.4	170	760
	Air	Air	Instron at 20.0 in./min	1.7(11)	-	2.5(16)	-	-	5 Specimens - Too Brittle to Test					200	760

[a] Values given as: average value/standard deviation on an individual basis.

Table 7.2 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	Vac	Air	Instron at 20.0 in./min	8.9(8)	1.0(13)	1.8(14)	7.0(13)	24	243 226 230 203 226 226/17	514 483 483 456 466 480/25	1358 1341 1348 1301 1385 1347/36	2257 1922 1970 2159 1932 2049/144	160 131 131 151 140 143/12	120	4.6(-6)
	Vac	Air	Instron at 20.0 in./min	5.3(9)	7.8(13)	6.8(14)	-	5	619 494 593 593 560 572/54	1483 1236 1433 1400 1384 1387/106	- - - - -	1681 1565 1845 1713 2175 1796/262	55 57 60 56 67 59/5	100	2.0(-6)
	-	Vac	Low Force Tester at 0.5 in./min	0	0	0	0	-	60 60 80 80 4 57/33	300 260 220 260 200 248/43	800 680 680 720 700 716/52	1663 1395 1543 1794 1682 1617/171	172 163 183 190 176 177/12	75	1.0(-3)
	Vac	Vac	Low Force Tester at 0.5 in./min	2.1(9)	4.5(13)	3.9(14)	1.4(14)	-	230 400 360 - - 330/100	545 732 730 - - 668/109	- 1680 - - - 1680	1197 1747 1543 - - 1496/325	88.7 104.4 90.1 - - 94.4/9.3	100	1.4(-6)

Table 7.3

PRP-737-70 FLX Seal (Compression Buttons)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Strength at 25% Compression[a] (psi)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)						
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev				
	-	Air	Instron at 0.5 in./min	0	0	0	0	-	595 580 585 587 550 579/19	75	760
	Air	Air	Instron at 0.5 in./min	3.3(10)	-	5.4(15)	-	21	8590 8650 8600 8200 8800 8568/258	170	760
	Air	Air	Instron at 0.5 in./min	1.7(11)	-	2.5(16)	-	21	7250[b] 6760[b] 7500[b] 7800[b] 7400[b] 7342/447	200	760

[a]Values given as: average value/standard deviation on an individual basis.
[b]Strength at 10% compression.

Table 7.4

PRP-2277 Seal (O-Rings)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (r/cm^2) E<0.48ev	E>2.9Mev	E>6.1Mev		@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	152 198 198 198 204 190/22	298 297 330 323 339 317/13	587 659 629 649 646 634/31	2705 2201 2392 2639 2231 2434/217	265 220 235 250 223 239/19	75	760
	Air	Air	Instron at 20.0 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	4	353 362 - 362 376 363/11	824 830 - 840 840 834/8	2307 - - - - 2307/X	2307 2224 2340 2191 2290 2270/64	100 95 - 92 93 95/4	100	760
	Air	Air	Instron at 20.0 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	4	593 600 626 659 659 627/28	1532 1532 1615 1664 1763 1621/99	- - - - -	2142 2142 1878 1895 2059 2023/113	61 62 55 53 53 57/4	140	760
	Vac	Air	Instron at 20.0 in./min	5.3(9)	7.8(13)	6.8(14)	-	5	567 494 488 481 508/42	1170 1021 1038 1005 1059/80	- - - -	2109 2010 2142 2405 2167/144	68 81 81 92 81/12	100	2.0(-6)
	Vac	Air	Instron at 20.0 in./min	8.5(9)	1.0(14)	1.7(15)	-	5	1384 1269 1318 1318 1322/55	- - - -	- - - -	1944 2867 2702 2603 2529/448	31 43 42 40 39/6	140	2.0(-6)

[a]Values given as: average value/standard deviation on an individual basis.

Table 7.5

PRP-2277 Seal (Compression Buttons)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Strength at 25% Compression[a] (psi)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)						
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev				
	-	Air	Instron at 0.5 in./min	0	0	0	0	-	495 509 545 507 495 510/21	75	760
	Air	Air	Instron at 0.5 in./min	3.3(10)	-	5.4(15)	-	21	7350[b] 7300[b] 7150[b] 7250[b] 7250[b] 7260/86	170	760
	Air	Air	Instron at 0.5 in./min	1.7(11)	-	2.5(16)	-	21	7150[b] 7640[b] 7550[b] 7450[b] 7450[b] 7448/211	200	760

[a]Values given as: average value/standard deviation on an individual basis.
[b]Strength at 10% compression.

Table 7.6

Polymer SP-1 Seal
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.45 ev	E>2.9 Mev	E>3.1 Mev					
70A-6 70A-7 70A-8 70A-9 70A-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	17	10,677 9,238 10,690 9,558 8,917 9810/762	3.19 2.53 3.26 2.35 2.26 2.82/0.43	200	760
70A-111 70A-112 70A-113	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	15,357 12,462 14,292 14,037/1709	2.37 1.90 2.49 2.25/0.35	-423	760
70A-126 70A-127 70A-128	LH_2	LH_2	CTT at 0.05 in./min	6.2(9)	-	1.1(15)	-	-	14,602 15,045 12,018 13,388/1787	2.32 2.34 2.01 2.23/0.19	-423	760
70A-131 70A-132 70A-133 70A-134	LH_2	LH_2	CTT at 0.05 in./min	2.3(10)	-	4.1(15)	-	-	17,903 15,448 10,884 16,349[b] 14,745/4146	2.57 2.47 2.29 6.57[b] 2.44/0.17	-423	760

[a]Values given as: average value/standard deviation on an individual basis.
[b]Values not included in average or standard deviation.

Table 7.7

V495-7 Seal (O-Rings)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	191 214 181 224 214 205/18	330 330 297 346 343 329/21	616 626 593 626 593 611/14	1664 1746 1911 1713 1713 1739/106	216 217 220 227 239 224/10	75	760
	Air	Air	Instron at 20.0 in./min	3.3(10)	-	5.4(15)	-	14	- - - - -	- - - - -	- - - - -	277[b] 386 389 458 409 411/35	7.8[b] 12.5 11.1 14.9 10.2 12.2/2.3	170	760
	Air	Air	Instron at 10.0 in./min	1.7(11)	-	2.5(16)	-	14	- - - - -	- - - - -	- - - - -	234 234 244 297 303 262/30	3.4 3.4 3.6 4.4 4.1 3.8/0.4	200	760

[a]Values given as: average value/standard deviation on an individual basis.
[b]Value not included in average and standard deviation.

Table 7.8

PRP-19007 Seal (0-Rings)
Summary Table of Test Results

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48ev	Neutrons (n/cm^2): E>2.9Mev	Neutrons (n/cm^2): E>8.1Mev	Time Until Test (days)	Tensile Strength (psi)[a]: @ 25% Elong.	Tensile Strength (psi)[a]: @ 50% Elong.	Tensile Strength (psi)[a]: @ 100% Elong.	Tensile Strength (psi)[a]: @ Rupture	Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Air	Air	Instron at 20.0 in./min	0	0	0	0	-	175 181 185 181 168 178/7	287 290 297 293 280 289/7	527 540 544 547 531 538/9	1763 1697 1598 1862 1532 1690/142	266 250 235 266 229 249/16	75	760
	Air	Air	Instron at 20.0 in./min	1.8(8)	6.0(12)	3.8(13)	1.7(12)	2	191 175 175 185 185 182/7	316 313 306 316 316 313/4	659 652 643 672 672 660/12	1905 2003 1888 1872 1911 1916/56	225 247 232 220 224 230/12	75	760
	Air	Air	Instron at 20.0 in./min	5.7(8)	6.1(12)	1.4(14)	4.6(12)	2	198 198 214 214 211 207/7	395 386 395 412 389 395/11	939 883 923 933 939 923/24	2083 2076 1872 1951 2125 2021/109	189 189 177 177 185 183/5	75	760
	Air	Air	Instron	3.1(10)	-	5.1(15)	-	-	5 Specimens - Too Brittle to Test					170	760
	Air	Air	Instron	2.0(11)	-	2.8(16)	-	-	5 Specimens - Too Brittle to Test					200	760
	Vac	Air	Instron at 20.0 in./min	8.9(8)	1.0(13)	1.8(14)	7.0(13)	-	206 209 189 182 193 196/12	449 463 419 405 422 432/25	1145 1159 1095 1051 1078 1106/46	2223 1986 1875 1861 1632 1915/254	170 154 152 155 140 154/13		

[a]Values given as: average value/standard deviation on an individual basis.

Table 7.8 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48ev	Neutrons (n/cm^2) E>2.9Mev	Neutrons (n/cm^2) E>8.1Mev		@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
	Vac	Air	Instron at 20.0 in./min	5.3(9)	7.8(13)	6.8(14)	-	5	692 659 659 659 643 662/30	- - 1746 - 1779 1763/29	- - - - -	1681 1483 1746 1565 1911 1677/184	46 49 50 44 52 48/3	100	2.0(-6)
	-	Vac	Low Force Tester at 0.50 in./min	0	0	0	0	-	39 72 79 39 57.3/ 19.4	161 180 172 160 168.3/ 9.7	372 358 362 300 348/35	Specimens Did Not Break		75	1.0(-3)
	Vac	Vac	Low Force Tester at 0.50 in./min	2.3(8)	5.1(12)	4.4(13)	1.6(13)	-	100 95 100 82 92.3/ 8.7	260 229 229 180 224.5/ 38.9	410 380 357 388 383.8/ 25.7	Specimens Did Not Break		80	5.0(-7)
	Vac	Vac	Low Force Tester at 0.50 in./min	5.3(9)	1.1(14)	9.7(14)	3.5(14)	-	295 405 295 415 415 365/52	- - - - -	- - - - -	780 1027 872 639 983 860/167	43.6 46.7 44.4 32.7 42.9 42.1/6.0	125	9.0(-7)

Table 7.9

PRP-19007 Seal (Compression Buttons)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Strength at 25% Compression[a] (psi)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)						
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev				
	-	Air	Instron at 0.5 in./min	0	0	0	0	-	477 475 476/2	75	760
	Air	Air	Instron at 0.5 in./min	3.3(10)	-	5.4(15)	-	21	6150[b] 6580[b] 6365/381	170	760
	Air	Air	Instron at 0.5 in./min	1.7(11)	-	2.5(16)	-	21	6595[b] 5500[b] 6048/371	200	760

[a]**Values given as: average value/standard deviation on an individual basis.**
[b]**Strength at 10% compression.**

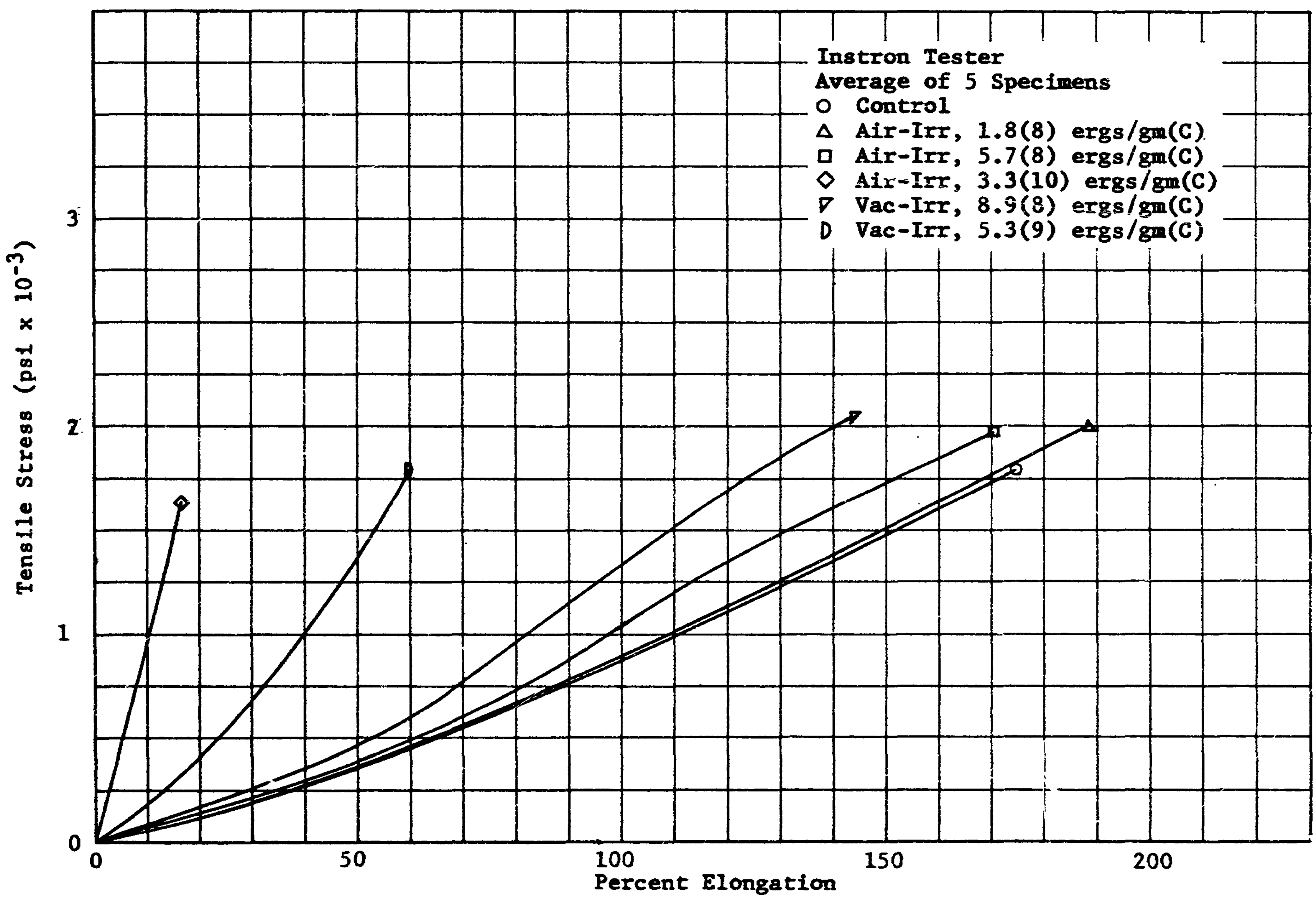

Figure 7.1 PRP-737-70 FLX Seal Stress-Strain Curves: Air and Vacuum Irradiations; Static Tests

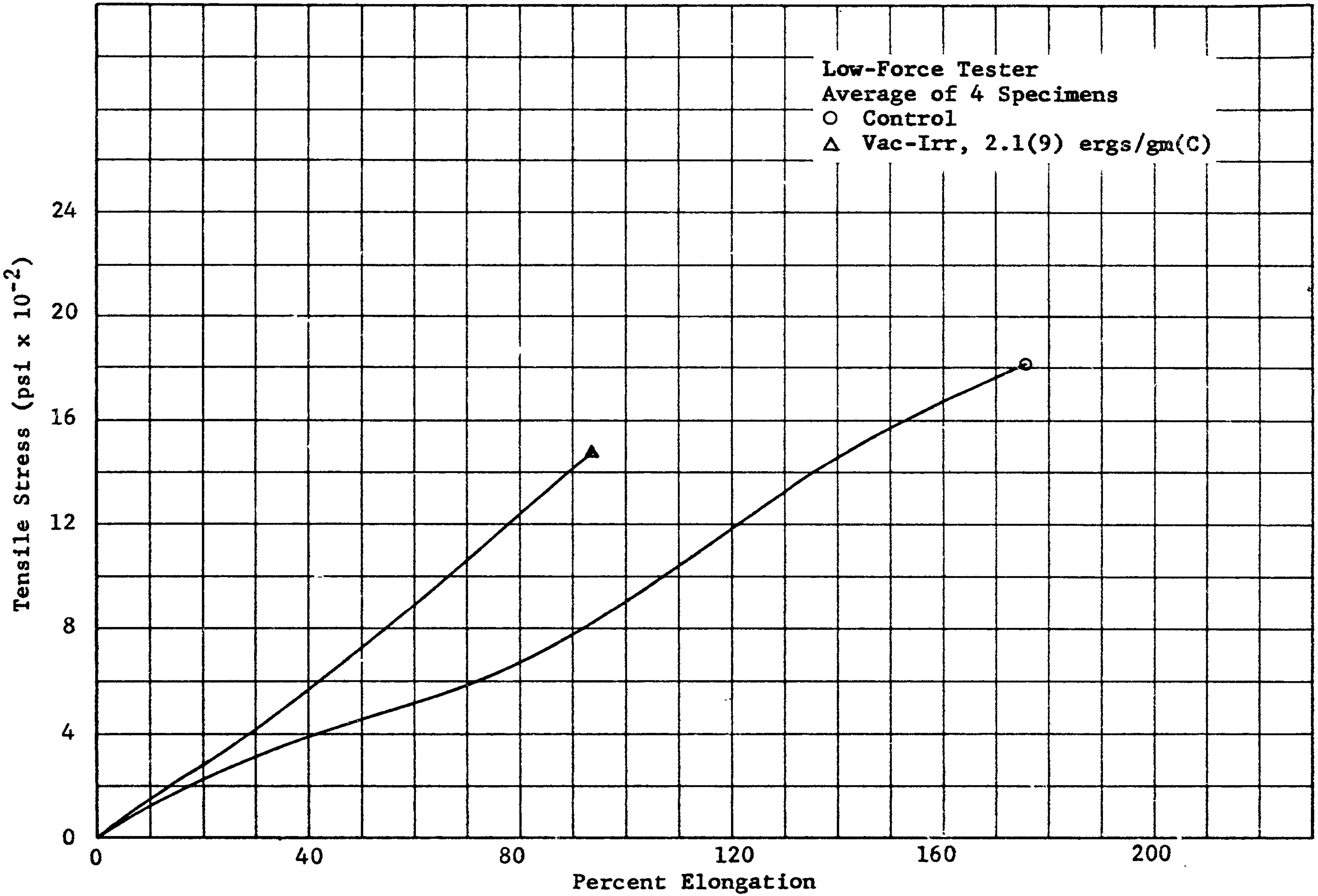

Figure 7.2 PRP-737-70 FLX Seal Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

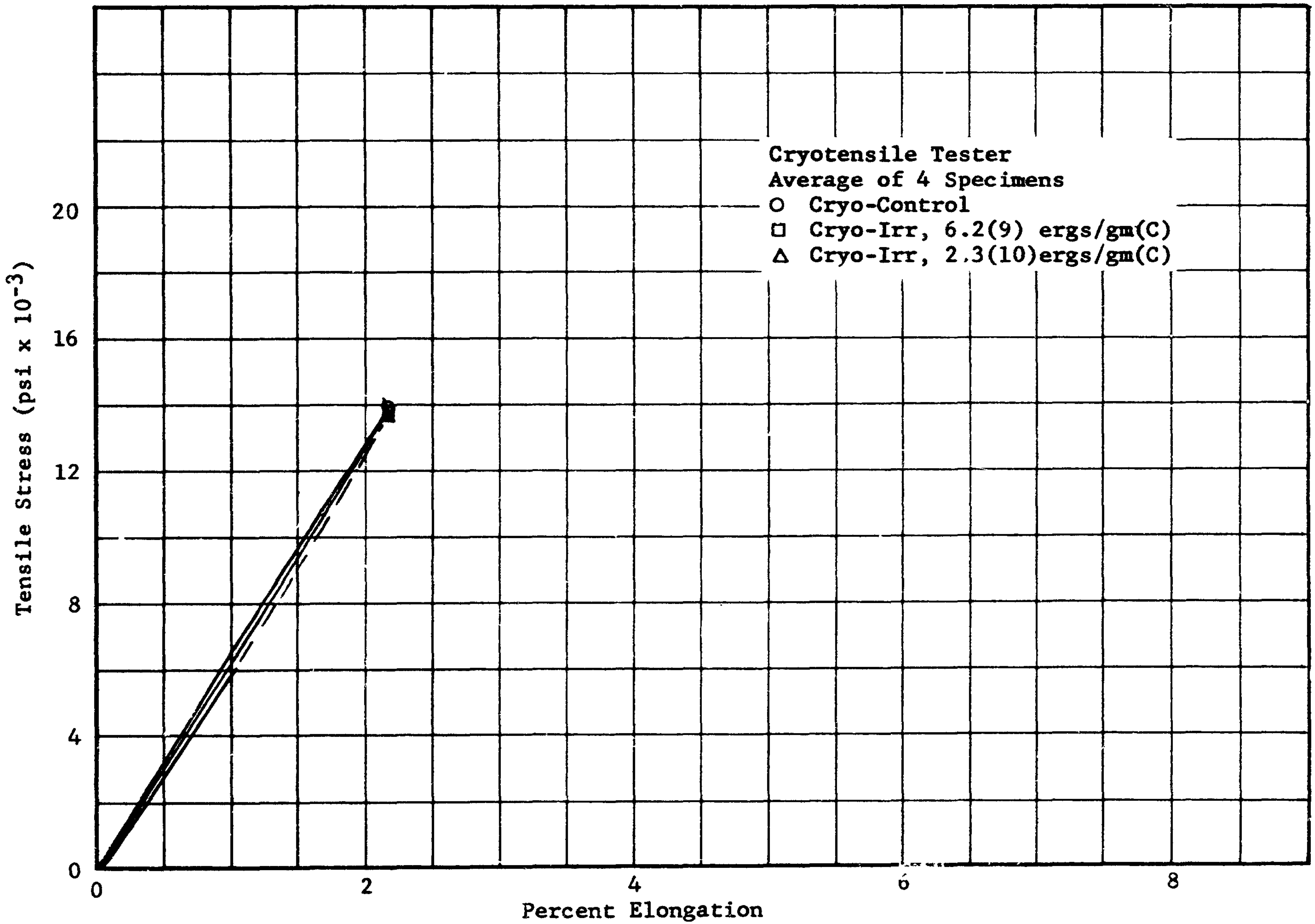

Figure 7.3 Polymer SP-1 Stress-Strain Curves: LH_2 Irradiation; Dynamic Tests

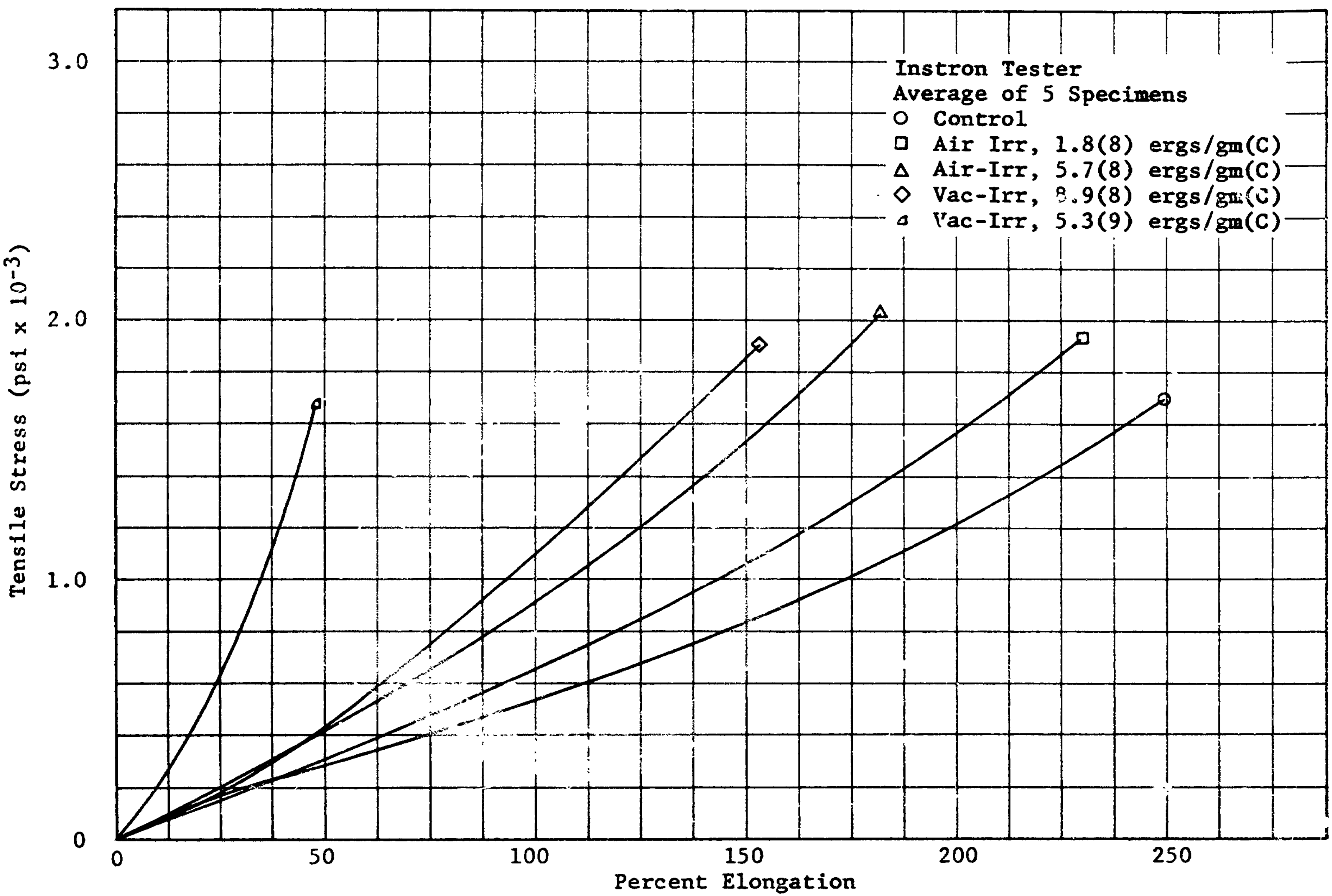

Figure 7.4 **PRP-19007 Seal Stress-Strain Curves: Air and Vacuum Irradiations; Static Tests**

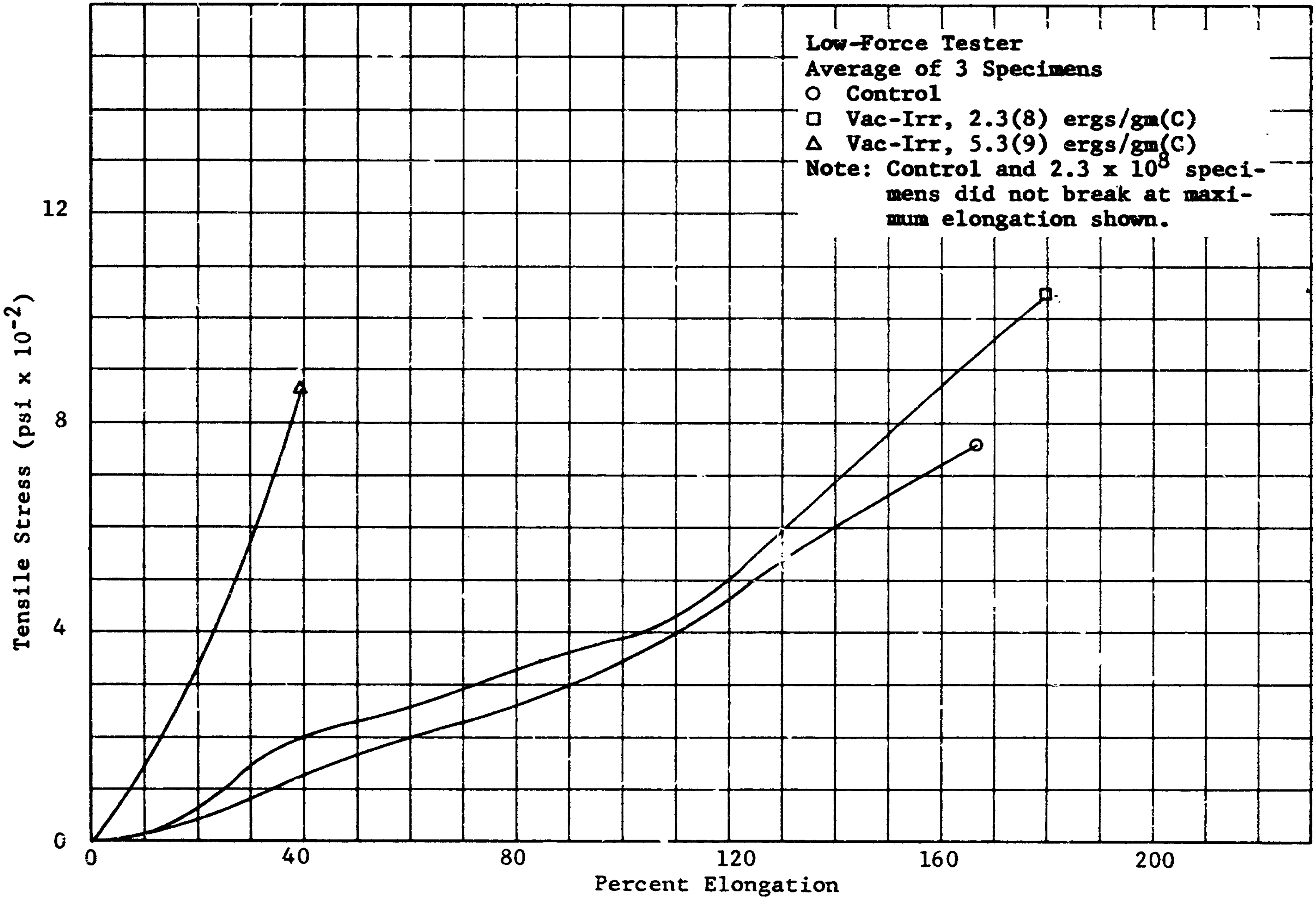

Figure 7.5 PRP-19007 Seal Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

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VIII. SEALANT TEST METHODS AND RESULTS

Table 8.1

Outline of Sealant Tests

Material	Type of Test	Irradiation Environment	Nominal Gamma Dose [ergs/gm(C)]	Materials Tester	ASTM Test Method	Test Data
Dow Corning 92-018	Static	Air	2(8),1(9),1(10)	Instron	D-412-62T (DIE-C)	Tensile Strength at Rupture, Modulus, Elongation at Rupture
	Static	Air	2(8),1(9),1(10)	Instron	D-1002-64, Mod.	Ultimate Tensile Shear Strength, Percent Adhesive Failure
Dow Corning 94-002	Static	Air	5(8),1(9),5(9)	Instron	D-1002-64, Mod.	Ultimate Tensile Shear Strength, Percent Adhesive Failure
	Static	Vacuum	5(8),1(9),5(9)	Instron	D-1002-64, Mod.	Ultimate Tensile Shear Strength, Percent Adhesive Failure

VIII. SEALANT TEST METHODS AND RESULTS

This section of the report contains all of the data generated on sealant materials during this testing period. The Program Summary table at the front of this report lists all of the sealant materials tested during the three contractual periods and the corresponding referenced reports containing the data. Table 8.1 (facing page) is a résumé of the test conditions, environments, and doses for the two materials tested during the current period under this category. The results of these tests are presented in tabular form at the end of this section.

One of the seal materials was tested in air in the form of ASTM D-412 Die C dumbbell-type tensile specimens and also as modified ASTM D-1002 lap-shear specimens. The other material was tested as a lap shear in both air and vacuum environments. Both sealants are silicone-base polymers.

8.1 Dow Corning 92-018

This adhesive/sealant was irradiated and tested both in lap-shear and tensile specimen configurations. There was a progressive change in tensile property but no change from its original black color. This material is a soft, rubbery-type of sealant. Initially, as controls, the lap-shear specimens had cohesive failure with a smooth adhesive film separation. After irradiation in air to 2 x 10^8 ergs/gm(C), the material was still soft and pliable and demonstrated about a 2% adhesive failure. After irradiation to 1 x 10^9 ergs/gm(C) in air, the sealant separated into ripples with continued cohesive failure. Some embrittlement also occurred. At the highest air dose of 1 x 10^{10} ergs/gm(C) there was a decided change in the material: a 95% adhesive failure, which was a reversal of the control and low-dose conditions. The material was also very hard and brittle. The data for the lap-shear specimens are given in Table 8.2.

The Die C tensile specimens tested as controls were flexible and fractured with "A"- and "B"-type breaks. After the first radiation level of 2 x 10^8 ergs/gm(C), there were flexible "A" breaks, but the rubber was a little stiffer. At 1 x 10^9 ergs/gm(C) the tensile specimens still had "A" breaks, but were definitely brittle. Finally, at 1 x 10^{10} ergs/gm(C) the tensile specimens still had "A" breaks, but the material was definitely no longer a sealant-type material, being more like a hard rubber, with the specimens tolerating little bending before breaking. The Die C tensile data for this material are given in Table 8.3.

8.2 Dow Corning 94-002

This material was tested in the form of lap-shear specimens as prepared by the Dow Corning Laboratory. The amount of adhesive failure changed with irradiation, but no change in color was experienced. The general property changes in 94-002 were similar to those that occurred with 92-018. The type of failure was originally cohesive, then progressed to adhesive as it reached higher irradiation levels. The vacuum irradiation of Dow Corning 94-002 resulted in a higher threshold of damage than did the air irradiation, as is suggested by the degree of change from cohesive to adhesive failure. The exact failure modes of these materials are shown in Table 8.4. The application and required retention of pliability of the sealants will influence the radiation level considered to be a safe margin in actual design applications. There is a definite indication that vacuum does extend the useful life of these sealants during irradiation.

8.3 General Discussion of Results

These sealants do not change color during irradiation. Failure of lap-shear specimens progressively changes from cohesive to adhesive separation with successively higher levels of radiation. Since the pliable sealants stiffened and hardened with radiation, aerospace service requirements will determine the actual allowable service life expectancy.

Table 8.2

DC-92-018 Sealant (Lap Shear)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm2)							
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
107-11 107-12 107-13 107-14 107-15	-	Air	Instron at 0.05 in./min	0	0	0	0	-	553 490 450 410 386 458/72	1 avg	75	760
107-26 107-27 107-28 107-29 107-30	Air	Air	Instron at 0.05 in./min	1.8(8)	6.0(12)	3.8(13)	1.7(12)	2	657 541 592 627 440 571/93	2 avg	75	760
107-36 107-37 107-38 107-39 107-40	Air	Air	Instron at 0.05 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	420 427 456 433 352 418/45	2 avg	75	760
107-46 107-47 107-48 107-49 107-50	Air	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	4	369 302 418 389 340 364/50	95 avg	150	760

[a]Values given as: average value/standard deviation on an individual basis.

Table 8.3

DC-92-018 Sealant (Die C Specimens)
Summary Table of Test Results

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Radiation Exposure: Neutrons (n/cm^2) E<0.48ev	Neutrons (n/cm^2) E>2.9Mev	Neutrons (n/cm^2) E>8.1Mev	Time Until Test (days)	Tensile Strength (psi)[a] @ 25% Elong.	Tensile Strength (psi)[a] @ 50% Elong.	Tensile Strength (psi)[a] @ 100% Elong.	Tensile Strength (psi)[a] @ Rupture	Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
107-11A	-	Air	Instron at 20.0 in./min	0	0	0	0	-	80	108	165	894	580	75	760
107-12A									60	96	180	820	548		
107-13A									96	128	193	825	540		
107-14A									55	104	162	777	525		
107-15A									75	117	177	636	420		
									73/18	111/14	175/13	730/111	523/69		
107-26A	Air	Air	Instron at 20.0 in./min	1.8(8)	6.0(12)	3.8(13)	1.7(12)	2	92	129	203	831	460	75	760
107-27A									96	134	210	1081	460		
107-28A									87	120	194	867	490		
107-29A									92	136	219	913	450		
107-30A									89	127	202	759	420		
									91/4	129/7	206/11	890/138	456/30		
107-36A	Air	Air	Instron at 20.0 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	108	151	269	806	300	75	760
107-37A									126	184	308	741	250		
107-38A									117	168	294	685	232		
107-39A									125	183	308	795	268		
107-40A									113	161	285	549	190		
									118/8	169/14	293/17	715/110	248/47		
107-46A	Air	Air	Instron at 20.0 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	4	507	-	-	507	25	140	760
107-47A									-	-	-	471	21		
107-48A									591	-	-	665	28		
107-49A									-	-	-	522	21		
107-50A									-	-	-	314	13		
									549/74			496/151	21.6/6.4		

[a]Values given as: average value/standard deviation on an individual basis.

Table 8.4

Q94-002 Sealant (Lap Shear)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength[a] (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm²) E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
94A-11	-	Air	Instron at 0.05 in./min	0	0	0	0	-	484		75	760
94A-12									385			
94A-13									478	2 avg		
94A-14									491			
94A-15									486			
									465/46			
94A-31	Air	Air	Instron at 0.05 in./min	5.7(8)	6.1(12)	1.4(14)	4.6(12)	2	384		75	760
94A-32									393			
94A-33									431	55 avg		
94A-34									204			
94A-35									235			
									329/55			
94A-36	Air	Air	Instron at 0.05 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	228		75	760
94A-37									267			
94A-38									153	75 avg		
94A-39									267			
94A-40									157			
									214/49			
94A-41	Air	Air	Instron at 0.05 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	3	-		125	760
94A-42									144			
94A-43									148	95 avg		
94A-44									98			
94A-45									183			
									143/41			

[a]Values given as: average value/standard deviation on an individual basis.

Table 8.4 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate Tensile Shear Strength (psi)	% Adhesive Failure	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)							
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev					
94A-61	Vac	Air	Instron at 0.05 in./min	5.4(8)	7.2(12)	6.6(13)	2.5(13)	24	414		145	4.6(-6)
94A-62									330			
94A-63									358	5 avg		
94A-64									387			
94A-65									315			
									361/43			
94A-66	Vac	Air	Instron at 0.05 in./min	1.2(9)	1.6(13)	1.8(14)	6.7(13)	24	260		145	4.6(-6)
94A-67									273			
94A-68									269	80 avg		
94A-69									300			
94A-70									343			
									289/36			
94A-71	Vac	Air	Instron at 0.05 in./min	5.3(9)	7.8(13)	6.8(14)	-	6	155		125	2.0(-6)
94A-72									138			
94A-73									116	98 avg		
94A-74									168			
94A-75									131			
									141/22			

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IX. ELECTRICAL INSULATION AND DIELECTRIC MATERIAL TEST METHODS AND RESULTS

Table 9.1

Outline of Electrical Insulation and Dielectric Materials Tests

Material	Type of Test	Irradiation Environment	Nominal Gamma Dose [ergs/gm(C)]	Materials Tester	ASTM Test Method	Test Data[a]
Duroid 5600	Dynamic	Vac-Cryo	1(10)	Cryomechanical	D-638-61T, Mod.	T,E,S
	Dynamic	LH_2	5(9),1(10)	Cryotensile	D-638-61T, Mod.	T,E,S
Estane 5740X1	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
Epon 828/Z	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
H-Film	Static	Air	3(10),1(11)	Instron	D-882-61T	M,T,E
Kel F-81	Dynamic	Vacuum	3(9)	Low-Force	D-790-63, Mod.	F
Kynar 400	Static	Air	5(8),1(9),5(9),1(10),3(10),1(11)	Instron	D-638-61T, Mod.	T,E
	Static	Vacuum	5(8),1(9),1(10)	Instron	D-638-61T	T,E
	Dynamic	Vacuum	1(10)	High-Force	D-638-61T, Mod.	T,E,S
	Dynamic	LN_2	5(9),1(10)	Cryotensile	D-638-61T, Mod.	T,E,S
	Dynamic	LH_2	5(9),1(10)	Cryotensile	D-638-61T, Mod.	T,E,S
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
	Dynamic	Air	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Air	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
Lamicoid 6038E	Static	Air	1(11)	Instron	D-638-61T, Mod.	T,E,S
	Static	Vacuum	1(10)	Instron	D-638-61T, Mod.	T,E,S
	Dynamic	Vacuum	1(10)	High-Force	D-638-61T, Mod.	T,E,S
	Dynamic	Vac-Cryo	1(10)	Cryomechanical	D-638-61T, Mod.	T,E,S
	Dynamic	LH_2	1(10),3(10)	Cryotensile	D-638-61T, Mod.	T,E,S
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
	Dynamic	Air	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Air	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
Lexan	Static	Air	5(8),1(9),1(10),3(10),1(11)	Instron	D-638-61T, Mod.	T,E
	Static	Vacuum	5(8),1(9),5(9),1(10)	Instron	D-638-61T, Mod.	T,E
	Dynamic	Vacuum	5(8),5(9)	Low-Force	D-790-63, Mod.	F
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
	Dynamic	Air	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Air	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
Marlex 6001	Static	Air	3(10),1(11)	Instron	D-638-61T	T,E
Marlex 6002	Static	Vacuum	1(10)	Instron	D-638-61T	T,E
	Dynamic	Vacuum	1(10)	High-Force	D-638-61T, Mod.	T,E,S
Mylar 100C	Static	Air	5(8),5(9),1(10),3(10),1(11)	Instron	D-882-61T	M,T,E,S
	Static	Vacuum	5(8)	Instron	D-882-61T	M,T,E
	Dynamic	Vacuum	5(8),5(9)	Low-Force	D-882-61T, Mod.	M,T,E,S
Plaskon CTFE X2204	Static	Air	1(9),5(9)	Instron	D-638-61T	T,E
	Static	Vacuum	1(9),5(9),1(10)	Instron	D-638-61T	T,E
RTV 501	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
Silastic 950	Static	Air	5(8),1(9),5(9),1(10)	Instron	D-412-62T	M,T,E
	Dynamic	LN_2	5(9),1(10)	Cryotensile	D-638-61T, Mod.	M,T,E,S
	Dynamic	LH_2	5(9),1(10)	Cryotensile	D-638-61T, Mod.	M,T,E
Silastic 1410	Static	Air	5(8),1(9),5(9),1(10)	Instron	D-412-62T	M,T,E
	Static	Vacuum	5(8),1(9),5(9)	Instron	D-412-62T	M,T,E
	Dynamic	LH_2	5(9),1(10)	Cryotensile	D-638-61T, Mod.	M,T,E
	Dynamic	LN_2	5(9),1(10)	Cryotensile	D-638-61T, Mod.	M,T,E,S
Sylgard 182 (DC 93-022)	Static	Air	5(8),1(9),1(10)	Instron	D-575-46	LD
	Static	Vacuum	1(10)	Instron	D-575-46	LD
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
	Dynamic	Air	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Air	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R
Tedlar	Static	Air	3(10),1(11)	Instron	D-882-61T	M,T,E
Teflon FEP (2-mil)	Static	Air	1(9),5(9),1(10)	Instron	D-882-61T	M,T,E
	Static	Vacuum	1(9),5(9),1(10)	Instron	D-882-61T	M,T,E
Teflon FEP (10-mil)	Static	Air	1(9),5(9),1(10)	Instron	D-882-61T	M,T,E
	Static	Vacuum	1(9),5(9),1(10)	Instron	D-882-61T	M,T,E
Teflon FEP (40-mil)	Static	Air	1(9),5(9),1(10)	Instron	D-412-62T	M,T,E
	Static	Vacuum	1(9),5(9),1(10)	Instron	D-412-62T	M,T,E
Teflon TFE-7 (2.5-mil)	Static	Air	1(7),5(7),2(8),5(8)	Instron	D-882-61T	M,T,E
	Static	Vacuum	5(7),1(8),5(8),1(9)	Instron	D-882-61T	M,T,E
Teflon TFE-7 (5-mil)	Static	Air	1(7),5(7),2(8),5(8)	Instron	D-882-61T	M,T,E
	Static	Vacuum	5(7),1(8),5(8),1(9)	Instron	D-882-61T	M,T,E
Teflon TFE-7 (10-mil)	Static	Air	1(7),5(7),2(8),5(8)	Instron	D-882-61T	M,T,E
	Static	Vacuum	5(7),1(8),5(8),1(9)	Instron	D-882-61T	M,T,E
	Dynamic	Vacuum	3(9)	Low-Force	D-882-61T, Mod.	M,T,E
Teflon TFE-7 (20-mil)	Static	Air	1(7),5(7),2(8),5(8)	Instron	D-882-61T	M,T,E
	Static	Vacuum	5(7),1(8),5(8),1(9)	Instron	D-882-61T	M,T,E
Teflon TFE-7 (40-mil)	Static	Air	1(7),5(7),2(8),5(8)	Instron	D-412-62T	M,T,E
	Static	Vacuum	5(7),1(8),5(8),1(9)	Instron	D-412-62T	M,T,E
Teflon TFE-7 (125-mil)	Dynamic	LH_2	1(9),5(9)	Cryotensile	D-638-61T, Mod.	T,E,S
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-150-59T, Mod.	DC,DF
	Dynamic	Vac-Cryo	1(7),1(8),1(9),1(10)	Dielectric	D-257-61, Mod.	R

[a]T - Tensile Strength at Rupture
E - Elongation at Rupture
S - Stress-Strain Curve
DC - Dielectric Constant
DF - Dissipation Factor
R - Resistivity (volume)
M - Modulus
F - Flexure
LD - Load Deflection

IX. ELECTRICAL INSULATION AND DIELECTRIC MATERIAL TEST METHODS AND RESULTS

This section of the report contains all of the data obtained during the current period on electrical insulations and dielectric materials. The Program Summary table at the front of this report lists all of the materials tested under this category during the first two annual and current biennial periods. The reports containing the data are referenced in the summary table.

Table 9.1 (facing page) lists the test conditions, environments, doses, and materials tested during the current period. As the table shows, the materials were subjected to a variety of radiation exposures and environments. Background information, test methods, and results for each material tested are discussed in each of the subsections that follow below. Data tabulation and summary stress-strain plots are presented at the end of this section.

Both mechanical and dielectric properties were determined for materials under control and irradiation conditions. The test equipment and procedures used are discussed in Sections II and III.

Various materials within the category of electrical insulations were subjected to mechanical property tests under the following conditions:

1. In air after air irradiation
2. In air after vacuum irradiation
3. In vacuum after vacuum irradiation
4. In LN_2 before and after irradiation in LN_2
5. In LH_2 before and after irradiation in LH_2

Dielectric properties measured were dielectric constant, k_n (normalized), dissipation factor, and volume resistivity. The measurements were made in accordance with ASTM D-150-59T, "A-C Capacitance, Dielectric Constant, and Loss Characteristics of Electrical Insulating Materials," and ASTM D257-61, "Electrical Resistance of Insulating Materials."

Dielectric tests were conducted under the following four conditions:

1. At ambient temperature and pressure before irradiation.
2. At ambient temperature and pressure during and after irradiation.
3. At cryotemperature and vacuum before irradiation.
4. At cryotemperature and vacuum during and after irradiation.

Dielectric property values are given in Tables 9.2 through 9.9. The tabulated dielectric constants (k_n) are the true dielectric constants normalized to a value of 1.0 for initial room-temperature atmospheric-pressure unirradiated conditions. Each value represents an average of two specimens. The test frequency was 1000 cps.

New specimens of the materials tested during the previous period in the dielectric tester in vacuum and cryotemperature were retested this year in the modified Dielectric Tester. Retesting of the cryotemperature specimens was necessary because of the excessively high temperatures encountered during the previous periods. The air test was not repeated during this test program, and only the one test condition was used with these materials.

9.1 Duroid 5600

The specimens for this test were cut from new sheets of Duroid 5600 material received during the current period. Tests included one control test and two radiation exposure tests in LH_2 (-423°F) and one control (-250°F) and one radiation exposure (-290°F) at cryotemperatures while in a vacuum. The radiation exposures and subsequent testing at cryotemperatures were accomplished with the Cryomechanical and Cryotensile Testers. These testers are described in Sections 2.5 and 2.8, respectively.

Mechanical property tests were performed in accordance with ASTM D-638-61T, Modified. The modification of this test standard was concerned with an alteration in the test specimens necessary to adapt them for remote testing in the Cryotensile and Cryo-mechanical Testers. The test specimens were of the wide-gage type described in Section 4.1. Average stress-strain curves are shown in Figures 9.1 and 9.2, and tabulated test data are given in Table 9.10. The test specimens used in the current period showed no change in color after the various environmental exposures and all specimens broke in the gage length.

This material was previously tested in environments of air and LN_2 and reported in Reference 4. The LN_2 tensile-strength values of 7100 psi for controls and 5800 psi at 1.4×10^{10} ergs/gm(C) are higher than the air control value of 2700 psi and the air-irradiated value of 700 psi at 1.2×10^{10} ergs/gm(C). The LH_2 values of 9200 psi for the control and 7200 psi at 8.6×10^{9} ergs/gm(C) are higher than the respective LN_2 values and represent a 22% decrease in tensile strength. The vacuum-LN_2 control values of 7600 psi and irradiated values of 7500 psi at 1.1×10^{10} ergs/gm(C) show the smallest radiation-effects change.

9.2 <u>Estane 5740X1</u>

The test specimens were taken from the same lot as used in the dielectric tests conducted in a previous period. The dielectric properties for Estane are presented in Table 9.2. The initial true dielectric constant measured at room temperature and pressure was 7.5.

Estane showed significant increases in k_n after irradiation in air but not during or after irradiation and testing in a vacuum-cryotemperature environment. No significant changes were observed in the dissipation factor or volume resistivity in postirradiation tests on specimens in a vacuum-cryotemperature environment. However, when measurements on these parameters were made during irradiation in a vacuum-cryotemperature environment, significant increases in dissipation factor were observed and the volume resistivity decreased by two orders of magnitude.

9.3 Epon 828/Z

The Epon specimens were prepared by casting a fresh stock of liquid Epon 828 resin and Z catalyst in polished circular molds. The dielectric property values for Epon are presented in Table 9.3. The initial true dielectric constant measured at room temperature and pressure was 4.5.

Epon showed significant increases in k_n after irradiation and testing in the air and in the vacuum-cryotemperature environments. Small increases in dissipation factor and decreases in volume resistivity were observed in postirradiation tests on specimens in a vacuum-cryotemperature environment. However, when measurements of these parameters were made during irradiation in a vacuum-cryotemperature environment, the dissipation factor was about an order of magnitude higher and the volume resistivity was about two orders of magnitude lower.

9.4 H-Film*

H-Film was subjected to two radiation exposures in air with postirradiation testing being accomplished in the Instron under standard laboratory conditions. These specimens, cut from the same roll as that used in previous tests, were 0.002 in. thick, 0.5 in. wide, and 6.0 in. long. Testing was conducted in accordance with ASTM D-882-61T. The test data are presented in Table 9.11

The H-Film tensile strength at break began to show a change at 3.3×10^{10} ergs/gm(C), and there was noticeable damage at 1.7×10^{11} ergs/gm(C). The change was even more apparent in the values obtained for elongation. The initial control value in air of 109% decreased at the low dose to 66% and at the high dose to 28%. There was no apparent color change during these tests.

9.5 Kel F-81

Kel F-81 was subjected to only one radiation exposure in vacuum with postirradiation testing being conducted in vacuum in

*DuPont has recently changed the trade name to Kapton.

the Low-Force Tester. This material was tested for flexural properties in accordance with ASTM D-790-63, with the exception that the span of the flexural test positions on the Low-Force Tester was 2.0 in. instead of the ASTM-specified value of 1.5 in. The test specimens were 0.094 in. thick, 1.0 in. wide, and 4.0 in. long.

Table 9.12 presents the environmental conditions and results from control and postirradiation tests for this material. Figure 9.3 contains stress-strain plots for the data. Because of a malfunction of the tester, several data points were lost.

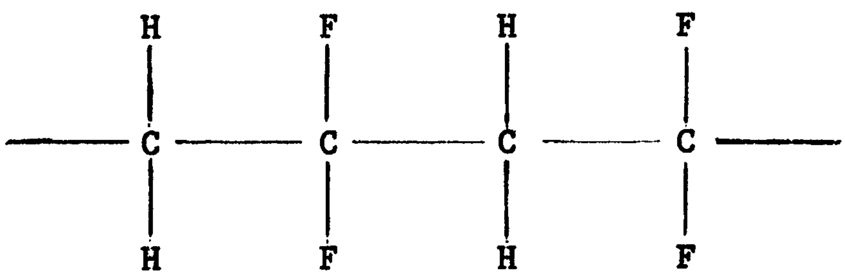
9.6 Kynar 400

9.6.1 Material Background Information

The fluorocarbon plastics have received wide acceptance as materials for aerospace service, but so far they are considered to have relatively low nuclear-radiation tolerance. This is based, mainly, on air irradiation of Kel F and Teflon.

Pennsalt Chemicals Corporation has developed a new halocarbon, Kynar, that has seen service in the Centaur vehicle in many applications. Kynar is a totally new fluorine-containing thermoplastic resin. It is unlike any other resin currently available, being a crystalline, high-molecular-weight polymer of vinylidene fluoride, $CH_2=CF_2$. Kynar contains 59% fluorine with a linear chain structure similar to ethylene, except that alternate carbon atoms have fluorine instead of hydrogen atoms attached. Teflon and Kel F have no hydrogen.

There is a plausible explanation of the apparent improved radiation stability of the vinylidene fluoride over that of the other halocarbon structures. Below is a typical structural formula of Kynar:



The energy required to break the C-F side-chain bonds is greater than that needed to break the C-C main-chain bonds, while that required to break the C-H side bonds is less. The relatively weak C-H bond in the Kynar thus results in hydrogen splitting off from the carbon chain in a radiation field, resulting in cross-linking between adjacent molecules rather than chain cleavage. This should give a more radiation-stable configuration than the chloro-trifluoro- and tetrafluoro-ethylene compounds that have no hydrogen atoms in the molecule.

Kynar was tested in a previous period in vacuum in accordance with ASTM D-882 and in the form of straight-film tensile specimens 1 in. wide and 6 in. long. However, the test results were inconclusive because the control values of 8.7% elongation were very low when compared to the vendor-published value of 300%. It was assumed in the data analysis that this batch of Kynar was not representative of the material. The ultimate tensile strength increased slightly when irradiated in ambient air at 1.4×10^9 ergs/gm(C). The vacuum irradiation to 9.4×10^8 ergs/gm(C) produced essentially no change in ultimate tensile strength. The elongation changed very little under these same conditions, except that the control values were lower than normal, as already explained.

Information on the radiation resistance of Kynar was reported by L. A. Decker (Ref. 5) in 1962. He tested several plastics for possible use as electrical insulators and spacers in an electrolytic dissolver (nitric acid-nitrate salt solution) used for processing irradiated nuclear fuels. The radiation program was carried out in the Materials Test Reactor (MTR) gamma facilities at the National Reactor Testing Station. Out of a group of 19 plastics carefully selected for corrosion and radiation stability, Kynar was one of the top four that were recommended.

Pennsalt Chemicals Corporation states in their sales brochure (Ref. 6) that the resistance of Kynar to gamma radiation is exceptional for a fluorocarbon. At a dose level exceeding 3×10^8 r (Co^{60} source), Kynar showed no change in tensile strength or elongation, though a darkened color was observed.

Although its stiffness increases sharply at extremely low temperatures, Kynar retains a moderate degree of impact strength at -300°F (Izod unnotched value of 3.2 ft-lb/in.) and should be serviceable in many applications at cryotemperatures. The Kynar weight loss in vacuum is similar to that of Teflon, Kel-F, and Halon (Fulk and Horr, Ref. 7), which are all very low.

9.6.2 Test Methods and Results

Kynar 400 was one of the most extensively tested materials in the current period. Table 9.1 lists the test conditions, environments, and doses to which this material was subjected.

The material was tested for tensile properties and dielectric properties. The tensile specimens were of the wide-gage type described in Section 4.1 and were tested in accordance with ASTM D-638-61T. The dielectric specimens that are described in Section 4.2 were tested in accordance with ASTM D-150-59T and ASTM D-257-61. Stress-strain plots are given in Figures 9.4 through 9.7, and the environmental conditions and test results of this material are presented in Table 9.13.

The dielectric property values for Kynar are presented in Table 9.4. The initial true dielectric constant measured at room temperature and pressure was 7.7.

No appreciable changes were observed in k_n except for temperature effects, but significant increases in dissipation factor were observed in postirradiation tests and during irradiation. Decreases of several orders of magnitude were observed in the volume resistivity in postirradiation tests and in tests during irradiation on specimens in an air environment. Decreases were also observed during the vacuum-cryotemperature tests, but they were of much less magnitude.

In the series of static air irradiations there was a definite decrease in the ultimate tensile strength and percent elongation when Kynar 400 reached a dose of 1.7×10^{11} ergs/gm(C). At doses up to and including 3.3×10^{10} ergs/gm(C) no significant change was noticed. The data agree roughly with data from other facilities.

The static vacuum-irradiation tensile data did not show a threshold of damage at the maximum dose of 8.5×10^{9} ergs/gm(C). However, there was a slight decrease in the elongation at maximum stress.

In the dynamic vacuum tests the Kynar control specimens pulled satisfactorily in the High-Force Tester, but after irradiation the four specimens failed within the long doubler section; the aluminum doublers had separated from the Kynar. Dynamic control values agreed with the Instron static air and static vacuum values for tensile strength and elongation. When pulled in air or vacuum, the Kynar "necked" to produce a uniform ultimate tensile strength. However, at break it showed a wide variation in both tensile strength and percent elongation, depending on the degree of necking. This discrepancy is shown in the curves of the vacuum-control dynamic test (Fig. 9.4) and the vacuum-irradiation dynamic test (Fig. 9.5).

In the cryotemperature environment the Kynar exhibited a completely different behavior from that in air and vacuum. The majority of the specimens did not break in the standard gage section of the dumbbell tensile specimens but in the section near the edge of the doublers, with some of the Kynar specimens breaking up in the doubler section. Since these breaks at cryotemperatures were brittle fractures, the ultimate tensile strength and tensile strength at break were virtually identical. The irradiation reduced the tensile strength and elongation of Kynar in progressive steps, with the stress-strain curves retaining essentially the same slope. Curves are presented in Figures 9.6 and 9.7 for LN_2 and LH_2 control and irradiation tests. Note that the initial tensile strength and elongation changed drastically at these temperatures relative to values obtained in the air and vacuum tests.

In all irradiations the specimen color progressively changed from light cream to yellow, to tan, and then to dark brown. For the cryotemperature irradiations, aluminum doublers were replaced with Kynar doublers. The aluminum doublers bonded with Epon 934 separated from the Kynar when the specimens were submerged in LN_2. The Kynar was not chemically treated for bonding, but both doublers and specimen ends were sanded until rough before applying the adhesive.

All the air and vacuum static specimens progressively changed break pattern and color at each successive radiation level. Controls were flexible specimens which were cream-colored and which necked extensively in the gage section during tensile tests. Air-irradiated specimens became progressively more brittle and darker in color with increasing dose. However, all breaks were "A" type within the gage section.

For the cryotemperature specimens, the color change was less intense than for the air-irradiated specimens. Break patterns of specimens irradiated in LN_2 were uniform and consistent "C" breaks for both control and irradiated specimens. The LH_2 specimens had multiple breaks, being combinations of "A," "B," "C," and "D."

9.7 Lamicoid 6038E

The test conditions, environments, and doses to which this material was subjected are listed in Table 9.1 at the beginning of this section. It is noted in the table that ASTM D-638-61T was modified. This modification changed the tensile-test specimen configuration so that it was adaptable to the testers. The specimens tested in the Cryomechanical Tester were of the narrow-gage type described in Section 4.1. The specimens tested in the Instron, Cryotensile Tester, and High-Force Tester were also of the narrow-gage type, but some of the Instron-tested specimens did not have doublers. Table 9.15 presents the environmental conditions and test results of this material. The stress-strain plots are given in Figures 9.8 through 9.11.

The dielectric property values for Lamicoid are presented in Table 9.5. The initial true dielectric constant measured at room temperature and pressure was 6.6.

No significant changes were observed in k_n except for temperature effects. Significant increases in dissipation factor were observed only during irradiation. Very significant decreases in volume resistivity were observed when measurements were made during irradiation in air, but no significant changes in this property occurred during vacuum-cryotemperature-irradiation testing. Significant decreases were also observed for volume resistivity in postirradiation tests on specimens in air.

The Lamicoid static air irradiation at the high dose of 1.7×10^{11} ergs/gm(C) produced a very slight decrease in tensile strength and elongation. Even in the static vacuum irradiation of 9.7×10^{9} ergs/gm(C), values were reduced very little. The curves in Figure 9.8 for the air and vacuum static irradiations clearly show that there was very little damage. The vacuum dynamic test in the High-Force Tester produced minimum changes, as shown in the curves of Figure 9.9.

All the specimens in the air and vacuum environmental tests had good "A" breaks in the narrow-gage section. However, some splitting and delaminating occurred at high doses for specimens in static air, static vacuum, and dynamic vacuum tests. The doublers either came off or partly separated in the High-Force

Tester, but the rivets held the doublers sufficiently to obtain good test data.

A comparison of the curves for vacuum dynamic tests in Figure 9.9 with those for vacuum-LN_2 dynamic tests in Figure 9.10 show that the low temperature increased both the elongation and tensile strength at break for the Lamicoid 6038E control and irradiated specimens. For the controls, tensile strength increased over 100% (60,000 psi to 128,000 psi) and percent elongation increased from about 4 to 7%. Irradiation to 1.2×10^{10} ergs/gm(C) increased the percent elongation slightly but reduced the tensile strength to only 111,000 psi, which is in the same ratio as the tensile-strength reduction under the two vacuum dynamic test conditions. The breaks continued to be in the gage section, with very irregular separations of the fiberglass at the breaks. Every ply of fiberglass delaminated (separated from resin) within the entire gage section, with some delaminations extending almost to the doublers in certain specimens.

For the LH_2 dynamic tests on Lamicoid, a rough average of the stress-strain values shown in Figure 9.11 was used because of the wide variation in values above 4% elongation. This situation in data scatter is indicated by the dashed lines in Figure 9.11 for the irradiated LH_2 dynamic tests. Actual data points and specimen failures are listed in Table 9.14. Dashed sections of curves should be interpreted as trend lines rather than reliable design information because of the specimen behavior in the extremely cold (-423°F) temperature. A visual analysis of specimens revealed several causes for the wide scatter of tensile data, other than the delaminations, and accounted for the data loss of certain specimens. Of the four control specimens, two separated in the gage section and two within the doublers; for the low dose of 1×10^{10} ergs/gm(C), there were three pulled out in the doublers with only one specimen breaking in the gage section; yet, for the high dose of 3×10^{10} ergs/gm(C), there were three "A" gage section breaks and only one failure in the doubler area.

The break in the resin-fiberglass bond was fan-shaped and composed of the individual fiberglass plies. Where the adhesive bond failed on a few specimens, the loose doublers were held during the tensile pull by the rivets.

No change in color could be detected by visual inspection of the specimens tested in any of the environments. After irradiation and warmup of the specimens, there did not seem to be any permanent damage to the melamine laminate. It is inferred here that the major effect was the cryotemperature environment and that radiation damage was not severe. Since the melamine-glass combination had good strength in LH_2 and other environments up to at least a tensile strength of 8000 psi, its qualification as a dielectric laminate can be based strictly on its electrical properties.

9.8 Lexan

9.8.1 Material Background Information

It was recommended that a polycarbonate be included in the current testing period, starting with the vacuum and dielectric tests. The factors that influenced its selection are radiation stability, polymer structure, engineering properties, and applications.

The polycarbonate plastics have been irradiated by several investigators. The radiation resistance of Lexan (General Electric polycarbonate resin) has been investigated by Harrington (Ref. 8), Giberson (Ref. 9), Barker (Ref. 10), Golden (Ref. 11), and Decker (Ref. 5). Fritz (Ref. 12), at the Fort Worth Division, reported on Merlon (Mobay Company polycarbonate resin). Decker investigated Lexan as a part of the same program already reported on Kynar (Sec. 9.6). Lexan was not as reliable under some conditions as Kynar, but it still had good radiation stability. A radiation dose of 1×10^{10} ergs/gm(C) produced a brittleness and darkening of the Lexan specimens, although they did retain some transparency. A dose of 1 x 10^{11} ergs/gm(C) caused swelling, cracking, severe embrittlement, and general disintegration. This is to be expected for plastics at this high dose, however.

The Merlon (Fritz, Ref. 12) was exposed to radiation from the GTR at room temperature in air to five levels of radiation, the highest being 1.2 x 10^{10} ergs/gm(C). The material showed an excellent postirradiation retention of various mechanical properties. No significant changes in ultimate tensile strength or shore-D hardness were observed up to an absorbed dose of 1.5 x 10^{9} ergs/gm(C). The yield-point stress, however, was found to decrease steadily with dose. At about 1 x 10^{10} ergs/gm(C) no definite yield point was apparent and the mode of fracture had changed from ductile to brittle. All irradiated samples turned progressively darker brown in color with increasing doses. No significant changes in the dc volume and surface resistivity were noted.

Fritz reviewed the irradiation studies referenced above and concluded that further study was needed. Some of these irradiations were in vacuum and some used thin films but none were in a cryotemperature environment. Furthermore, there seems to be disagreement between the investigators as to the relative influence of oxidation reactions on the radiation stability of the polycarbonates.

According to previous tests, polycarbonates such as Lexan should have a critical threshold of between 1×10^9 and 1×10^{10} ergs/gm(C). This apparently depends on such variables as environment, property tested, and polymer structure.

The polycarbonate structure is a point in favor of its selection. This resin is prepared from bisphenol A and has the phenyl groups in the main chain, which structure as a rule increases the radiation stability of organic polymers.

Another influential factor in the selection of the polycarbonate is its unusual combination of physical, mechanical, and electrical properties. This plastic is an excellent electrical insulator. It may be processed in most of the common forms by methods generally employed in plastics processing. Also, the polycarbonate thermoplastics have rapidly expanded in structural-component applications, including new fiberglass laminates. A better knowledge is needed of its radiation stability in the environments being investigated under this program.

9.8.2 Test Methods and Results

Lexan was subjected to the environments and tests shown in Table 9.1. The modification to ASTM D-638-61T changed the standard tensile specimen. Although Lexan was not tested for tensile properties on any of the dynamic testers, the tensile specimens were fabricated in the same configuration as the specimens that were. The specimens were of the wide-gage type described in Section 4.1.

Lexan was also tested for flexural properties in the Low-Force Tester in accordance with ASTM D-790-63, with the exception that the span of the flexural test positions on the Low-Force Tester is 2.0 in., and according to the standard it should be 1.5 in. for specimens with a nominal thickness of 0.095 in. The test specimens were 0.103 in. thick, 1.0 in. wide, and 4.0 in. long. The test results and radiation environments are presented in Tables 9.16 and 9.17.

The dielectric property values for Lexan are presented in Table 9.6. The initial true dielectric constant measured at room temperature and pressure was 3.0.

No significant changes were observed in k_n except for temperature effects. Significant increases in dissipation factor were observed both during and after irradiation in a vacuum-cryotemperature environment. Increases in dissipation factor observed from measurements made during irradiation in air were very significant, but postirradiation tests indicated insignificant changes.

Very significant decreases in volume resistivity were observed from measurements made both during and after irradiation in an air environment. Insignificant changes in this property (except for temperature effects) were observed from measurements made during and after irradiation tests on specimens in a vacuum-cryotemperature environment.

In the static air tests, the Lexan polycarbonate was exposed at room temperature to five levels of radiation, the highest being 1.7×10^{11} ergs/gm(C). As the radiation level increased, the ductility decreased, color darkened, and pulling characteristics changed from extensive necking and stretching to clean brittle breaks. The damage threshold for specimens irradiated in air was between 1×10^{9} and 1×10^{10} ergs/gm(C).

The irradiation in vacuum, with testing in air, produced essentially the same tensile-strength values as those in the air irradiations, but ultimate elongation was higher in all the vacuum series of irradiations. Table 9.16 shows values of elongation that were 20 to 40% higher for the same dose levels.

The vacuum dynamic test results are presented in Figure 9.12 as stress-strain curves for the flexure specimens. Table 9.17 presents all the data, including the tangent modulus of elasticity and outer-fiber stress at 5% strain. Information was inconclusive at these dose levels. Some flexural data were not available, since the travel did not reach 5% strain in the Low-Force Tester. At the dose levels selected for vacuum static irradiations with subsequent testing in air, the flexural specimens did not reach a damage threshold.

9.9 Marlex 6001

This material was subjected to two radiation exposures in air. Postirradiation testing was conducted on the Instron in accordance with ASTM D-638-61T. Table 9.18 is a tabulation of environmental conditions and test results.

Marlex 6001 is a high-density polyethylene of the ASTM D1248-63T classification Type III, Class A, Grade 3. The irradiations decreased the elongation at maximum stress from 11.4% for controls to 8.8% at 3.3×10^{10} ergs/gm(C) and 7.6% at 1.7×10^{11} ergs/gm(C). The same specimens had a reversal of tensile strength at maximum stress, starting at approximately 4500 psi for controls, increasing to 6100 psi at the low dose, and decreasing to 4100 psi at the high dose. Visual analysis of the specimens after testing showed a change from extreme stretching and necking for controls to clean breaks after irradiation.

Irradiation changed the color of the material from white to a light tan at the low dose and to a dark tan at the high dose.

Since elongation and tensile strength vary with crosshead pull speed for polyethylenes, the control and irradiated specimens need to be compared at similar pull speeds when feasible.

9.10 Marlex 6002

This material was subjected to two radiation exposures in vacuum. Subsequent testing of the specimens for one exposure was accomplished in the Instron at standard laboratory conditions. These test specimens were fabricated and tested in accordance with ASTM D-638-61T. Postirradiation testing of the specimens subjected to the other exposure was conducted on the High-Force Tester in vacuum. These test specimens were of the wide-gage type described in Section 4.1. Testing was accomplished in accordance with ASTM D-638-61T at a crosshead speed of 0.05 in./min. Stress-strain plots are given in Figure 9.13, and the environmental conditions and test results are presented in Table 9.19.

The 5000-psi tensile strength and 85% elongation at 2 in./min (vendor table) changed to 5157 psi and 54% after irradiation in vacuum to a dose level of 8.5×10^9 ergs/gm(C). These values imply that vacuum irradiation varied the average molecular chain length without an appreciable change in degree of crystallinity. These specimens necked slightly in the gage section before breaking. Color changed from the characteristic polyethylene milky white to a light tan.

The Marlex 6002 tensile specimens in the High-Force Tester were exposed to 9.2×10^9 ergs/gm(C) and then tested dynamically in vacuum. Tensile strength and elongation at maximum stress decreased from the control values; the tensile stress decreased from 3800 to 3100 psi and the elongation decreased from 8.5% to 6.0%.

Ultimate values could not be compared since the tensile control specimens did not break before the pull assembly reached the maximum travel. These trends are indicated by the dashed curves in Figure 9.13.

9.11 Mylar 100C

Test specimens for these tests were cut from the same roll of Mylar 100C film as was used in previous tests. This material was subjected to the test conditions, environments, and doses shown in Table 9.1. The test specimens were thin-film specimens 0.001 in. thick, 1.0 in. wide and 6 in. long. The specimens were tested in accordance with ASTM D-882-61T, with the exception of the specimens tested in the Low-Force Tester. These specimens were tested at a speed of 0.5 in./min, while those in the Instron were tested at the ASTM standard crosshead speed of 20 in./min.

The reasons for this necessary compromise in testing speed are given in the discussion of testing for O-rings in Section VII.

The air-irradiation test data in Table 9.20 show a detectable increase in mechanical properties at a low dose of 5.7×10^8 ergs/gm(C), but degradation started before 9.7×10^9 ergs/gm(C) and continued until at 3.3×10^{10} ergs/gm(C) and 1.6×10^{11} ergs/gm(C) the film was too brittle to test. The vacuum irradiation with testing in air (Table 9.20) produced only small changes in the mechanical properties at doses of 8.5×10^9 ergs/gm(C).

Average stress-strain curves are presented for the seven test conditions of the Mylar 100C in Figures 9.14 and 9.15. Each data point represents an average of three or more specimens. For the static air control test, nine specimens were tested in the Instron to establish an average control value, and a smooth average curve was drawn. The ultimate elongation varied from 25% to 114%, and the tensile strength ranged from 17,000 psi to 28,000 psi. This wide variation in test results was also observed during testing of the irradiated specimens in both the Instron and the Low-Force Tester. Nine specimens were tested in the Instron for each condition and the average test values plotted. The dynamic Low-Force Tester has the capability of testing only three films at each condition.

The dashed lines in Figure 9.15 represent trends indicated by the widely varying data obtained from specimens in the Low-Force Tester. The reason for this diversity of elongation values lies in the test method and the nature of the material. Necking and creeping are characteristic of Mylar film and, while being pulled in the Low-Force Tester, this creeping transmitted itself through the jaws toward the ends of the specimen. Consequently, the elongation values are not considered representative of the material. The ultimate tensile strength values, however, are considered reliable. These values are in Table 9.20; all specimens broke in the gage length, except as noted.

9.12 Plaskon CTFE X2204

As shown in Table 9.1 this material was subjected to two radiation exposures in air and three radiation exposures in vacuum. Postirradiation testing was conducted on the Instron. The specimens were fabricated and tested in accordance with ASTM D-638-61T.

The Plaskon CTFE X2204 reached a threshold of damage in the static air irradiations between 8.8×10^8 and 5.2×10^9 ergs/gm(C). In the static vacuum irradiations the threshold was between 7.0×10^8 and 5.3×10^9 ergs/gm(C). The vacuum environment during irradiation improves the radiation resistance of the material specimens slightly, but not sufficiently as shown in Table 9.21.

9.13 RTV-501

The dielectric property values for RTV-501 are presented in Table 9.7. The initial true dielectric constant measured at room temperature and pressure was 7.5.

RTV-501 showed no significant changes in k_n except for temperature effects. Significant increases in dissipation factor were observed during and after irradiation and testing in a vacuum-cryotemperature environment. Volume resistivity measurements made during irradiation and testing in a vacuum-cryotemperature environment showed very significant decreases.

9.14 Silastic 950

9.14.1 Material Background Information

There has been considerable irradiation information generated on the Dow Corning Silastic 7-170 (a methyl silicone rubber). In reviewing materials for the current cryotemperature irradiations, this item seemed, at first, to be a logical choice. However, Dow Corning is phasing this formulation out of production. It contains a mercury compound as a low-compression-set additive that prevents it from being handled easily by fabricators. In spite of its radiation qualifications, there is, therefore, no reason for continued testing of this particular rubber compound.

Of the four high-phenyl, high-strength, extreme-low-temperature silicone-rubber formulations considered (Silastic 651, 675, 950, and 960) Silastic 950 seems to have the best balance of properties as presented in the selection guide; however, cryotemperature behavior is not available for these silicones.

9.14.2 Test Methods and Results

This material was fabricated in two forms of test specimens for tensile-property testing. The specimens that were subjected to the air-irradiation exposures, shown in Table 9.1, were Die C specimens as described by ASTM D-412-62T. Postirradiation testing of these specimens was done on the Instron in accordance with this standard.

Specimens that were subjected to a radiation-cryotemperature environment and then tested at cryotemperatures were of the wide-gage type described in Section 4.1. Testing of these specimens was in accordance with ASTM D-638-61T. The stress-strain curves are plotted in Figure 9.16 and the test results are presented in Table 9.22.

The irradiation of the Silastic 950 silicone elastomer Die C specimens to 5.2×10^9 ergs/gm(C) in air produced an appreciable decrease in tensile strength and elongation (Table

4.22). At the highest dose of 9.7 x 10^9 ergs/gm(C), the elongation decreased further; however, tensile strength increased slightly. These results established the threshold at 1 x 10^9 ergs/gm(C) for static air irradiations. A progressive stiffening of the elastomer occurred at successively higher radiation levels, yet the color remained gray.

Since the Silastic 950 brittle point is at -178°F, the specimens remained rigid and brittle during the dynamic cryotemperature irradiations. Tensile strength and percent elongation for cryotemperature control specimens are entirely different from air control values; comparison of control and irradiated specimens in the same environment is required to indicate the degree of radiation damage. The variation in the tensile strength, elongation, and break pattern of individual specimens is such that relative effects of temperature and radiation are not discernible or readily analyzed. When available information is surveyed, the damage in LN_2 seems to be less severe than at comparable doses in air.

The specimens did not break in the gage section but broke near the doublers at one or both ends, with some separation of doublers from the rubber. The Silastic showed many small stress cracks within the doubler sections. Irradiated LN_2 specimens turned tan and were slightly stiffer than the controls. These changes indicate some deterioration. The curves in Figure 9.16 indicate relative trends and changes for the LN_2 tests.

The tensile specimens of Silastic 950 did not pull satisfactorily in the Cryotensile Tester when submerged in LH_2, either as controls or after irradiation. The extremely low temperature was too severe an environment for these silicone rubbers. However, visual inspection of all specimens after irradiation in LH_2 indicated no change in color. The LH_2 specimen breaks were similar to those in LN_2 in which the gage section remained unbroken; the specimens broke near the doublers.

9.15 Silastic 1410

9.15.1 Material Background Information

This material is a high-grade, high-strength, heat-shrink, silicone rubber that is being used as insulation on umbilical cable, spacecraft wiring, harnesses, etc. It passed the screening test with practically no change in tensile strength after a 2.6×10^9 ergs/gm(C) gamma irradiation in ambient air. Elongation decreased 58.8%, but its application does not require very high elongation characteristics when installed for service involving tensile stress.

9.15.2 Test Methods and Results

With the exception of being subjected to two vacuum-radiation exposures, this material was subjected to the same test conditions and procedures as Silastic 950. The test specimens of this material that were subjected to the vacuum-radiation exposures were fabricated and tested in the same manner as the static air specimens. The test results are presented in Table 9.23; the stress-strain curves are plotted in Figure 9.17.

The maximum radiation level of 9.7×10^9 ergs/gm(C) decreased the Silastic 1410 air static tensile strength to only 43 psi below the control value of 1335 psi. On the other hand, for the same series of specimens, the 503% elongation of the controls changed to 299% at 8.8×10^8 ergs/gm(C), to 52% at 5.2×10^9 ergs/gm(C), and to 26.4% at 9.7×10^9 ergs/gm(C).

The changes in the break and pull characteristics of the specimens followed the elongation changes, namely, (1) the controls stretched on pulling and, after breaking, remained extended and flexible; (2) at 5.7×10^8 ergs/gm(C) the specimens stretched the same as the controls; (3) at 8.8×10^8 ergs/gm(C) the specimens stretched but not as much as at the low dose; (4) at 5.2×10^9 ergs/gm(C) the specimens had clean breaks with no stretching and little stiffness; and (5) at 9.7×10^9 ergs/gm(C) the specimens had clean breaks and were much stiffer. These specimens had some color change at the two high doses, going from the gray to a yellow cast. These observations and test data established an elongation dose threshold in air of 1×10^9 ergs/gm(C).

Vacuum-radiation specimens followed the same general pattern of behavior as the air specimens described above. Silicones are not sensitive to air or ozone and, as expected, the vacuum environment did not materially affect the radiation resistance.

The cryotemperature-radiation results followed the same general behavior as Silastic 950. In LN_2 the tensile strength decreased at each dose level, with considerable variation in the specimens. The LH_2 test did not give sufficient data to consider the radiation effects. Temperature was a major environmental factor in the behavior of Silastic. Stress-strain curves for the trends in LN_2 are presented in Figure 9.17.

9.16 Sylgard 182 (DC 93-022)

9.16.1 Material Background Information

This material is a clear, pourable, low-temperature-curing, electronic potting and encapsulating resin. It is used to provide extreme-environment protection to electronic packages. For example, when a need arose recently to protect an electrical harness and plug assembly from moisture during vacuum irradiations, the Sylgard 182 was used with excellent results (the Sylgard was in the radiation field but outside the vacuum chamber). It was irradiated in ambient air in this application. Good response was also noted in radiation screening tests.

9.16.2 Test Methods and Results

This material was subjected to the radiation exposures listed in Table 9.1. Load-deflection tests in accordance with ASTM D-575-46 were performed on compression buttons before and after the exposures in air and vacuum. Dielectric specimens were tested in the Dielectric Tester in air and the triple radiation-vacuum-cryotemperature environment. The environmental conditions and compression test results are presented in Table 9.24. The test specimens for both compression buttons and dielectric tests were cut from sheets of the Sylgard that had been poured and cured by the manufacturer according to test specifications.

The dielectric property values for Sylgard are presented in Table 9.8. The initial true dielectric constant, k_n, measured at room temperature and pressure was 2.9. Significant decreases in k_n were observed after irradiation and testing in a vacuum-cryotemperature environment. However, when measurements were made during irradiation, very significant increases in dissipation factor were observed. Significant decreases in volume resistivity were observed during and after irradiation and testing in air but not during or after the vacuum-cryotemperature-irradiation tests.

In the static air irradiations the strength at 25% compression increased as the radiation level increased. Starting with controls at 143 psi, the values increased to 841 psi at the high level of radiation. The flexible, transparent, encapsulating material remained clear at low doses; however, it yellowed and stiffened with increasing radiation exposure. With sufficient radiation it eventually becomes a hard, glassy solid, but this state was not reached in these tests. Data from air irradiations indicated a threshold dose of between 1×10^9 and 5×10^9 ergs/gm(C).

After the vacuum irradiation, the Instron compression test in air showed that the specimens followed the general behavior of silicones. Vacuum does not materially improve the radiation resistance of the Sylgard: after irradiation in vacuum to 8.7×10^9 ergs/gm(C) the average compression strength measured 904 psi, a small increase over the value of 841 psi measured after irradiation in air to 9.7×10^9 ergs/gm(C).

9.17 Tedlar

Test specimens of Tedlar film were cut from the same roll of tape as used in previous tests. This material was subjected to only two radiation exposures in air, and subsequent testing was accomplished in the Instron in accordance with ASTM D-882-61T. The 2-mil test specimens were thin-film specimens that were 0.002 in. thick, 1.0 in. wide, and 6.0 in. long. The results of the postirradiation testing are presented in Table 9.25.

It was predicted that the high doses would severely damage the material. The test results confirm this and show that the dose range in which damage occurs has been bracketed.

9.18 Teflon FEP

This material was subjected to the radiation exposures shown in Table 9.1 for the three thicknesses listed. The 2-mil and 10-mil films that were 1.0 in. wide and 6.0 in. long were tested on the Instron in accordance with ASTM D-882-61T. The 40-mil sheet was Die-cut into "A" specimens and tested on the Instron in accordance with ASTM D-412-62T. The summary tables containing environmental results are presented in Tables 9.26 through 9.28.

A comparison is given in Figure 9.18 of the ultimate elongation values for Teflon FEP and Teflon TFE (Section 9.19) for static-vacuum and static-air irradiation tests. This figure shows that the thickness of the material affects the ultimate values in air and vacuum by a factor of 2. In vacuum, 10-mil-thick Teflon FEP film retains the elongation property for a factor-of-10-higher radiation exposure than does Teflon TFE. In air, the Teflon FEP is a factor of 16 more resistant than Teflon TFE. It can be seen from the data that Teflon FEP retains the elongation property to a factor-of-2-higher dose in vacuum than in air.

9.19 Teflon TFE-7

Several thicknesses of Teflon TFE were irradiated in vacuum and air and tested in air to obtain more information on the relationship between thickness and damage. As pointed out in Reference 3, the material showed a trend in the damage-thickness relationship. The various nominal radiation exposures are listed in Table 9.1.

Tensile properties were measured for six different thicknesses, and the dielectric properties were measured for one thickness. The 2.5-mil, 5-mil, 10-mil, and 20-mil specimens were straight-film specimens 1.0 in. wide and 6.0 in. long. They were tested on the Instron in accordance with ASTM D-882-61T. One set of the 10-mil specimens was also subjected to radiation in vacuum and tested in the Low-Force Tester in vacuum. They were also tested in accordance with ASTM D-882-61T, with the exception that the testing speed was 0.50 in./min instead of 20.0 in./min as specified in the standard. The 40-mil test specimens were Die "A" specimens fabricated and tested in accordance with ASTM D-412-62T. The summary tabulations containing the environmental conditions are presented in Tables 9.29 through 9.34.

The 125-mil-thick specimens that were tested in LH_2 were fabricated in accordance with ASTM D-638-61T, modified as shown in Figure 4.2. This thickness of material was also tested in the Dielectric Tester at vacuum-cryotemperature conditions, but was not the same stock as the tensile specimens.

The dielectric property values for Teflon TFE are presented in Table 9.9. The initial true dielectric constant measured at room temperature and pressure was 2.0. A somewhat unusual response for k_n was observed for this material. Irradiation and postirradiation tests in air indicated an initial decrease and then an increase. A very significant increase in k_n was observed when measurements were made during irradiation in a vacuum-cryotemperature environment. Postirradiation tests in a vacuum-cryotemperature environment indicated an initial increase and then a decrease. Teflon TFE showed no significant changes in k_n when tested under a normal temperature and pressure environment after irradiation in a vacuum-cryotemperature environment.

Significant increases in dissipation factor were observed in postirradiation measurements and measurements made during irradiation in a vacuum-cryotemperature environment. Significant decreases in volume resistivity were observed from measurements made during and after irradiation in a vacuum-cryotemperature environment.

Inspection of the Teflon TFE specimens irradiated in LH_2 showed no color change and all specimens had good "A" breaks. The specimens showed a brittle-type break, which accounts for some variation in data values. The average curves in Figure 9.19 that are drawn as solid lines show that the data are consistent and the values are considered to be reliable. The dashed portion of the curves represent trends in the data and are not numerical averages. This was used in cases where the ultimate values varied widely, and they are considered to be an area where additional testing of a larger number of specimens will produce more reliable information.

Figure 9.18 is a summary plot of the elongation values for the film-type specimens irradiated in vacuum and air. Results for both Teflon TFE and Teflon FEP are presented to show the effects of material thickness in the two environmental conditions. These results show that the material thickness is an important parameter in radiation damage evaluations. It influences the results more for the vacuum data than for the air data for Teflon TFE. These curves show that both the thickness and environment affect the ultimate elongation values by a factor of 2 to 3. These results also show that this trend is not predictable.

9.20 General Discussion of Results

In general, the dielectric-constant values showed no significant changes during testing in a vacuum-cryotemperature environment after irradiation. Significant changes were observed from measurements made during irradiation in both vacuum-cryotemperature and air environments. Significant changes were usually observed after irradiation and testing in an air environment. Significant increases in dissipation factor and decreases in volume resistivity were observed both during and after irradiation and testing in vacuum-cryotemperature and air environments. Kynar showed a marked degradation in loss characteristics when tested during and after irradiation in an air environment. However, the degradation was much less when tested during and after irradiation in a vacuum-cryotemperature environment. Similar effects were observed for Lexan.

The tabulated results (Tables 9.2 through 9.9) show that in some cases the dielectric properties changed progressively with increasing radiation dose and then showed a reversal when measured after the final irradiation. It is probable that an annealing effect and recovery occurred during a temperature rise of the specimens caused by gamma heating, since the specimens were exposed to a maximum dose rate for a relatively long period.

A summary discussion that compares the tensile test results of the electrical insulation and dielectric materials as a group is not feasible because the materials cannot be placed in a specific category such as adhesives or laminates. Furthermore, the materials have not been tested under the same environmental conditions. Because of these reasons, a separate discussion of results is presented for each material in Sections 9.1 through 9.19. The comments in this summary section concern materials that have characteristics in common.

The 1- to 2-mil DuPont plastic dielectric films - Mylar, Tedlar, and Kapton (H-Film) - are radiation resistant to 1×10^9 ergs/gm(C) in air (Ref. 3). After 3×10^{10} ergs/gm(C) in air, there is a marked change in the relative resistance of these films to the effects of radiation. Kapton is the most stable, undergoing very little change in tensile strength or percent elongation; Tedlar decreases about 40% in tensile strength; while Mylar is too brittle to test in the Instron. The H-Film (Kapton) is qualified for high doses, while Mylar and Tedlar will perform excellently below 1×10^9 ergs/gm(C).

A well-defined reduction in ultimate tensile strength after static irradiation occurred for Kynar at 1.7×10^{11} ergs/gm(C), for Marlex at 3.3×10^{10} ergs/gm(C), and for Lexan at 9.7×10^9 ergs/gm(C). The corresponding percent elongation was greatly decreased at these radiation levels; however, the percent elongation at rupture did not follow the same trend. Kynar had a percent elongation change at 8.8×10^8 ergs/gm(C) and Lexan underwent such a change at 9.7×10^9 ergs/gm(C). Therefore, in a radiation environment the allowable changes in critical properties in a specific application determine the recommended threshold. It may be concluded from these tests that Kynar, Lexan, and Marlex have a critical air dose of 1×10^9 ergs/gm(C) and that beyond this dose a careful analysis is required. Vacuum irradiations did not show any major change in radiation resistance for these three thermoplastics. When Kynar was irradiated in LN_2 and LH_2, the radiation effects were masked by the cryogenic effects. The rigid nature of these materials in the cryogen and the multiple breaks of the tensile specimens indicate that these materials are really not suitable for extreme low-temperature service unless the application is in a confined, static installation.

Silicone elastomers (Silastic 1410 and 950) after ambient-air irradiations began changing tensile properties at the low dose of 6×10^8 ergs/gm(C). A dose of 5×10^9 ergs/gm(C) was required to produce a marked reduction in percent elongation at rupture and a significant increase in tensile strength at 25% elongation. These results indicate that the silicone elastomers have slightly less radiation stability than the three thermoplastics, based on the relative changes in the tensile properties. But, here again, allowable radiation levels will be determined by the actual application and environmental conditions. The cryotemperature irradiations of the silicones were inconclusive because the cryogenic effects on the silicones overshadowed any radiation effects. However, postirradiation visual inspection after warm-up could detect no hardening, color change, or stiffening of the tensile specimens.

The Lamicoid 6038E should be an excellent dielectric laminate in the nuclear space environmental applications. It was not changed by irradiation in air or vacuum up to the maximum available radiation dose of 1.7 x 10^{11} ergs/gm(C). Although the low temperature of the cryogens changed the initial control values, the nuclear radiation at cryotemperatures seems to have little effect up to 1.2 x 10^{10} ergs/gm(C). The bonding properties of the laminate were altered, but it should be serviceable as a dielectric laminate when tensile strength and flexibility are not critical.

The data show that the Duroid 5600 was not significantly affected by the space-simulation tests imposed in this program. This plastic had good radiation stability at cryotemperatures, both when submerged and when cooled to -250°F in vacuum. Tensile strength at the cryotemperature is much higher after irradiation than is normal for ambient-air temperature controls. Duroid is recommended for further consideration in nuclear environmental applications. The reinforcement of the tetrafluoroethylene plastic increased the radiation resistance.

Since the variations in Teflon are discussed in detail in Sections 9.18 and 9.19, only a summary of the findings will be presented here. The Teflon thickness is an important parameter in radiation-damage evaluations; FEP (fluorinated ethylene propylene) is more radiation resistant than TFE (tetrafluoroethylene) in air; vacuum and temperature are very important in the overall behavior of Teflon; and, furthermore, manufacturing procedures and processes seem to be a major factor in the results obtained in various tests conducted on the TFE and the FEP.

Table 9.2

Dielectric Property Values for Estane 5740X1

Gamma Dose [ergs/gm(C)]	Pressure (torr)	Temperature (^oF)	K_n*	Dissipation Factor	Volume Resistivity (ohm-cm)
Vacuum-Cryotemperature Control Tests					
0	760	+ 75	1.0000	.0090	1(12)
0	2(-6)	-170	.5317	.0060	1(17)
0	2(-6)	-290	.4802	.0052	>5(17)
0	3(-6)	-310	.4698	.0031	>5(17)
Air-Irradiation Tests					
0	760	82	1.00	***	****
1.6(7)	760	97	1.00	***	****
4.0(8)	760	200	1.08	***	****
1.7(9)	760	136	1.15	***	****
1.1(10)	760	167	1.22	***	****
Vacuum-Cryotemperature-Irradiation Tests					
0	760	+ 75	1.0000	.0098	5(12)
0	1(-6)	-318	.4703	.0024	>5(17)
7.1(6)	6(-7)	-318	.4780	.0050	6(15)
6.7(7)	6(-7)	-319	.5137	.023	5(15)
7.0(8)	5(-7)	-272	.4751	.020	7(15)
2.5(9)	3(-7)	-254	.5321**	.030**	7(13)**
9.5(9)	1(-7)	-319	.4762	.0022	<5(17)
9.5(9)	760	+ 75	.9513	.0092	2(12)

*K_n is the normalized dielectric constant (see text).
**Values obtained during irradiation at maximum dose rate.
***Not reported
****Not measured

Table 9.3

Dielectric Property Values for Epon 828/Z

Gamma Dose [ergs/gm(C)]	Pressure (torr)	Temperature (°F)	K_n*	Dissipation Factor	Volume Resistivity (ohm-cm)
Vacuum-Cryotemperature Control Tests					
0	760	+ 75	1.0000	.0091	4(14)
0	2(-6)	-167	.8822	.0050	>5(17)
0	3(-6)	-320	.8063	.0020	>5(17)
Air-Irradiation Tests					
0	760	78	1.00	***	****
9.5(7)	760	91	.97	***	****
7.0(8)	760	165	.98	***	****
6.4(9)	760	119	1.10	***	****
1.8(10)	760	130	1.20	***	****
Vacuum-Cryotemperature-Irradiation Tests					
0	760	+ 75	1.0000	.0066	5(14)
0	5(-7)	-314	.8177	.0021	7(16)
7.1(6)	6(-7)	-310	.8421	.010	6(15)
6.7(7)	6(-7)	-318	.8834	.017	5(15)
7.0(8)	4(-7)	-290	.9181	.013	5(15)
8.7(9)	3(-7)	-298	.9232**	.025**	3(14)**
9.5(9)	1(-7)	-318	.8480	.0027	5(16)
9.5(9)	760	+ 75	1.0409	.0089	1(13)

*K_n is the normalized dielectric constant (see text).
**Values obtained during irradiation at maximum dose rate.
***Not reported
****Not measured

Table 9.4

Dielectric Property Values for Kynar 400

Gamma Dose [ergs/gm(C)]	Pressure (torr)	Temperature (^oF)	K_n*	Dissipation Factor	Volume Resistivity (ohm-cm)
Vacuum-Cryotemperature Control Tests					
0	760	+ 76	1.0000	.0041	6(14)
0	3(-6)	-128	.8253	.0265	8(15)
0	2(-6)	-219	.6195	.0056	1(16)
0	2(-6)	-312	.5885	.0018	1(16)
Air-Irradiation Tests					
0	760	55	1.0000	.0038	8(14)
2.3(7)	760	61	1.0070	.0049	5(14)
2.1(8)	760	77	1.0115	.0049	4(13)
2.1(9)	760	101	1.041	.0096	2(12)
1.4(10)	760	69	***	***	***
2.1(10)	760	65	.9994	.0056	< 1(10)
Vacuum-Cryotemperature-Irradiation Tests					
0	760	+ 76	1.0000	.0042	4(15)
0	2(-6)	-314	.5756	.0014	>6(15)
4.9(6)	1(-6)	-275	.5764	.0022	>3(15)
4.7(7)	1(-6)	-296	.5819	.0048	>3(15)
4.9(8)	1(-6)	-309	.5877	.0061	>3(15)
1.7(9)	2(-6)	-250	.6154**	.0251**	1(14)
6.6(9)	2(-6)	-315	.5845	.0075	>6(15)
6.6(9)	760	56	.9880	.0100	5(13)

*K_n is the normalized dielectric constant (see text).
**Values obtained during irradiation at maximum dose rate.
***Values could not be obtained during irradiation because of the low resistance of the samples.

Table 9.5

Dielectric Property Values for Lamicoid 6038E

Gamma Dose [ergs/gm(C)]	Pressure (torr)	Temperature (^oF)	K_n*	Dissipation Factor	Volume Resistivity (ohm-cm)
Vacuum-Cryotemperature Control Tests					
0	760	+ 75	1.0000	.0020	1(14)
0	3(-6)	- 85	.9710	.0043	5(15)
0	3(-6)	-195	.9093	.0052	6(15)
0	2(-6)	-302	.8561	.0014	>6(15)
Air-Irradiation Tests					
0	760	55	1.0000	.0026	6(14)
2.3(7)	760	60	1.005	.0032	5(14)
2.1(8)	760	78	1.007	.0021	2(14)
2.1(9)	760	152	1.025	.0028	2(14)
1.4(10)	760	126	1.028**	.0048**	4(10)**
2.1(10)	760	63	.9992	.0032	2(12)
Vacuum-Cryotemperature-Irradiation Tests					
0	760	+ 75	1.0000	.0019	7(14)
0	2(-6)	-305	.8632	.0013	3(15)
4.9(6)	1(-6)	-272	.8641	.0013	4(15)
4.7(7)	1(-6)	-273	.8783	.0037	3(15)
4.9(8)	1(-6)	-291	.8838	.0071	1(15)
1.7(9)	1(-5)	-268	.9070**	.0161**	1(15)**
6.6(9)	2(-6)	-316	.8661	.0018	>5(15)
6.6(9)	760	+ 57	.9900	.0017	1(15)

*K_n is the normalized dielectric constant (see text).
**Values obtained during irradiation at maximum dose rate.

Table 9.6

Dielectric Property Values for Lexan

Gamma Dose [ergs/gm(C)]	Pressure (torr)	Temperature (^{o}F)	K_n*	Dissipation Factor	Volume Resistivity (ohm-cm)
Vacuum-Cryotemperature Control Tests					
0	760	+ 75	1.0000	.0016	8(14)
0	3(-6)	- 56	.9991	.0010	5(16)
0	2(-6)	-174	.9915	.0024	6(16)
0	2(-6)	-317	.9762	.0003	>5(17)
Air-Irradiation Tests					
0	760	55	1.0000	.0015	2(15)
2.3(7)	760	60	1.0025	.0035	9(14)
2.1(8)	760	76	.9977	.0016	2(14)
2.1(9)	760	130	.9952	.0014	4(13)
1.4(10)	760	125	1.024**	.093**	6(10)**
2.1(10)	760	63	.9970	.0019	3(12)
Vacuum-Cryotemperature-Irradiation Tests					
0	760	+ 75	1.0000	.0012	6(15)
0	1(-6)	-318	.9577	<.0002	1(17)
4.9(6)	1(-6)	-271	.9560	.0014	1(16)
4.7(7)	1(-6)	-289	.9619	.0022	6(15)
4.9(8)	1(-6)	-311	.9662	.0037	8(15)
1.7(9)	7(-6)	-303	.9739**	.0164**	2(15)**
6.6(9)	2(-6)	-320	.9612	.0019	>5(17)
6.6(9)	760	+ 56	.9802	.0014	7(14)

*K_n is the normalized dielectric constant (see text).
**Values obtained during irradiation at maximum dose rate.

Table 9.7

Dielectric Property Values for RTV-501

Gamma Dose [ergs/gm(C)]	Pressure (torr)	Temperature (°F)	K_n*	Dissipation Factor	Volume Resistivity (ohm-cm)
Vacuum-Cryotemperature Control Tests					
0	760	+ 75	1.0000	.0059	1(14)
0	1(-5)	-150	.9568	.0022	>5(17)
0	3(-6)	-317	.9386	.0008	>5(17)
Air-Irradiation Tests					
0	760	82	1.00	***	****
1.6(7)	760	90	1.00	***	****
4.0(8)	760	157	1.11	***	****
1.5(9)	760	147	1.18	***	****
1.7(10)	760	157	1.22	***	****
Vacuum-Cryotemperature-Irradiation Tests					
0	760	+ 75	1.000	.0024	1(14)
0	5(-7)	-295	.8942	.0019	>5(17)
7.1(6)	6(-7)	-318	.9004	.0047	3(15)
6.7(7)	6(-7)	-310	.9261	.014	2(15)
7.0(8)	4(-7)	-273	.9721	.016	1(15)
5.5(9)	3(-7)	-266	.9804**	.029**	6(12)**
9.5(9)	3(-7)	-320	.8684	.0028	1(16)
9.5(9)	760	+ 75	.9852	.0038	2(14)

*K_n is the normalized dielectric constant (see text).
**Values obtained during irradiation at maximum dose rate.
***Not reported
****Not measured

Table 9.8

Dielectric Property Values for Sylgard 182 (DC 93-022)

Gamma Dose [ergs/gm(C)]	Pressure (torr)	Temperature (°F)	K_n*	Dissipation Factor	Volume Resistivity (ohm-cm)
Vacuum-Cryotemperature Control Tests					
0	760	+ 76	1.0000	.0015	2(14)
0	3(-6)	- 55	1.0653	.0012	>3(15)
0	2(-6)	-180	1.0948	.0045	>3(15)
0	2(-6)	-310	1.0363	.0003	>3(15)
Air-Irradiation Tests					
0	760	57	1.0000	.0011	2(14)
2.3(7)	760	61	1.0030	.0035	2(14)
2.1(8)	760	67	.9938	.0012	1(14)
2.1(9)	760	61	.9863	.0017	3(13)
1.4(10)	760	98	1.0034**	.11**	7(10)**
2.1(10)	760	68	1.0115	.0015	4(12)
Vacuum-Cryotemperature-Irradiation Tests					
0	760	+ 75	1.0000	.0018	7(14)
0	2(-6)	-313	1.0286	.0027	>8(15)
4.9(6)	1(-6)	-285	1.0165	.0030	8(15)
4.7(7)	1(-6)	-298	.9905	.0084	9(15)
4.9(8)	1(-6)	-309	.9483	.0090	7(15)
1.7(9)	2(-6)	-285	1.0481**	.0575**	2(15)**
6.6(9)	2(-6)	-317	.9727	.0017	2(15)
6.6(9)	760	+ 56	.9984	.0017	1(15)

*K_n is the normalized dielectric constant (see text).
**Values obtained during irradiation at maximum dose rate.

Table 9.9

Dielectric Property Values for Teflon TFE-7

Gamma Dose [ergs/gm(C)]	Pressure (torr)	Temperature (^oF)	K_n*	Dissipation Factor	Volume Resistivity (ohm-cm)
Vacuum-Cryotemperature Control Tests					
0	760	+ 75	1.000	<.0002	>5(17)
0	9(-6)	-154	1.001	<.0002	>5(17)
0	4(-6)	-180	1.006	<.0002	>5(17)
0	2(-6)	-260	1.008	<.0002	>5(17)
0	4(-6)	-305	1.016	<.0002	>5(17)
Air-Irradiation Tests					
0	760	80	1.00	***	****
9.5(7)	760	100	0.76	***	****
7.0(8)	760	165	0.70	***	****
6.4(9)	760	118	1.01	***	****
1.2(10)	760	125	1.06	***	****
Vacuum-Cryotemperature-Irradiation Tests					
0	760	+ 75	1.000	<.0002	>5(17)
0	5(-7)	-299	1.015	<.0002	>5(17)
7.1(6)	6(-7)	-296	1.067	.023	4(15)
6.7(7)	6(-7)	-294	1.147	.036	5(15)
7.0(8)	4(-7)	-230	1.092	.035	5(15)
2.5(9)	5(-7)	-255	1.235**	.043**	1(14)**
9.5(9)	3(-7)	-301	1.019	.0026	>5(17)
9.5(9)	760	+ 75	0.9977	.0045	2(14)

*K_n is the normalized dielectric constant (see text).
**Values obtained during irradiation at maximum dose rate.
***Not reported
****Not measured

Table 9.10

Duroid 5600 Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48 ev	Neutrons (n/cm^2) E>2.9 Mev	Neutrons (n/cm^2) E>8.1 Mev		Tensile Strength (psi)	Elongation (%)		
21-111	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	9074	1.10	-423	760
21-112									10,491	1.27		
21-113									8709	1.14		
21-114									8466	1.09		
									9185/983	1.14/.08		
21-121	LH_2	LH_2	CTT at 0.05 in./min	4.4(9)	-	7.9(14)	-	-	9194	1.24	-423	760
21-122									9105	.99		
21-123									8476	1.11		
21-124									8546	1.04		
									8830/349	1.09/.12		
21-126	LH_2	LH_2	CTT at 0.05 in./min	8.6(9)	-	1.5(15)	-	-	6848	.73	-423	760
21-127									7294	.92		
21-128									6982	1.00		
21-129									7818	1.22		
									7235/471	.91/.24		
21-136	-	Vac-LN_2	CMT at 0.05 in./min	0	0	0	0	-	5758	1.34	-250	.2-.02
21-137									7662	1.45		
21-138									6438	1.41		
21-139									6922	1.41		
21-140									11,309	-		
									7618/2386	1.56/.05		
21-141	Vac-LN_2	Vac-LN_2	CMT at 0.05 in./min	1.1(10)	5.9(13)	1.5(15)	-	-	6747	-	-290	.13-.07
21-142									7037	-		
21-143									8517	1.68		
21-144									6183	1.28		
21-145									9163	1.57		
									7529/1281	1.51/.20		

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.11

H-Film (2 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48ev	Neutrons (n/cm^2): E>2.9Mev	Neutrons (n/cm^2): E>8.1Mev	Time Until Test (days)	Tensile Strength (psi)[a] @ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture	Elongation at Rupture[a] (%)	Avg. Temp (F)	Avg. Press. (torr)
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	17,800	19,100	22,000	23,500	130	75	760
									18,300	19,200	-	20,000	65		
									17,700	17,000	21,800	22,600	112		
									18,000	17,100	22,000	24,500	142		
									18,250	19,500	22,500	25,800	152		
									18,500	19,600	22,800	23,700	114		
									17,300	18,400	-	20,000	81		
									18,200	19,500	-	22,200	96		
									18,300	19,500	-	21,800	92		
									18,039/404	18,767/875	22,220/430	22,678/1,953	109/29		
	Air	Air	Instron at 20.0 in./min	3.3(10)	-	5.4(15)	-	21	18,200	19,200	-	21,800	95	170	760
									18,500	20,000	-	22,000	90		
									18,700	20,000	-	21,500	78		
									18,700	-	-	19,000	33		
									18,300	19,500	-	20,700	70		
									19,000	20,200	-	22,000	81		
									18,500	-	-	19,500	41		
									19,100	-	-	19,600	33		
									18,600	19,700	-	22,500	98		
									19,500	-	-	20,400	42		
									18,710/422	19,767/395	-	20,900/1,137	66/21		
	Air	Air	Instron at 20.0 in./min	1.7(11)	-	2.5(16)	-	21	17,500	-	-	17,800	32	200	760
									18,000	-	-	18,400	31		
									18,500	-	-	19,100	33		
									-	-	-	17,600	22		
									-	-	-	18,500	23		
									18,300	-	-	18,700	30		
									17,700	-	-	19,200	28		
									-	-	-	18,990	22		
									18,000/430	-	-	18,536/561	28/4		

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.12

Kel-F-81 Electrical Insulation (Flexure)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Outer Fiber Stress at 3% Strain[a] (psi)	Outer Fiber Stress at 5% Strain[a] (psi)	Tangent Modulus of Elasticity (psi)	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48ev	E>2.9Mev	E>8.1Mev						
		Vac	Low Force Tester at 0.05 in./min	0	0	0	0	-	4,500 4,400 4,450/89	6,840 6,180 6,510/585	169,425	75	1.0(-3)
	Vacuum	Vac	Low Force Tester at 0.05 in./min	2.1(9)	4.5(13)	3.9(14)	1.4(14)	-	5,970	7,800	180,050	100	1.4(-6)

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.13

Kyna. 400 Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate[a]		At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm²) E<0.48ev	E>2.9Mev	E>8.1Mev		Tensile Strength (psi)	Elongation (%)	Tensile Strength (psi)	Elongation (%)		
96-11	-	Air	Instron at 2.0 in./min	0	0	0	0	-	-	-	-	-	75	760
92-12									7419	10	4738	110		
96-13									7169	10	4562	35		
96-14									7310	11	4579	160		
96-15									7375	10	4479	57		
									7318/121	10.6/0.9	4619/111	91/61		
96-31	Air	Air	Instron at 2.0 in./min	5.8(8)	6.1(12)	1.4(14)	4.6(12)	2	7570	10	4661	60	75	760
9/,-32									7426	10	4594	110		
96-33									7555	10	4573	25		
96-34									7458	10	4583	90		
96-35									7560	10	4637	100		
									7514/62	10/0	4610/38	77/37		
96-36	Air	Air	Instron at 2.0 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	7617	10	6979	40	75	760
96-37									-	-	-	-		
96-38									7668	10	7016	20		
96-39									7586	10	6761	30		
96-40									7588	10	6725	40		
									7615/40	10/0	6870/141	32.5/9.7		
96-41	Air	Air	Instron at 2.0 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	3	7751	8	7594	9	100	760
96-42									7725	11	7449	15		
96-43									7819	11	7703	12		
96-44									7816	10	7665	11		
96-45									7826	9	7747	10		
									7787/43	9.8/1.3	7632/128	11.4/2.6		
96-46	Air	Air	Instron at 2.0 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	3	7698	14	7698	14	140	760
96-47									7665	8	7665	8		
95-48									7456	5	7456	5		
96-49									7684	7	7684	7		
96-50									6454	1	6454	1		
									7391/535	7.0/5.6	7391/535	..0/5.6		

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.13 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate		At Rupture		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm²)				Tensile Strength (psi)	Elonga-tion (%)	Tensile Strength (psi)	Elonga-tion (%)		
					E<0.48ev	E>2.9Mev	E>8.1Mev							
96-46A	Air	Air	Instron at 2.0 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	3	[illegible]	13	7757	13	140	760
96-47A									7813	11	7813	11		
96-48A									8024	9	8024	9		
96-49A									7869	10	7869	10		
96-50A									7943	11	7943	11		
									7881/115	10.8/1.7	7881/115	10.8/1.7		
96-1	Air	Air	Instron at 2.0 in./min	3.3(10)	-	5.4(15)	-	17	7564	10	7564	10	170	760
96-2									7275	12	7275	12		
96-3									7410	11	7269	13		
96-4									7631	9	7570	10		
96-5									7525	8	7525	8		
									7481/153	10.0/1.7	7441/129	10.6/2.1		
96-6	Air	Air	Instron at 2.0 in./min	1.7(11)	-	2.5(16)	-	17	5480	5	5480	5	200	760
96-7									3122	3	3122	3		
96-8									4859	4	4890	4		
96-9									5521	4	5521	4		
96-10									6076	5	6076	5		
									5018/1270	4.2/0.9	5018/1270	4.2/0.9		
96-61	Vac	Air	Instron at 2.0 in./min	5.0(8)	9.0(12)	7.5(13)	2.9(13)	51	7075	3	4346	5	120	4.6(-6)
96-62									3298	18	4497	40		
96-63									7276	18	4533	45		
96-64									7416	21	4398	75		
96-65									7298	18	4517	38		
									7273/147	16/8	4458/80	41/30		
96-66	Vac	Air	Instron at 2.0 in./min	7.6(8)	1.7(13)	1.7(14)	6.2(13)	51	6739	15	4545	30	120	4.6(-6)
96-67									7407	14	5021	25		
96-68									7470	14	4980	25		
96-69									7386	14	5705	25		
96-70									7298	17	4536	38		
									7260/314	15/1	4957/503	29/6		

Table 9.13 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate		At Rupture		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elonga-tion (%)	Tensile Strength (psi)	Elonga-tion (%)		
					E<0.48ev	E>2.9Mev	E>8.1Mev							
96-76 96-77 96-78 96-79 96-80	Vac	Air	Instron at 2.0 in./min	8.5(9)	1.0(14)	1.7(15)	-	7	8267 8316 8206 8463 8400 8330/110	14 13 12 14 12 13/1	7968 7547 8082 8443 8103 8029/385	20 26 15 15 20 19.2/4.7	140	2.0(-6)
96-81 96-82 96-83 96-84	-	Vac	High Force Tester at 0.05 in./min	0	0	0	0	-	7391 6340 6944 6227 6726/565	9.23 8.80 9.33 8.90 9.07/0.26	4763 753 3671 2755 2986/1948	70.8 27.7 26.6 39.2 41.1/21.5	75	1.0(-3)
96-86 96-87 96-88 96-89	Vac	Vac	High Force Tester at 0.05 in./min	9.2(9)	1.1(14)	1.5(15)	-	-	- - - -	- - - -	4008 - 4162 4131 4100/91	6.75 - 6.16 5.96 6.22/0.47	140	2.0(-6)
96-91 96-92 96-[illegible] 96-94	-	LN_2	CTT at 0.05 in./min	0	0	0	0	-	- - - -	- - - -	22,938 19,167 21,396 19,049 20,639/1889	1.95 1.52 1.74 1.78 1.75/0.21	-320	760
96-96 96-97 96-98 96-99	LN_2	LN_2	CTT at 0.05 in./min	3.9(9)	-	6.9(14)	-	-	- - - -	- - - -	15,837 9,160 13,666 20,923 14,897/5713	1.38 0.90 1.30 2.18 1.44/0.62	-320	760

Table 9.13 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate		At Rupture		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)	Tensile Strength (psi)	Elongation (%)		
					E<0.48ev	E 2.9Mev	E>8.1Mev							
96-101 96-102 96-103 96-104	LN_2	LN_2	CTT at 0.05 in./min	7.8(9)	-	1.4(15)	-	0	- - - -	- - - -	16,726 14,956 11,633 8,763 13,020/ 3867	1.65 1.65 1.25 1.08 1.41/ 0.28	-320	760
96-111 96-112 96-113 96-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	- - - -	- - - -	17,594 22,864 21,169 19,175 20,201/ 2559	1.77 2.46 2.33 1.98 2.14/ 0.34	-423	760
96-121 96-122 96-123 96-124	LH_2	LH_2	CTT at 0.05 in./min	4.0(9)	-	7.1(14)	-	0	- - - -	- - - -	14,744 19,482 16,135 14,791 16,288/ 2278	1.65 2.06 1.88 1.63 1.81/ 0.21	-423	760
96-126 96-127 96-128 96-129	LH_2	LH_2	CTT at 0.05 in./min	7.9(9)	-	1.4(15)	-	0	- - - -	- - - -	14,012 15,570 13,180 10,714 13,351/ 2358	1.46 1.53 1.53 1.19 1.43/ 0.17	-423	760

Table 9.14

Results of a Visual Inspection of Kynar Specimens

Test Conditions (Irrad-Test)	Gamma Dose [ergs/gm(C)]	Tensile Break Type	Specimen Color	Specimen Condition At Break
Air-Air	0	A	Cream	Flexible, significant necking
Air-Air	5.8(8)	A	Light yellow	Flexible, slight necking
Air-Air	8.8(8)	A	Light tan	Flexible, slight pinch
Air-Air	5.2(9)	A	Light brown	Flexible, clean breaks
Air-Air	9.7(9)	A	Dark brown	Stiff, brittle breaks
Air-Air	3.3(10)	A	Very dark brown	Rigid, very brittle
Air-Air	1.7(11)	A	Extremely dark brown	Extremely brittle
Vac-Air	5.0(8)	A	Light yellow	Flexible, significant necking
Vac-Air	7.6(8)	A	Yellow	Flexible, slight necking
Vac-Air	8.5(9)	A	Dark brown	Stiff, brittle breaks
Vac-Vac	0	A	Cream	Necked, then broke
Vac-Vac	9.2(9)	D	Dark brown	Doublers pulled off
LN_2- LN_2	0	C	Cream	Clean break
LN_2- LN_2	3.9(9)	C	Brown	Clean break
LN_2- LN_2	7.8(9)	C	Brown	Clean break
LH_2- LH_2	0	C	Cream	Clean break
LH_2- LH_2	4.0(9)	B/C/D	Brown	Clean break
LH_2- LH_2	7.9(9)	A/C/C	Brown	Clean break

Table 9.15

Lamicoid 6038E Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
40-11 40-12 40-13 40-14	-	Air	Instron at 0.05 in./min	0	0	0	0	-	54,290 59,610 57,300 59,770 57,743/2760	2.24 2.32 2.22 1.95 2.18/0.18	75	760
40-6 40-7 40-8 40-9 40-10	Air	Air	Instron at 0.05 in./min	1.7(11)	-	2.5(16)	-	17	54,330 53,540 54,440 54,310 55,340 54,392/774	2.21 2.00 1.97 2.15 2.14 2.09/0.10	200	760
40-76 40-77 40-78 40-79 40-80	Vac	Air	Instron at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	8	50,451 45,249 53,141 49,178 53,827 50,269/3689	1.75 1.56 1.70 1.54 1.60 1.63/0.09	140	2.0(-6)
40-81 40-82 40-83 40-84	-	Vac	High-Force Tester at 0.05 in./min	0	0	0	0	-	51,440 55,732 55,945 54,548 54,416/2188	3.58 4.29 3.80 3.84 3.88/0.34	75	1.0(-3)
40-86 40-87 40-88 40-89	Vac	Vac	High-Force Tester at 0.05 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	-	61,018 63,010 56,469 59,062 59,890/3177	4.42 4.66 4.00 4.42 4.38/0.32	140	2.0(-6)

[a] Values given as: average value/standard deviation on an individual basis.
[b] Value not included in average or standard deviation.

Table 9.15 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
40-111 40-112 40-113 40-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	117,725 91,527[b] 109,098 - 113,412/7,648	8.54 3.77[b] 8.45 - [illegible]/0.08	-423	760
40-126 40-127 40-128 40-129	LH_2	LH_2	CTT at 0.05 in./min	6.2(9)	-	1.1(15)	-	-	124,909 - 102,833 125,807 117,850/13,569	8.19 - 5.26 9.13 7.53/2.29	-423	760
40-131 40-132 40-133 40-134	LH_2	LH_2	CTT at 0.05 in./min	2.3(10)	-	4.1(15)	-	-	106,538 115,892 102,789 114,179 109,850/6363	6.02 9.22 6.04 8.38 7.42/1.55	-423	760
40-136 40-137 40-138 40-139 40-140	-	Vac-LN_2	CMT at 0.05 in./min	0	0	0	0	-	115,953 126,336 119,974 139,504 133,926 127,138/8396	6.49 7.20 6.66 7.93 7.47 7.15/.76	-250	.2-.02
40-141 40-142 40-143 40-144 40-145	Vac-LN_2	Vac-LN_2	CMT at 0.05 in./min	1.2(10)	8.4(13)	9.4(14)	-	-	122,397 92,299 118,689 104,106 107,408 108,980/12,939	7.51 7.60 7.06 6.06 8.57 7.36/1.08	-290	.13-.07

Table 9.16

Lexan - Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate[a]		At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48ev	E>2.9Mev	E>8.1Mev		Tensile Strength (psi)	Elonga-tion (%)	Tensile Strength (psi)	Elonga-tion (%)		
97-11	-	**Air**	**Instron at 2.0 in./min**	**0**	**0**	**0**	**0**	-					75	760
97-12									9704	5	9130	105		
97-13									9726	5	7436	50		
97-14									9743	5	7411	50		
97-15									9800	5	9460	100		
									9743/47	5/0	8359/995	76/27		
97-31	**Air**	**Air**	**Instron at 2.0 in./min**	**5.7(8)**	**6.1(12)**	**1.4(14)**	**4.6(12)**	2	9462	5	8982	45	75	760
97-32									9432	5	8414	43		
97-33									9386	5	8316	42		
97-34									9412	5	8550	44		
97-35									9454	5	7618	39		
									9430/33	5/0	8376/586	43/3		
97-36	**Air**	**Air**	**Instron at 2.0 in./min**	**8.8(8)**	**4.1(12)**	**1.7(14)**	**5.7(12)**	2	9211	5	7790	90	75	760
97-37									9260	5	7420	75		
97-38									9150	5	7075	92		
97-39									9180	5	7129	95		
97-40									9180	5	7246	88		
									9196/47	5/0	7332/307	88/9		
97-46	**Air**	**Air**	**Instron at 2.0 in./min**	**9.7(9)**	**3.5(13)**	**2.0(15)**	**6.3(13)**	7	3513	2.0	3513	2.0	**140**	760
97-47									3131	2.0	3131	2.0		
97-48									3789	2.5	3789	2.5		
97-49									3458	1.0	3458	1.0		
97-50									3800	1.0	3800	1.0		
									3538/288	1.7/0.6	3538/288	1.7/0.6		

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.16 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate		At Rupture		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48ev	E>2.9Mev	E>8.1Mev		Tensile Strength (psi)	Elonga-tion (%)	Tensile Strength (psi)	Elonga-tion (%)		
97-1 97-2 97-3 97-4 97-5	Air	Air	Instron at 2.0 in./min	3.3(10)	-	5.4(15)	-	17	5 Specimens - Too Brittle to Test				170	760
97-6 97-7 97-8 97-9 97-10	Air	Air	Instron at 2.0 in./min	1.7(11)	-	2.5(16)	-	17	5 Specimens - Too Brittle to Test				200	760
97-61 97-62 97-63 97-64 97-65	Vac	Air	Instron at 2.0 in./min	5.1(8)	1.1(13)	8.5(13)	3.3(13)	51	9473 9336 9460 9431 9256 9391/93	13 15 13 12 12 13/3.3	7809 7520 8000 8118 7965 7882/257	100 100 100 100 100 100/0	120	4.6(-6)
97-66 97-67 97-68 97-69 97-70	Vac	Air	Instron at 2.0 in./min	7.8(8)	1.9(13)	1.2(14)	4.7(13)	51	9267 9336 9209 9216 9157 9237/77	11 15 12 12 10 12/5	8416 7539 8103 8020 8588 8133/451	100 100 100 100 100 100/0	120	4.6(-6)
97-76 97-77 97-78 97-79 97-80	Vac	Air	Instron at 2.0 in./min	8.5(9)	1.0(14)	1.7(15)	-	7	7287 5353 6245 7866 6416 6633/1080	8.5 7.1 7.5 9.5 7.5 8.0/1.0	7287 5353 6245 7866 6416 6633/1080	8.5 7.1 7.5 9.5 7.5 8.0/1.0	140	2.0(-6)

Table 9.17

Lexan Electrical Insulation (Flexure)
Summary Table of Test Results

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester[b]	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48ev	Neutrons (n/cm^2): E>2.9Mev	Neutrons (n/cm^2): E>8.1Mev	Time Until Test (days)	Outer Fiber Stress at 3% Strain (psi)	Outer Fiber Stress at 5% Strain[a] (psi)	Tangent Modulus of Elasticity[a] (psi)	Avg. Temp. (F)	Avg. Press. (torr)
		Air	Instron	0	0	0	0	-	10,494 10,356 10,324 10,391/100	14,116 13,841 13,969 13,975/162	379,473 360,980 366,990 369,148/ 10,923	75	760
97-61A 97-62A	Vacuum	Air	Instron	2.4(8)	5.1(12)	4.4(13)	1.6(13)	52	9,783 9,924 9,854/125	13,552 13,184 13,368/326	354,958 349,398 352,178/ 5,124	80	5.0(-7)
97-71A 97-72A	Vacuum	Air	Instron	5.3(9)	1.1(14)	9.7(14)	3.5(14)	8	10,374 10,200 10,287/154	12,766 12,670 12,718/85	351,171 379,925 365,548/ 25,490	100	2.0(-6)
	-	Air	Low Force Tester	0	0	0	0	-	9,900 9,200 9,550/620	13,250 13,700 13,475/399	372,780	75	760
	-	Vac	Low Force Tester	0	0	0	0	-	10,400 9,100 9,750/1152	13,850 13,850 13,850/0	311,706	75	1.0(-3)
	Vacuum	Vac	Low Force Tester	2.4(8)	5.1(12)	4.4(13)	1.6(13)	-	10,040 8,660 9,350/1223	Did not reach 5%	316,223	80	5.0(-7)
	Vacuum	Vac	Low Force Tester	5.3(9)	1.1(14)	9.7(14)	3.5(14)	-	10,600 9,700 10,150/798	Did not reach 5%	290,935	125	9.0(-7)

[a]Values given as: average value/standard deviation on an individual basis.
[b]All specimens were tested at 0.05 in./min.

Table 9.18

Marlex 6001 Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate[a]		At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)	Tensile Strength (psi)	Elongation (%)		
					E<0.48ev	E>2.9Mev	E>8.1Mev							
101-11	-	Air	Instron at 2.0 in./min	0	0	0	0	-	3741[b]	10	-	-	75	760
101-12									4514	10	250[b]	500[b]		
101-13									4411	12	-	-		
101-14									4433	10	-	-		
101-15									4909[b]	15	4909[b]	15[b]		
									4453/61	11.4/2.1	-	-		
101-1	Air	Air	Instron at 2.0 in./min	3.3(10)	-	5.4(15)	-	17	6051	10	5976	11	170	760
101-2									6065	8	6003	9		
101-3									6105	9	6105	9		
101-4									6090	9	6002	10		
101-5									6061	8	6061	8		
									6074/23	8.8/0.9	6029/55	9.4/1.3		
101-6	Air	Air	Instron at 2.0 in./min	1.7(11)	-	2.5(16)	-	17	4221	10	4221	10	200	760
101-7									4175	7	4175	7		
101-8									4258	7	4258	7		
101-[illegible]									4423	8	4423	8		
101-10									3506	6	3506	6		
									4117/394	7.6/1.7	4117/394	7.6/1.7		

[a]Values given as: average value/standard deviation on an individual basis.
[b]Value not included in average or standard deviation.

Table 9.19

Marlex 6002 Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48ev	Neutrons (n/cm^2): E>2.9Mev	Neutrons (n/cm^2): E>8.1Mev	Time Until Test (days)	Ultimate[a]: Tensile Strength (psi)	Ultimate[a]: Elongation (%)	At Rupture[a]: Tensile Strength (psi)	At Rupture[a]: Elongation (%)	Avg. Temp. (F)	Avg. Press. (torr)
98-76	Vac	Air	Instron at 2.0 in./min	8.5(9)	1.0(14)	1.7(15)	-	7	5179	9	4781	40	140	2.0(-6)
98-77									5145	9	4716	40		
98-78									5125	9	4835	58		
98-79									5158	9	4802	55		
98-80									5178	10	4684	32		
									5157/23	9.2/0.4	4764/65	45/11		
98-81	-	Vac	High Force Tester at 0.05 in./min	0	0	0	0	-	4429	9.53	2677[b]	94.5[b]	75	1.0(-3)
98-82									3319	7.65	2041[b]	95.2[b]		
98-83									4015	8.40	2417[b]	95.7[b]		
98-84									3504	8.55	1693[b]	90.4[b]		
									3817/539	8.53/0.91	2207/478	94.0/2.6		
98-86	Vac	Vac	High Force Tester at 0.05 in./min	9.2(9)	1.1(14)	1.5(15)	-	-	3551	6.99	3300	7.23	140	2.0(-6)
98-87									3624	6.94	-	-		
98-88									2962	6.20	2612	7.10		
98-89									2142	3.81	1726	4.31		
									3070/720	5.99/1.54	2546/930	6.21/1.72		

[a]Values given as: average value/standard deviation on an individual basis.
[b]Unirradiated specimens did not fracture. Specimen extension exceeded pull rod travel limits. Values reported are those at maximum extension for High Force Tester.

Table 9.20

Mylar 100C Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron	0	0	0	0	-	22,000	26,200	-	27,800	61	75	760
			at 20.0						16,800	-	-	17,000[b]	28[b]		
			in./min						17,200	19,800	-	25,300	88		
									20,300	23,300	-	28,300	80		
									16,000	18,000	-	19,000	60		
									16,000	18,500	-	24,600	92		
									16,500	-	-	16,500[b]	25[b]		
									16,100	18,500	25,600	28,000	114		
									15,700	17,600	-	[illegible]	62		
									17,420/	20,270/	-	[illegible]/	80/20		
									2,190	3,180		3,439			
	Air	Air	Instron	5.7(8)	6.1(12)	1.4(14)	4.6(12)	2	16,500	18,500	-	19,300	59	75	760
			at 20.0						16,100	17,800	-	20,400	75		
			in./min						16,250	18,300	24,600	27,700	120		
									17,300	19,800	-	24,400	85		
									16,800	19,900	27,500	27,500	100		
									16,600	18,800	25,100	27,600	115		
									16,300	18,000	-	20,300	71		
									16,600	19,000	-	20,500	61		
									17,000	19,500	26,400	26,900	105		
									16,600	18,700	25,000	27,000	115		
									16,600/	18,830/	25,720/	24,160/	91/20		
									390	680	1,250	2,730			
	Air	Air	Instron	5.2(9)	5.5(13)	1.1(15)	3.4(13)	4	-	-	-	22,800	-	100	760
			at 20.0						16,400	18,000	22,600	23,200	105		
			in./min						16,000	17,500	22,200	23,000	110		
									16,500	18,400	23,400	24,000	108		
									16,300	18,300	-	22,700	95		
									16,500	18,300	-	22,300	91		
									16,300	18,000	22,400	23,700	113		
									16,300	18,000	22,500	23,800	[illegible]		
									16,300	18,500	-	22,600	92		
									16,600	19,000	-	21,000	70		
									16,350/	18,200/	22,600/	22,910/	100/[illegible]		
									200	500	500	975			

[a] Values given as: average value/standard deviation on an individual basis.
[b] Values not included in average or standard deviation.

Table 9.20 (cont'd)

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48ev	Neutrons (n/cm^2): E>2.9Mev	Neutrons (n/cm^2): E>8.1Mev	Time Until Test (days)	Tensile Strength (psi): @ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture	Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Air	Air	Instron at 20.0 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	4	16,200 15,800 16,000 15,500 15,400 15,600 15,900 15,900 15,800 15,700 15,780/ 260	17,700 17,300 17,400 16,800 16,600 16,900 17,400 17,300 - 17,100 17,170/ 370	- - - - - - - - - -	19,300 18,100 17,400 19,200 16,600 17,700 19,500 17,300 16,700 19,800 18,160/ 1,040	71 61 50 92 50 61 82 50 41 95 65/18	140	760
	Air	Air	Instron	3.3(10)	-	5.4(15)	-	-	10 specimens - too brittle to test					170	760
	Air	Air	Instron	1.7(11)	-	2.5(16)	-	-	10 specimens - too brittle to test					200	760
	Vac	Air	Instron at 20.0 in./min	2.4(8)	5.1(12)	4.4(13)	1.6(13)		17,300 17,200 17,700 17,500 17,100 16,700 17,250/ 395	19,500 19,500 20,500 20,000 19,200 18,600 19,550/ 750	- - - - 25,700 25,100 25,400/ 532	24,300 23,300 27,400 21,800 26,500 25,600 24,817/ 2,210	87 79 96 65 104 102 89/15	80	5(-7)
	Vac	Air	Instron at 20.0 in./min	8.5(9)	1.0(14)	1.7(15)	-	8	16,300 15,800 15,600 15,600 15,500 15,760/ 340	17,200 17,000 16,800 17,000 17,000 17,000/ 170	- - - 20,100 20,200 20,150/ 90	19,000 17,300 19,600 20,500 20,600 19,400/ 1,420	71 55 95 108 105 87/23	140	2.0(-6)

Table 9.20 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Low-Force Tester at 0.5 in./min	0	0	0	0	-	14,800 12,600 13,700/ 1,950	18,300 13,500 15,900/ 4,250	23,100 16,700 19,900/ 5,670	26,200 27,100 26,650/ 800	141 186 164/40	75	760
	-	Vac	Low-Force Tester at G.5 in./min	0	0	0	0	-	13,500 18,000 15,550 15,683/ 2,658	15,130 18,950 17,200 17,093/ 2,255	18,750 20,950 20,150 19,950/ 1,300	28,400 31,200 29,500 29,700/ 1,654	211 214 209 211/3	75	1.0(-3)
	Vac	Vac	Low-Force Tester at 0.5 in./min	2.4(8)	5.1(12)	4.4(13)	1.6(13)	-	15,200 16,000 15,200 15,466/ 473	15,900 15,500 16,200 15,866/ 413	18,100 17,600 19,200 18,300/ 945	20,100[a] 20,900 20,700 20,800/ 97.1	130[a] 193 141 167/25.3	80	5(-7)
	Vac	Vac	Low-Force Tester at 0.5 in./min	5.3(9)	1.1(14)	9.7(14)	3.5(14)	-	- 17,250 - 17,250/ 0	- 15,700 - 15,700/ 0	- - -	14,700 16,900 15,300 15,630/ 1,299	24 95 13 44/48	125	9(-7)

[a]Specimen tore - ultimate values not included in average and standard deviation.

Table 9.21

Plaskon CTFE X2204 Electrical Insulation
Summary Table of Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Ultimate[a]		At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm²) E<0.48ev	E>2.9Mev	E>8.1Mev		Tensile Strength (psi)	Elongation (%)	Tensile Strength (psi)	Elongation (%)		
121-11 121-12 121-13	-	Air	Instron at 2.0 in./min	0	0	0	0	-	4351 4706 4560 4539/210	10 10 10 10/0	3607 3608 3640 3618/19	70 75 90 78/12	75	760
121-36 121-37 121-38	Air	Air	Instron at 2.0 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	5333 5100 5300 5244/138	10 10 10 10/0	3519 3300 3300 3373/129	25 13 80 39/40	75	760
121-41 121-42 121-43	Air	Air	Instron at 2.0 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	3	80 239 259 193/106	1 1 1 1/0	80 239 259 193/106	<1 <1 <1 <1/0	100	760
121-66 121-67 121-68	Vac	Air	Instron at 2.0 in./min	7.0(8)	1.8(13)	1.5(14)	5.7(13)	51	4864 4918 4909 4897/32	14 13 14 14/0.6	3198 3422 3421 3347/132	45 55 65 55/12	120	4.6(-6)
121-71 121-72 121-73	Vac	Air	Instron at 2.0 in./min	5.3(9)	7.8(13)	6.8(14)	-	7	1183 1421 1410 1338/141	1 1 1 1/0	1183 1421 1410 1338/141	<1 <1 <1 <1/0	100	2.0(-6)
121-76 121-77 121-78	Vac	Air	Instron at 2.0 in./min	8.5(9)	1.0(14)	1.7(15)	-	7	285 62 139 162/132	1 1 1 1/0	285 62 139 162/132	<1 <1 <1 <1/0	140	2.0(-6)

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.22

Silastic 950 Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48ev	Neutrons (n/cm^2): E>2.9Mev	Neutrons (n/cm^2): E>8.1Mev	Time Until Test (days)	Tensile Strength (psi)[a]: @ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture	Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
93-11	-	Air	Instron at 20.0 in./min	0	0	0	0	-	95	114	133	1588	>600[b]	75	760
93-12									112	124	155	1538	680		
93-13									113	126	158	1538	680		
93-14									81	93	124	1514	685		
93-15									82	95	127	1518	675		
									97/14	110/14	139/15	1539/32	680/5		
93-31	Air	Air	Instron at 20.0 in./min	5.7(8)	6.1(12)	1.4(14)	4.6(12)	2	105	130	192	1501	528	75	760
93-32									111	137	196	1463	520		
93-33									108	133	203	1557	532		
93-34									99	128	191	1409	500		
93-35									100	130	194	1440	515		
									105/5	132/4	195/5	1474/64	519/14		
93-36	Air	Air	Instron at 20.0 in./min	8.8(8)	[illegible].1(12)	1.7(14)	5.7(12)	2	118	144	222	1123	390	75	760
93-37									-	135	212	1478	482		
93-38									110	144	226	1538	490		
93-39									111	142	235	1521	475		
93-40									116	148	231	1536	475		
									114/4	143/6	225/10	1439/178	462/43		
93-41	Air	Air	Instron at 20.0 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	4	416	-	-	605	40	100	760
93-42									419	-	-	594	40		
93-43									425	-	-	603	40		
93-44									422	-	-	554	36		
93-45									358	-	-	584	44		
									408/29			588/22	40/3		

[a]Values given as: average value/standard deviation on an individual basis.
[b]Values not included in average or standard deviation.

Table 9.22 (cont'd)

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48ev	Neutrons (n/cm^2): E>2.9Mev	Neutrons (n/cm^2): E>8.1Mev	Time Until Test (days)	Tensile Strength (psi): @ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture	Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
93-46	Air	Air	Instron at 20.0 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	4	-	-	-	587	10	140	760
93-47									-	-	-	712	11		
93-48									-	-	-	634	11		
93-49									-	-	-	727	12		
93-50									-	-	-	794	14		
												691/89	11.6/1.7		
93-91	-	LN_2	CTT at 0.05 in./min	0	0	0	0	-	-	-	-	6906	1.20	-320	760
93-92									-	-	-	5966	0.82		
93-93									-	-	-	7221	1.25		
93-94									-	-	-	7098	0.96		
												6798/610	1.06/0.21		
93-96	LN_2	LN_2	CTT at 0.05 in./min	2.6(9)	-	4.6(14)	-	0	-	-	-	-	-	-320	760
93-97									-	-	-	6863[b]	1.49[b]		
93-98									-	-	-	1814	0.96		
93-99									-	-	-	3975	0.96		
												2895/1916	0.46/0.00		
93-101	LN_2	LN_2	CTT at 0.05 in./min	6.7(9)	-	1.2(15)	-	0	-	-	-	3709	0.80	-320	760
93-102									-	-	-	5765	1.03		
93-103									-	-	-	1784	0.61		
93-104									-	-	-	2388	0.58		
												3412/1933	0.76/0.22		

Table 9.22 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
93-111	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	-	-	-	2702	.35	-423	760
93-112									-	-	-	-	-		
93-113									-	-	-	-	-		
93-114									-	-	-	-			
												2702/0	.35/0		
93-121	LH_2	LH_2	CTT at 0.05 in./min	3.8(9)	-	6.6(14)	-	0	-	-	-	704	.13	-423	760
93-122									-	-	-	674	.20		
93-123									-	-	-	1181	.19		
93-124									-	-	-	1971	.28		
												1132/630	.20/.07		
93-126	LH_2	LH_2	CTT at 0.05 in./min	8.4(9)	-	1.5(15)	-	0	-	-	-	-	-	-423	760
93-127									-	-	-	-	-		
93-128									-	-	-	1536	.73		
93-129									-	-	-	1552	1.06		
												1544/14	.89/.29		

Table 9.23

Silastic 1410 Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
92A-11	-	Air	Instron at 20.0 in./min	0	0	0	0	-	135	170	240	1260	492	75	760
92A-12									146	198	279	1461	512		
92A-13									129	153	235	1247	500		
92A-14									151	201	272	1459	515		
92A-15									137	161	238	1249	495		
									140/9	177/21	253/19	1335/91	503/10		
92A-31	Air	Air	Instron at 20.0 in./min	5.7(8)	6.1(12)	1.4(14)	4.6(12)	2	195	258	419	1377	350	75	760
92A-32									222	296	439	1575	405		
92A-33									224	296	435	1607	410		
92A-34									189	258	402	1377	370		
92A-35									224	290	441	1541	390		
									211/15	280/16	427/17	1495/99	385/26		
92A-36	Air	Air	Instron at 20.0 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	214	304	485	1245	300	75	760
92A-37									214	307	493	1304	310		
92A-38									217	309	497	1206	280		
92A-39									206	303	480	1223	290		
92A-40									206	294	476	1294	315		
									211/5	303/6	486/9	1254/42	299/15		
92A-41	Air	Air	Instron at 20.0 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	4	794	1118	-	1240	58	100	760
92A-42									764	1103	-	1143	55		
92A-43									771	1086	-	1086	50		
92A-44									791	1113	-	1189	55		
92A-45									803	-	-	1071	42		
									785/17	1105/16		1146/73	52/7		
92A-46	Air	Air	Instron at 20.0 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	4	1259	-	-	1382	30	140	760
92A-47									1286	-	-	1286	25		
92A-48									1246	-	-	1420	30		
92A-49									-	-	-	1126	22		
92A-50									1247	-	-	1247	25		
									1206/19			1292/126	26.4/3.4		

[a] Values given as: average value/standard deviation on an individual basis.

Table 9.23 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
92A-61	Vac	Air	Instron at 20.0 in./min	5.0(8)	9.0(12)	7.5(13)	2.9(13)	24	383	503	714	1891	325	120	4.6(-6)
92A-62									237	353	578	1659	320		
92A-63									250	375	614	1563	290		
92A-64									275	280	620	1637	300		
92A-65									257	377	600	1491	285		
									280/63	398/64	625/58	1648/172	304/17		
92A-66	Vac	Air	Instron at 20.0 in./min	7.6(8)	1.7(13)	1.7(14)	6.2(13)	24	153	324	1041	1735	180	120	4.6(-6)
92A-67									253	453	812	1206	180		
92A-68									298	476	786	1577	230		
92A-69									445	613	896	1855	245		
92A-70									427	602	901	1509	198		
									315/126	494/124	887/110	1576/279	207/28		
92A-71	Vac	Air	Instron at 20.0 in./min	5.3(9)	7.8(13)	6.8(14)	-	6	1294	-	-	1524	31	100	2.0(-6)
92A-72									1274	-	-	1493	30		
92A-73									1260	-	-	1506	30		
92A-74									-	-	-	1104	20		
92A-75									1324	-	-	1324	25		
									1288/31			1390/181	27.2/4.7		
92A-91	-	LN_2	CTT at 0.05 in./min	0	0	0	0	-	-	-	-	8936	1.35	-320	760
92A-92									-	-	-	8520	1.33		
92A-93									-	-	-	8629	1.17		
92A-94									-	-	-	7375	0.96		
												8365/758	1.20/ 0.19		

Table 9.23 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
92A-96 92A-97 92A-98 92A-99	LN_2	LN_2	CTT at 0.05 in./min	4.2(9)	-	7.4(14)	-	-	- - - -	- - - -	- - - -	- 5759 4703 3244 4569/1486	- 0.78 0.75 0.78 0.77/0.02	-320	760
92A-101 92A-102 92A-103 92A-104	LN_2	LN_2	CTT at 0.05 in./min	8.4(9)	-	1.5(15)	-	-	- - -	- - -	- - -	7539 4469 - 7002 6337/1496	1.37 1.44 - 1.47 1.43/0.06	-320	760
92A-111 92A-112 92A-113 92A-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	- - - -	- - - -	- - - -	- - 505 432 468/65	- - .15 .23 .19/.07	-423	760
92A-121 92A-122 92A-123 92A-124	LH_2	LH_2	CTT at 0.05 in./min	3.8(9)	-	6.6(14)	-	-	1350 - - -	- - - -	- - - -	1600 617 - - 1108/871	.28 .12 - - .20/.14	-423	760
92A-126 92A-127 92A-128 92A-129	LH_2	LH_2	CTT at 0.05 in./min	8.4(9)	-	1.5(15)	-	-	Material Too Brittle - No Data					-423	760

Table 9.24

Sylgard 182 Electrical Insulation (Compression Buttons)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Strength at 25% Compression[a] (psi)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)						
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev				
	-	Air	Instron at 0.5 in./min	0	0	0	0	-	139 134 142 144 144 155 143/8	75	760
	Air	Air	Instron at 0.5 in./min	5.7(8)	6.1(12)	1.4(14)	4.6(12)	2	164 183 192 188 180 181/12	75	760
	Air	Air	Instron at 0.5 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	232 234 223 217 207 223/12	75	760
	Air	Air	Instron at 0.5 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	8	642 957 1000 760 845 841/154	140	760
	Vac	Air	Instron at 0.5 in./min	8.7(9)	7.6(13)	-	-	6	835 1010 875 880 920 904/75	140	2.0(-6)

[a] Values given as: average value/standard deviation on an individual basis.

Table 9.25

Tedlar Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	3611	3611	3611	5777	260	75	760
									3889	3417	3417	6500	290		
									3611	3611	3611	6583	300		
									3722	3722	3611	5833	250		
									3472	3472	3472	6277	281		
									3750	3750	3750	6277	304		
									3833	3417	3417	5556	256		
									3806	3389	3472	6277	232		
									3889	3333	3444	5916	271		
									3731/140	3526/131	3534/112	6111/346	272/24		
	Air	Air	Instron at 20.0 in./min	3.3(10)	-	5.4(15)	-	21	-	-	-	3889	7	170	760
									3611	-	-	3611	30		
									-	-	-	3889	11		
									3611	-	-	3750	30		
									-	-	-	3611	10		
									-	-	-	3806	10		
									-	-	-	4056	8		
									-	-	-	3944	10		
									3617	-	-	3667	30		
									3611	-	-	3611	10		
									3613/3			3783/145	15.6/7.5		
	Air	Air	Instron at 20.0 in./min	1.7(11)	-	2.5(16)	-	21	-	-	-	3889	1	200	760
									-	-	-	4100	1		
									-	-	-	4277	1		
									-	-	-	4277	1		
									-	-	-	3889	1		
												4086/167	1/0		

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.26

Teflon FEP 200A (2 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	2000 2000 1900 1900 2000 1960/ 43	2000 2000 1950 2000 2100 2010/ 64	2300 2300 2200 2200 2300 2260/ 43	2450[b] 2400[b] 3400 3500 4300 3733/ 532	153[b] 155[b] 263 272 302 279/23	75	760
	Air	Air	Instron at 20.0 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	- 1900 1825 1860 - 1862/ 44	- 1950 1850 - - 1900/ 59	- - - - -	1850[b] 1950 1900 1850 1850 1888/ 49	13[b] 91 98 30 13 58/41	75	760
	Air	Air	Instron at 20.0 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	4	5 specimens - too brittle to test					100	760
	Air	Air	Instron at 20.0 in./min	9.7(9)	5.5(13)	2.0(15)	6.3(13)	4	5 specimens - too brittle to test					140	760

[a]Values given as: average value/standard deviation on an individual basis.
[b]Specimen broke in grips - rupture values not included in average and standard deviation.

Table 9.26 (cont'd)

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48ev	Neutrons (n/cm^2): E>2.9Mev	Neutrons (n/cm^2): E>8.1Mev	Time Until Test (days)	Tensile Strength (psi): @ 25% Elong.	Tensile Strength (psi): @ 50% Elong.	Tensile Strength (psi): @ 100% Elong.	Tensile Strength (psi): @ Rupture	Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Vac	Air	Instron at 20.0 in./min	8.0(8)	1.5(13)	1.5(14)	5.9(13)	-	1900	1975	2125	2175	186	120	4.6(-6)
									1850	1875	1950	1975	153		
									1800	1850	2000	2125	198		
									1825	1900	2050	2050	166		
									1825	1900	2025	2100	188		
									1840/43	1900/54	2030/75	2085/86	178/19		
	Vac	Air	Instron at 20.0 in./min	5.3(9)	7.8(13)	6.8(14)	-	5	-	-	-	2143	23	100	2.0(-6)
									-	-	-	2041	20		
									-	-	-	1979	20		
									-	-	-	2062	24		
									-	-	-	2121	15		
												2069/71	20.4/3.9		
	Vac	Air	Instron at 20.0 in./min	8.5(9)	1.0(14)	1.7(15)	-	5	-	-	-	689	<1	140	2.0(-6)
									-	-	-	179	<1		
									-	-	-	82	<1		
									-	-	-	214	<1		
												291/295	<1/0		

Table 9.27

Teflon FEP 1000A (10 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	1919 1789 1970 1773 1940 1878/85	2020 1881 2071 1864 2030 1973/89	2121 1972 2172 1954 2130 2070/94	3333 2844 3434 2864 2900 3075/254	310 294 318 300 280 300/13	75	760
	Air	Air	Instron at 20.0 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	2	1800 1820 1830 1760 1800 1802/30	- 1860 1870 1790 1830 1837/39	- 1880 1880 1840 1870 1867/19	1780 1870 1870 1810 1810 1828/39	33 105 102 132 142 103/47	75	760
	Air	Air	Instron at 20.0 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	21	(3 specimens - Too brittle to test)			495 287 391/184	<1 <1 <1/0	100	760
	Air	Air	Instron at 20.0 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	21	(5 specimens - Too brittle to test)					140	760
	Vac	Air	Instron at 20.0 in./min	8.0(8)	1.5(13)	1.5(14)	5.9(13)	45	1900 1280 1870 1780 1860 1858/52	1940 1930 1910 1800 1900 1896/60	1970 1970 1960 1870 1970 1948/43	2270 2120 2060 1860 2080 2078/176	292 273 250 141 270 245/65	120	4.6(-6)

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.27 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	5.3(9)	7.8(13)	6.8(14)	-	5	- - - - -	- - - - -	- - - - -	1990 2250 2200 1970 2250 2132/ 120	5 4 5 6 5 5/0.9	100	2.0(-6)
	Vac	Air	Instron at 20.0 in./min	8.5(9)	1.0(14)	1.7(15)	-	5	2 specimens - too brittle to test) - - -	- - -	- - -	160 260 86 169/103	<1 <1 <1 <1	140	2.0(-6)

Table 9.28

Teflon FEP 4000A (40 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	1920 1914 1931 1920 1833 1904/42	1984 1956 1995 1995 1914 1969/35	2083 2084 2102 2118 2013 2080/45	3844 3955 3582 3619 3131 3626/354	362 325 297 300 279 313/36	75	760
	Air	Air	Instron at 20.0 in./min	8.8(8)	4.1(12)	1.7(14)	5.7(12)	45	1848 1817 1813 1883 1871 1846/30	1896 1861 1860 1927 1910 1891/29	1919 1875 1893 1932 1940 1912/28	1957 1957 2070 2073 1965 2004/50	200 210 250 219 152 206/42	75	760
	Air	Air	Instron at 20.0 in./min	5.2(9)	5.5(13)	1.1(15)	3.4(13)	22	- - -	- - -	- - -	157 198 92 149/63	<1 < <1 <1	100	760
	Air	Air	Instron at 20.0 in./min	9.7(9)	3.5(13)	2.0(15)	6.3(13)	22	(5 specimens - too brittle to test)					140	760
	Vac	Air	Instron at 20.0 in./min	8.0(8)	1.5(13)	1.5(14)	5.9(13)	45	2000 1784 1922 1912 1922 1908/93	2044 1828 1971 1956 1936 1947/93	2206 1873 1980 2005 2020 2017/143	2549 2588 2711 2892 2721 2692/147	308 358 338 370 340 343/27	120	4.6(-6)

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.28 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	Vac	Air	Instron at 20.0 in./min	5.3(9)	7.8(13)	6.8(14)	-	5	-	-	-	1930	22	100	2.0(-6)
									-	-	-	2350	15		
									-	-	-	1321	5		
									-	-	-	1874	20		
									-	-	-	1915	20		
												1878/442	16.4/7.		
	Vac	Air	Instron at 20.0 in./min	8.5(9)	1.0(14)	1.7(15)	-	5	-	-	-	323	<1	140	2.0(-6)
									-	-	-	109	<1		
									-	-	-	184	<1		
												205/68	<1/0		

Table 9.29

Teflon TFE-7 (2.5 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	1760 1680 1880 1760 1880 1792/ 86	2000 1880 2080 1960 2080 2000/ 86	2280 2200 2400 2240 2360 2296/ 86	4040 4480 4160 4040 4840 4312/ 344	243 274 245 245 275 256/14	75	760
	Air	Air	Instron at 20.0 in./min	8.7(6)	2.4(12)	1.7(12)	6.3(10)	2	1000 2000 2000 1920 1679 1720/ 430	1200 2080 2080 2080 1786 1845/ 378	1320 2240 2160 2160 1929 1962/ 396	1560 2560 2520 2520 2179 2268/ 430	266 306 265 280 310 285/19	75	760
	Air	Air	Instron at 20.0 in./min	4.5(7)	1.7(12)	8.2(12)	3.6(11)	2	1792 1800 1760 1750 1760 1772/21	- - - - -	- - - - -	1792 1800 1800 1708 1760 1772/40	27 29 47 36 34 35/9	75	760
	Air	Air	Instron at 20.0 in./min	1.8(8)	6.0(12)	3.8(13)	1.7(12)	2	- - - - -	- - - - -	- - - - -	1800 1880 1680 1240 1760 1672/ 275	1 2 1 1 3 1.6/0.9	75	760

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.29 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48ev	E>2.9Mev	E>8.1Mev		@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
	Air	Air	Instron at 20.0 in./min	5.7(8)	6.1(12)	1.4(14)	4.6(12)	2	- - - - -	- - - - -	- - - - -	372 136 540 1000 600 530/371	1 1 1 1 1 1	75	760
	Vac	Air	Instron at 20.0 in./min	1.3(8)	1.4(12)	1.1(13)	-	21	1860 1880 1860 1820 1800 1844/34	1988 2000 2000 1940 1940 1974/26	2164 2200 2160 2160 2140 2165/26	2372 2680 2840 2820 2940 2730/244	151 190 205 209 218 195/29	75	2.5(-7)
	Vac	Air	Instron at 20.0 in./min	2.3(8)	1.5(12)	1.8(13)	-	21	1880 1860 1900 1732 1843/82	1980 1960 2000 1800 1935/97	2160 2160 2200 2000 2130/97	2520 2420 2560 2100 2400/223	155 145 152 130 146/12	75	2.5(-7)
	Vac	Air	Instron at 20.0 in./min	5.1(8)	1.1(13)	8.4(13)	3.3(13)	45	1780 1820 1760 1760 1780/29	1840 1880 1820 1820 1840/29	1940 2000 - - 1970/53	1960 2040 1920 1960 1970/58	103 105 90 99 99/7	120	4.6(-6)
	Vac	Air	Instron at 20.0 in./min	8.0(8)	1.5(13)	1.5(14)	5.4(13)	45	1960 1920 1872 1917/52	1980 1940 1880 1933/59	- 2380 - 2080	2280 2080 1888 2083/231	69 100 59 76/24	120	4.6(-6)

Table 9.30

Teflon TFE-7 (5 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2): E<0.48ev	Neutrons (n/cm^2): E>2.9Mev	Neutrons (n/cm^2): E>8.1Mev	Time Until Test (days)	Tensile Strength (psi)[a]: @ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture	Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	-	Air	Instron at 0 in./min	0	0	0	0	-	1698 1700 1800 1700 1600 1700/ 86	1887 1800 1900 1800 1800 1837/ 43	2075 2000 2100 2000 2000 2035/ 43	5000 5200 5000 4600 4200 4800/ 430	333 340 328 318 298 323/18	75	760
	Air	Air	Instron at 20.0 in./min	8.7(6)	2.4(12)	1.7(12)	6.3(10)	2	1804 1820 1860 1820 1900 1841/ 41	1843 1880 1900 1880 1940 1889/ 42	1902 1940 1980 1980 2020 1964/ 51	2039 2100 2240 2220 2240 2168/ 86	298 276 312 298 277 292/15	75	760
	Air	Air	Instron at 20.0 in./min	4.5(7)	1.7(12)	8.2(12)	3.6(11)	2	1700 1720 - - - 1710/ 18	- - - - -	- - - - -	1660 1700 1620 1620 1640 1648/ 34	33 30 19 22 10 23/10	75	760
	Air	Air	Instron at 20.0 in./min	1.8(8)	6.0(12)	3.8(13)	1.7(12)	2	- - - -	- - - -	- - - -	1800 1780 1780 1780 1785/ 10	4 2 2 2 2.5/1.0	75	760
	Air	Air	Instron at 20.0 in./min	5.7(8)	6.1(12)	1.4(14)	4.5(12)	2	- - - - -	- - - - -	- - - - -	154 168 184 334 366 241/91	1 1 1 1 1 1	75	760

[a]Values given as: average value/standard deviation on an individual b[illegible]s.

Table 9.30 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm²)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	Vac	**Air**	**Instron at 20.0 in./min**	1.3(8)	1.4(12)	1.1(13)	-	9	1700 1710 1700 1680 1660 1690/ 21	1760 1780 1770 1740 1740 1758/ 17	1860 1880 1870 1860 1860 1866/9	2360 2010 2330 2020 2260 2196/ 150	195 195 189 194 174 189/9	75	2.5(-7)
	Vac	**Air**	**Instron at 20.0 in./min**	2.3(8)	1.5(12)	1.8(13)	-	9	1660 1720 1650 1680 1640 1670/ 17	1700 1760 1700 1730 1690 1716/ 30	1800 1880 1810 1840 1810 1828/34	1900 1990 2070 2140 1950 2010/ 73	133 128 146 154 146 141/11	75	2.5(-7)
	Vac	**Air**	**Instron at 20.0 in./min**	5.1(8)	1.1(13)	8.4(13)	3.3(13)	45	1700 1680 1680 1690 1720 1694/ 17	1700 1680 1690 1700 1720 1698/ 17	- - - - -	1720 1710 1750 1740 1800 1744/ 39	90 86 83 76 90 85/6	120	4.6(-6)
	Vac	**Air**	**Instron at 20.0 in./min**	8.0(8)	1.5(13)	1.5(14)	5.9(13)	45	1730 1740 1750 1760 1700 1736/ 26	1720 1740 1740 1760 - 1740 19	- - - - -	1740 1760 1740 1740 1690 1734/ 30	80 70 55 58 43 61/16	120	4.6(-6)

Table 9.31

Teflon TFE-7 (10 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	1712	1802	1937	3153	295	75	760
									1727	1818	2045	4182	318		
									1727	1818	2000	4364	332		
									1667	1802	1982	3784	333		
									1818	1970	2121	4596	344		
									1730/65	1842/72	2017/79	4016/620	324/21		
	Air	Air	Instron at 20.0 in./min	8.7(6)	2.4(12)	1.7(12)	6.3(10)	2	2111	2089	2044	1956	113	75	760
									1827	1808	-	1702	90		
									1940	1930	1910	1920	175		
									1806	1787	1750	1769	140		
									1694	1676	1649	1622	150		
									1876/179	1858/178	1838/192	1794/144	134/37		
	Air	Air	Instron at 20.0 in./min	4.5(7)	1.7(12)	8.2(12)	3.6(11)	2	1618	-	-	1618	25	75	760
									-	-	-	1683	9		
									-	-	-	1514	19		
									-	-	-	1532	6		
									-	-	-	1514	10		
									1618			1572/73	14/8		
	Air	Air	Instron at 20.0 in./min	1.8(8)	6.0(12)	3.8(13)	1.7(12)	2	-	-	-	898	<1	75	760
									-	-	-	909	<1		
									-	-	-	889	<1		
									-	-	-	1349	<1		
									-	-	-	1533	<1		
												1116/277	<1		

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.31 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	Air	Air	Instron at 20.0 in./min	5.7(8)	6.1(12)	1.4(14)	4.5(12)	2	- - - - -	- - - - -	- - - - -	117 172 190 142 198 164/35	<1 <1 <1 <1 <1 <1/0	75	760
	Vac	Air	Instron at 20.0 in./min	1.3(8)	1.4(12)	1.1(13)	-	9	1810 1840 1800 1730 1680 1772/ 69	1820 1860 1810 1750 1740 1796/ 52	1920 1990 1900 1860 1830 1900/ 69	2040 2110 2110 2000 1900 2032/ 90	138 135 158 144 130 141/12	75	2.5(-7)
	Vac	Air	Instron at 20.0 in./min	2.3(8)	1.5(12)	1.8(13)	-	9	1840 1910 2020 1850 1905/ 87	1870 2030 2080 1910 1972/ 102	1990 - - - 1990	2000 2040 2160 1910 2028/ 121	105 54 77 50[a] 72/27	75	2.5(-7)
	Vac	Air	Instron at 20.0 in./min	5.1(8)	1.1(13)	8.5(13)	3.3(13)	51	- - - - -	- - - - -	- - - - -	1770 1730 1790 1710 1780 1756/ 34	<10 <10 15 <10 <10	120	4.6(-6)
	Vac	Air	Instron at 20.0 in./min	8.0(8)	1.4(13)	1.5(14)	5.9(13)	51	- - - - -	- - - - -	- - - - -	1790 1850 1800 1700 1780 1784/ 64	<10 <10 <10 <10 <10 <10	120	4.6(-6)

[a]Extrapolated elongation data

Table 9.32

Teflon TFE-7 (20 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)[a]				Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	1699 1651 1667 1602 1651 1654/ 42	1845 1792 1762 1699 1745 1769/ 63	1990 1887 1905 1845 1887 1903/ 62	3689 3585 3571 3301 3632 3556/ 167	382 375 410 374 416 391/18	75	760
	Air	Air	Instron at 20.0 in./min	8.7(6)	2.4(12)	1.7(12)	6.3(10)	2	1755 1596 1596 1548 1580 1615/ 89	1724 1562 1502 1466 1486 1548/ 111	1673 1423 - - - 1548/ 222	1454 1361 1432 1416 1462 1425/ 43	188 118 58 59 56 96/57	75	760
	Air	Air	Instron at 20.0 in./min	4.5(7)	1.7(12)	8.2(12)	3.6(11)	2	- - - -	- - - -	- - - -	1787 1818 1804 1682 1773/ 56	2 2 2 1 2/0.5	75	760
	Air	Air	Instron at 20.0 in./min	1.8(8)	6.0(12)	3.8(13)	1.8(12)	2	- - - - -	- - - - -	- - - - -	1264 1306 976 752 1131 1086/ 238	1 2 1 1 1 1.2/0.5	75	760

[a]Values given as: average value/standard deviation on an individual basis.

Table 9.3[illegible] (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
					E<0.48ev	E>2.9Mev	E>8.1Mev								
	Air	Air	Instron at 20.0 in./min	5.7(8)	6.1(12)	1.4(14)	4.5(12)	2	- - - - -	- - - - -	- - - - -	63 97 104 94 88 89/18	<1 <1 <1 <1 <1 <1/0	75	760
	Vac	Air	Instron at 20.0 in./min	1.3([illegible])	1.4(12)	1.1(13)	-	9	1600 1700 1605 1525 1510 1588/ 82	1600 1700 1640 1515 1515 1594/ 80	1625 1735 1715 1565 1555 1639/ 77	1930 1980 1970 1865 1860 1921/ 52	223 194 189 190[a] 235 206/20	75	2.5(7)
	Vac	Air	Instron at 20.0 in./min	2.3(8)	1.5(12)	1.8(13)	-	9	1490 1525 1465 1585 1521/ 58	1510 1530 1485 1605 1533/ 58	1560 1540 1510 1670 1570/ 78	1675 1620 1595 1725 1654/ 63	165 149 160[a] 134 152/15	75	2.5(-7)
	Vac	Air	Instron at 20.0 in./min	5.1(8)	1.1(13)	8.4(13)	3.3(13)	51	1660 - - - -	1595 - - - -	- - - - -	1580 1560 1570 1500 1600 1562/ 43	61 <10 13 <10 <10	120	4.6(-6)
	Vac	Air	Instron at 20.0 in./min	8.0(8)	1.5(13)	1.5(14)	5.8(13)	51	- - - - -	- - - - -	- - - - -	1750 1625 1450 1750 1570 1629/ 129	<10 <10 <10 <10 ≤10 <10	120	4.6(-6)

[a]Extrapolated elongation data.

Table 9.33

Teflon TFE-7 (40 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment: Irradiation	Environment: Test	Environment: Tester	Radiation Exposure: Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48ev	Neutrons (n/cm^2) E>2.9Mev	Neutrons (n/cm^2) E>8.1Mev	Time Until Test (days)	Tensile Strength (psi)[a] @ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture	Elongation at Rupture[a] (%)	Avg. Temp. (F)	Avg. Press. (torr)
	-	Air	Instron at 20.0 in./min	0	0	0	0	-	1713 1741 1784 1784 1767 1758/31	1852 1920 1925 1972 1907 1915/52	1991 2098 2113 2113 2047 2072/52	4120 3929 3944 3991 4512 4099/251	329 318 320 314 342 325/12	75	760
	Air	Air	Instron at 20.0 in./min	8.7(6)	2.4(12)	1.7(12)	6.3(10)	2	1765 1718 1769 1718 1792 1752/32	1810 1731 1769 1758 1858 1785/55	1796 1771 1822 1775 1863 1805/40	1946 1811 1898 1850 1867 1874/58	352 231 259 272 348 292/52	75	760
	Air	Air	Instron at 20.0 in./min	4.5(7)	1.7(12)	8.2(12)	3.6(11)	2	1595 1522 1584 - - 1567/43	1520 1443 - - - 1482/68	- - - - -	1480 1403 1527 1569 1542 1504/71	62 60 32 12 23 38/21	75	760
	Air	Air	Instron at 20.0 in./min	1.7(8)	6.0(12)	3.8(13)	1.7(12)	2	- - - - -	- - - - -	- - - - -	1841 1832 1767 1791 1826 1811/32	3 1 2 2 2 2/0.9	75	760

[a] Values given as: average value/standard deviation on an individual basis.

Table 9.33 (cont'd)

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Tensile Strength (psi)				Elongation at Rupture (%)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2) E<0.48ev	E>2.9Mev	E>8.1Mev		@ 25% Elong.	@ 50% Elong.	@ 100% Elong.	@ Rupture			
	Air	Air	Instron at 20.0 in./min	5.7(8)	6.1(12)	1.4(14)	4.5(12)	2	- - - - -	- - - - -	- - - - -	248 280 260 251 265 261/14	<1 <1 <1 <1 <1 <1/0	75	760
	Vac	Air	Instron at 20.0 in./min	1.3(8)	1.4(12)	1.1(13)	-	9	1708 1718 1777 1678 1747 1726/43	1782 1802 1827 1787 1832 1806/21	1916 1931 1945 1891 1926 1922/23	2812 2831 2767 2762 2772 2789/30	241 241 216 230 234 232/11	75	2.5(-7)
	Vac	Air	Instron at 20.0 in./min	2.3(8)	1.5(12)	1.8(13)	-	9	1832 1851 1822 1832 1832 1833/12	1901 1896 1871 1881 1871 1884/13	2059 2064 2025 2005 2015 2034/21	2460 2564 2500 2614 2455 2519/68	173 173 174 196 163 176/14	75	2.5(-7)
	Vac	Air	Instron at 20.0 in./min	5.1(8)	1.1(13)	8.5(13)	3.3(13)	45	1800 1810 1825 1800 1765 1800/26	1840 1840 1845 1805 - 1833/19	2025 1920 1930 1875 - 1938/73	2130 2150 2170 2190 1770 2082/181	115 140 140 155 39 118/50	75	760
	Vac	Air	Instron at 20.0 in./min	8.0(8)	1.5(13)	1.5(14)	5.8(13)	45	1900 1810 1825 1800 1834/49	1850 1795 1845 1785 1819/32	1865 - - 1800 1833/58	1900 1810 1860 1840 1853/44	125 85 79 128 104/24	75	760

Table 9.34

Teflon TFE-7 (125 mil) Electrical Insulation
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	At Rupture[a]		Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)				Tensile Strength (psi)	Elongation (%)		
					E<0.48 ev	E>2.9 Mev	E>8.1 Mev					
37A-111 37A-112 37A-113 37A-114	-	LH_2	CTT at 0.05 in./min	0	0	0	0	-	5,087[b] 10,703 10,818 13,298 11,606/1533	1.31[b] 3.37 3.41 2.95 3.24/0.27	-423	760
37A-116 37A-117 37A-118 37A-119	LH_2	LH_2	CTT at 0.05 in./min	7.5(8)	-	1.3(14)	-	-	10,139 10,821 13,061 8,882 10,726/2029	2.26 3.39 2.16 1.86 2.42/0.74	-423	760
37A-121 37A-122 37A-123 37A-124	LH_2	LH_2	CTT at 0.05 in./min	4.0(9)	-	7.1(14)	-	-	10,387 12,736 13,776 7,565 11,138/3016	2.03 2.04 2.14 1.66 1.97/.23	-423	760

[a]Values given as: average value/standard deviation on an individual basis.
[b]Values not included in average or standard deviation.

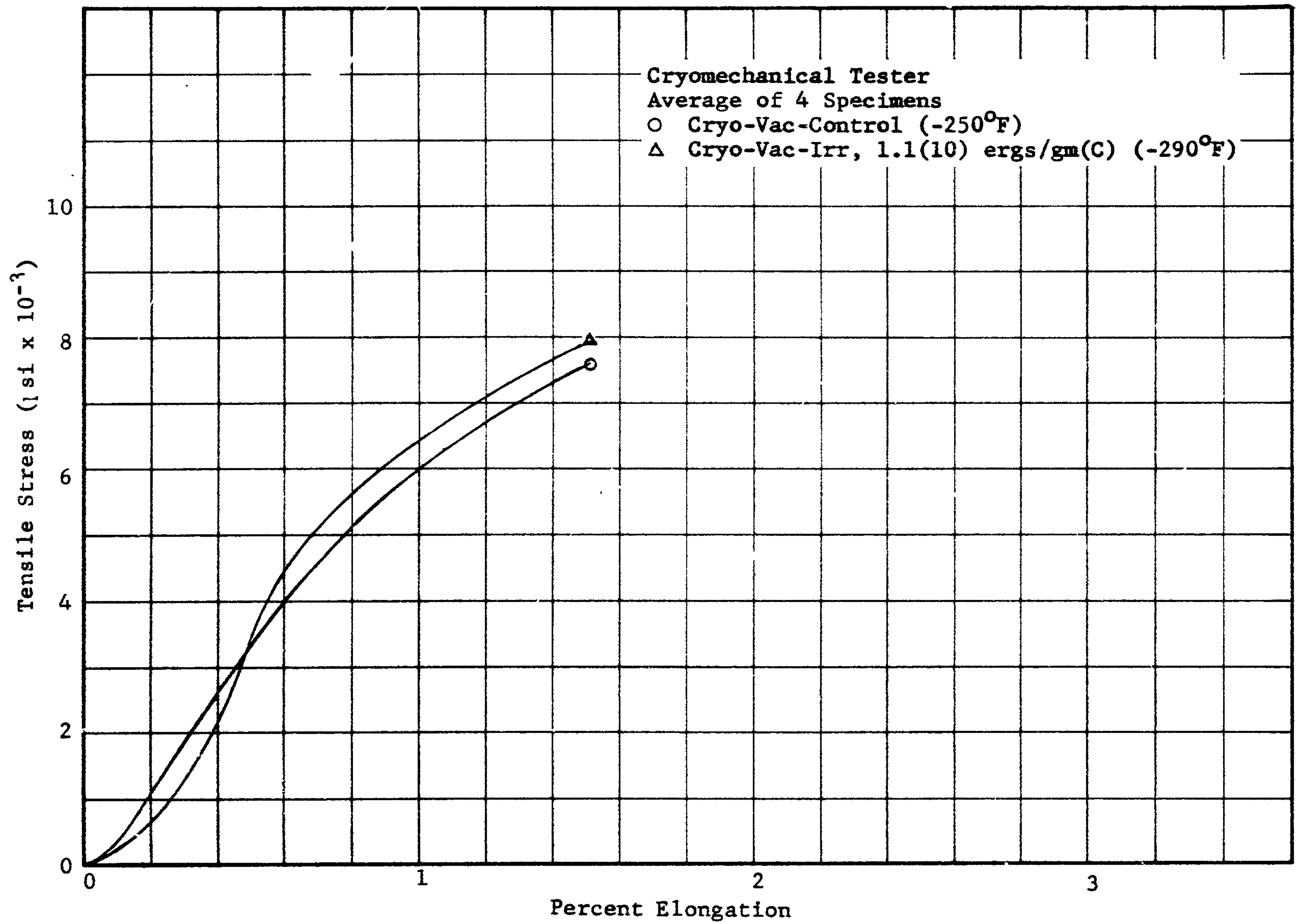


Figure 9.1 Duroid 5600 Stress-Strain Curves: Vacuum/LN_2 Irradiation; Dynamic Tests

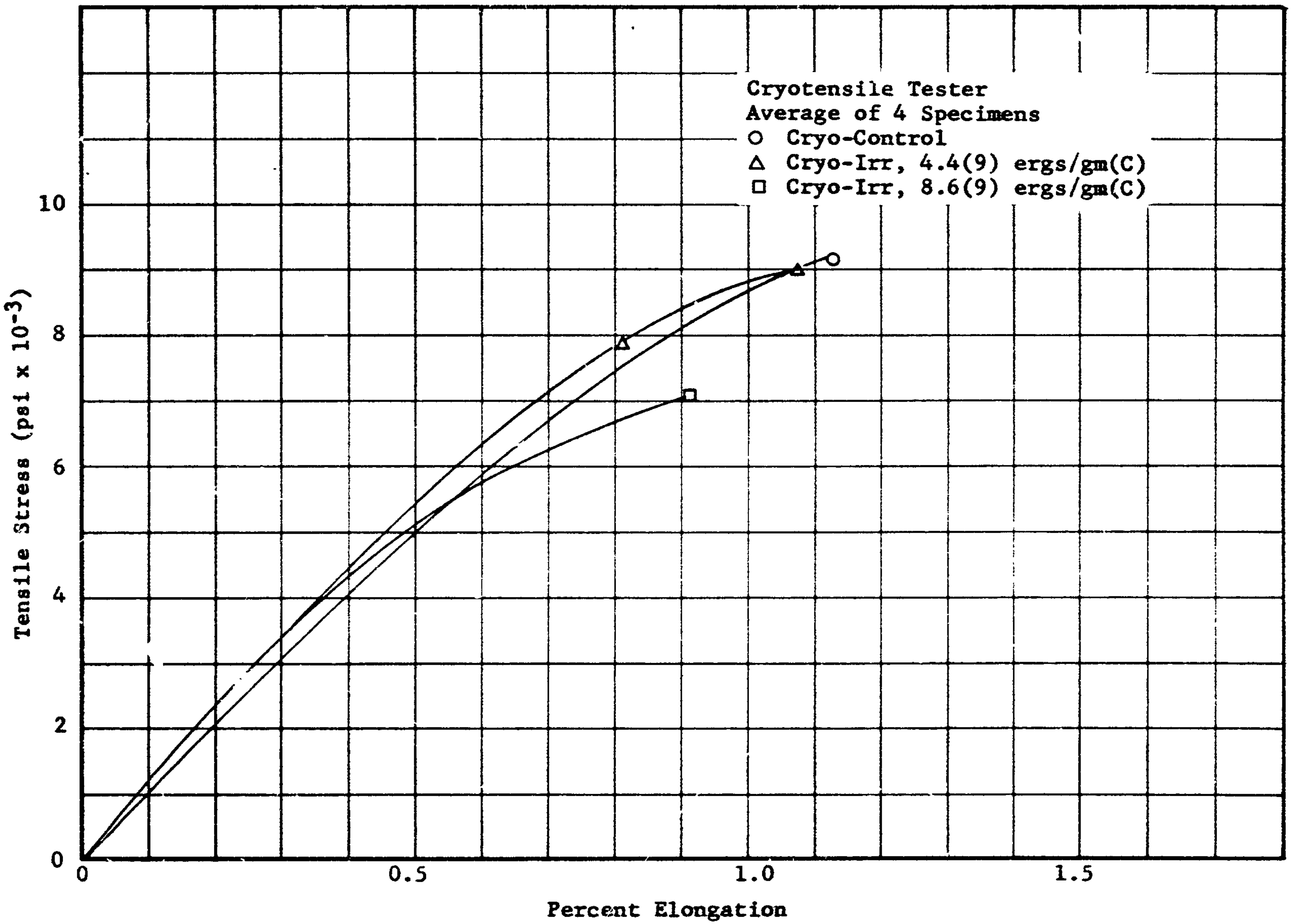


Figure 9.2 Duroid 5600 Stress-Strain Curves: LH_2 Irradiation; Dynamic Tests

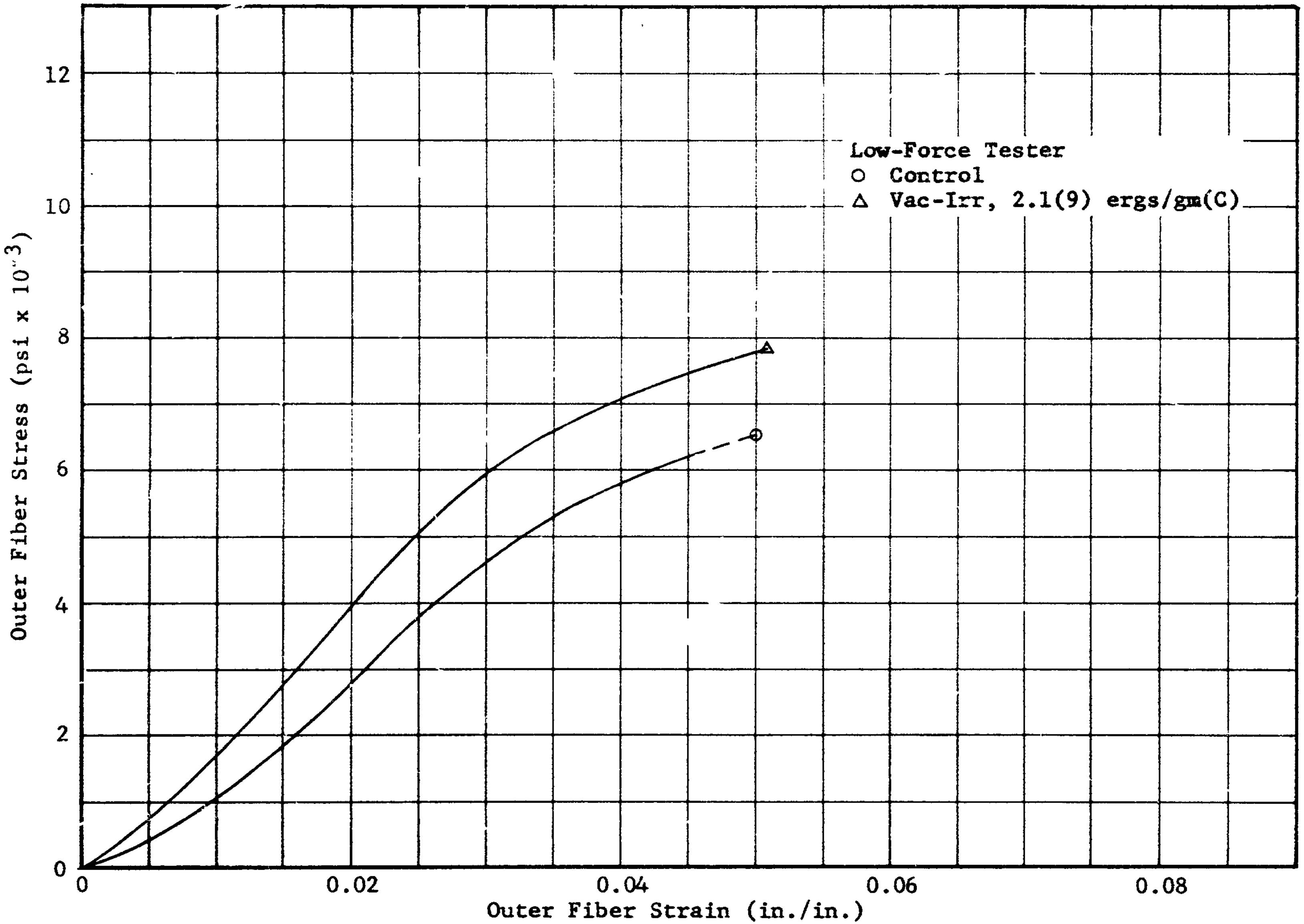


Figure 9.3 Kel-F-81 (Flexure) Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

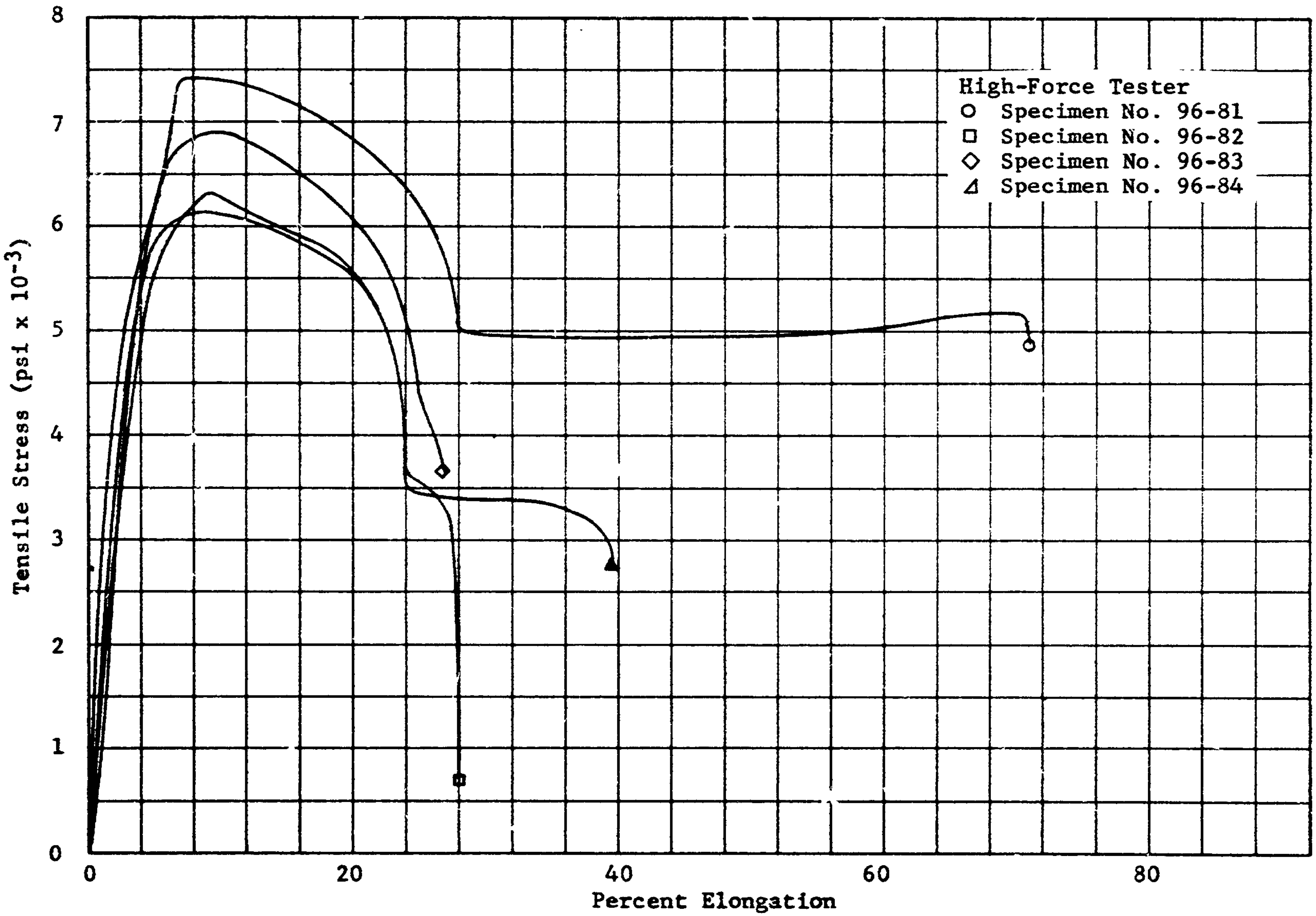


Figure 9.4 Kynar 400 Stress-Strain Curves: Vacuum Control; Dynamic Tests

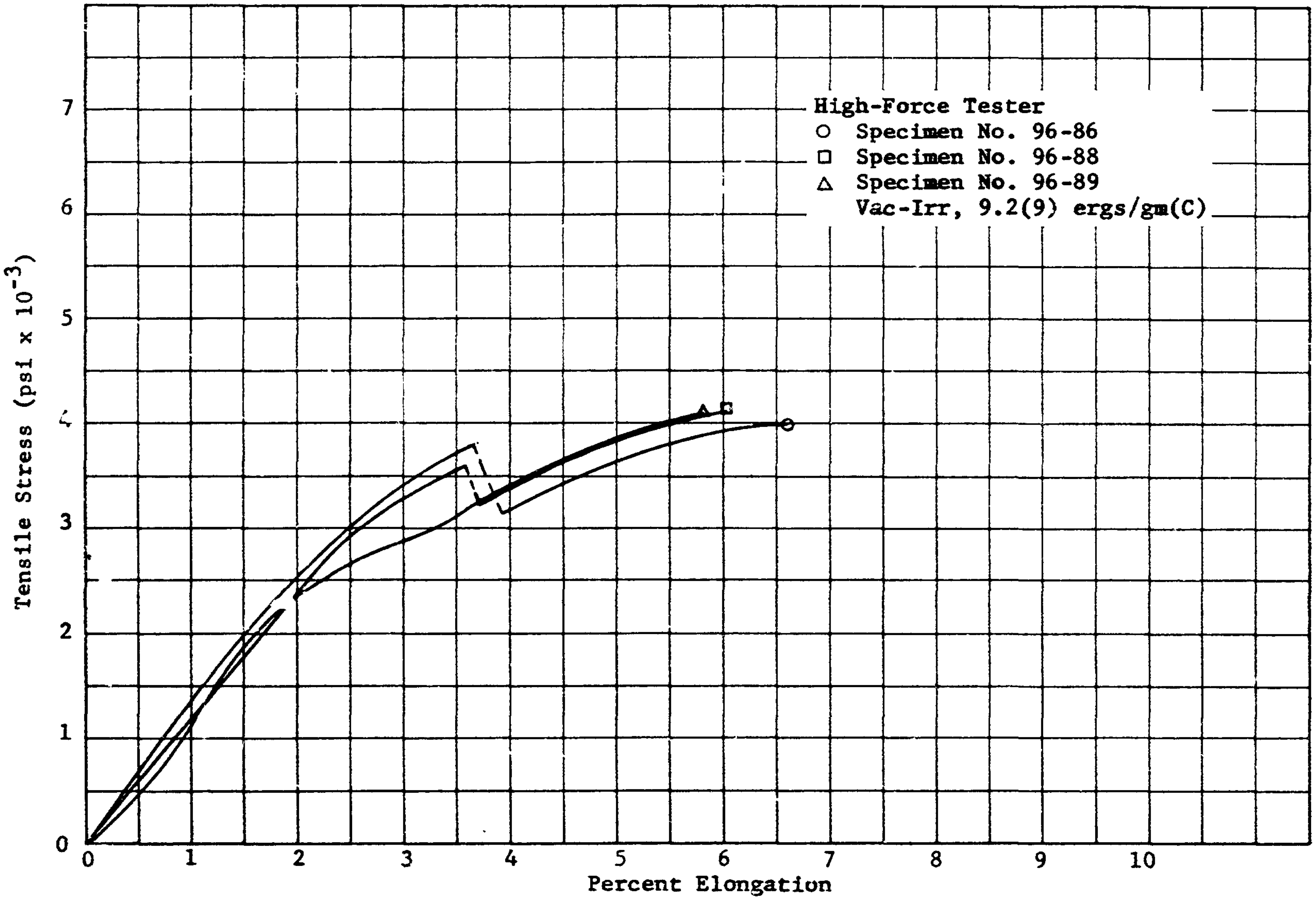


Figure 9.5 Kynar 400 Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

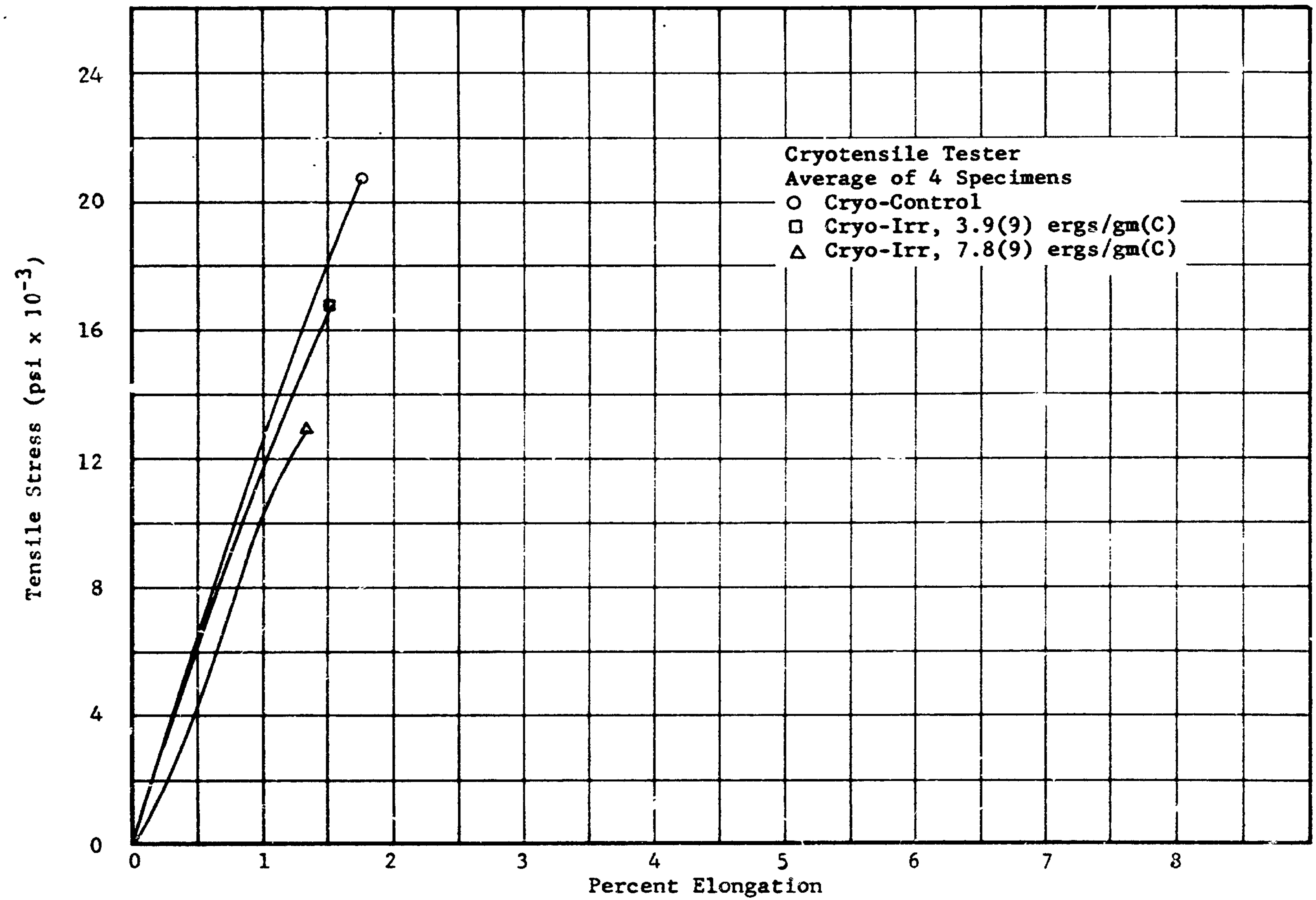


Figure 9.6 Kynar 400 Stress-Strain Curves: LN_2 Irradiation; Dynamic Tests

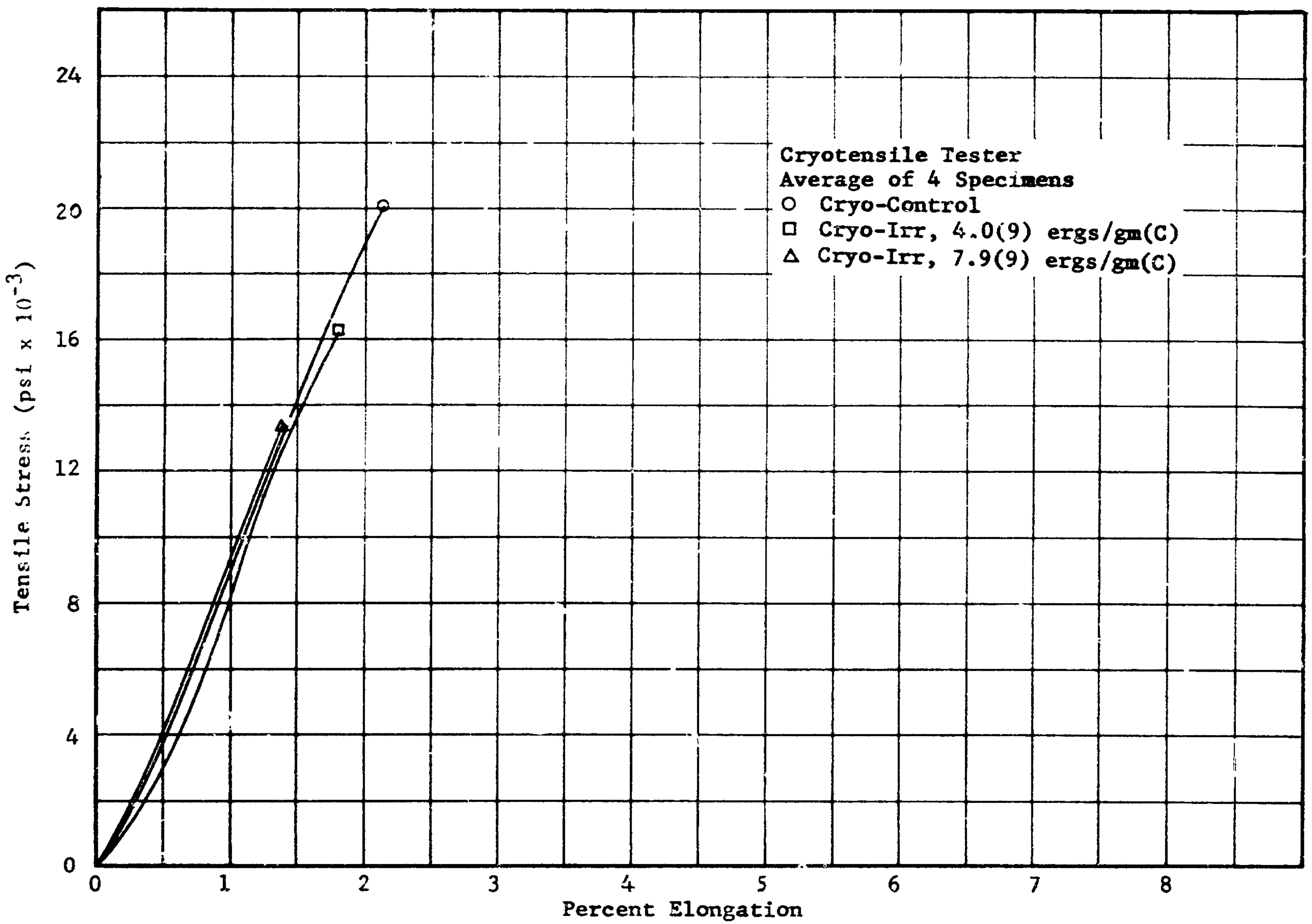


Figure 9.7 Kynar 400 Stress-Strain Curves: LH_2 Irradiation; Dynamic Tests

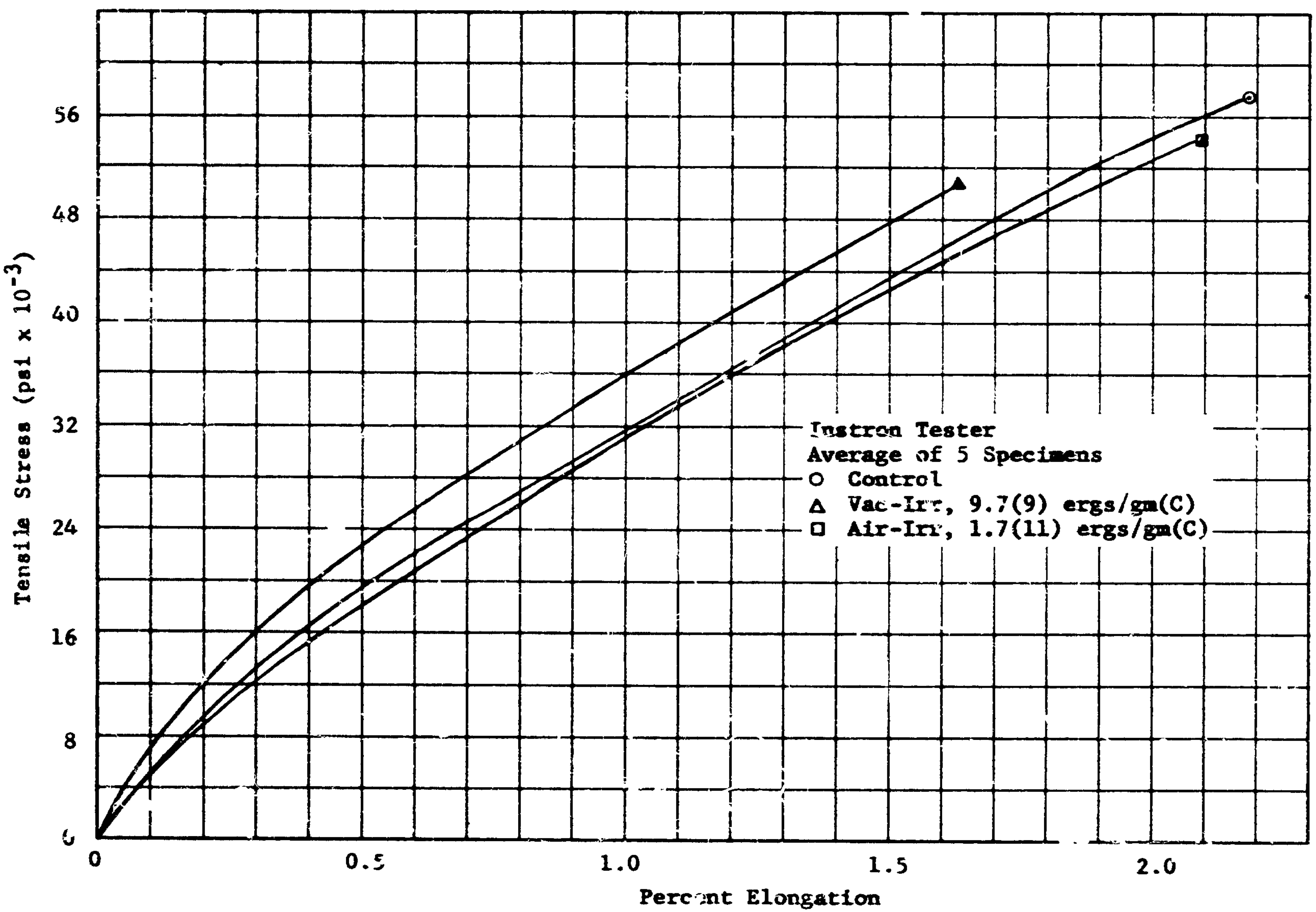


Figure 9.8 Lamicoid 6038E Stress-Strain Curves: Air and Vacuum Irradiations; Static Tests

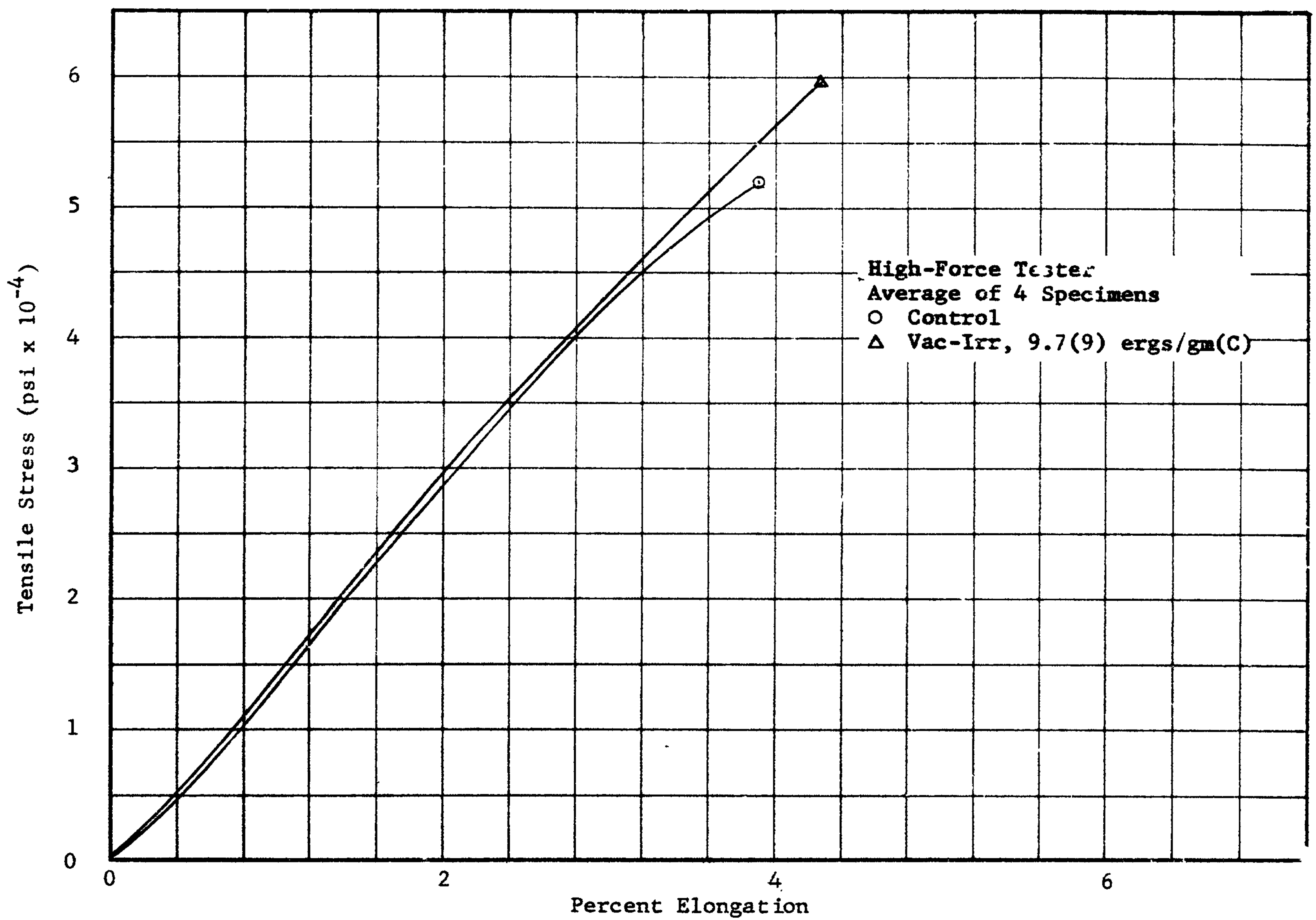


Figure 9.9 Lamicoid 6038E Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

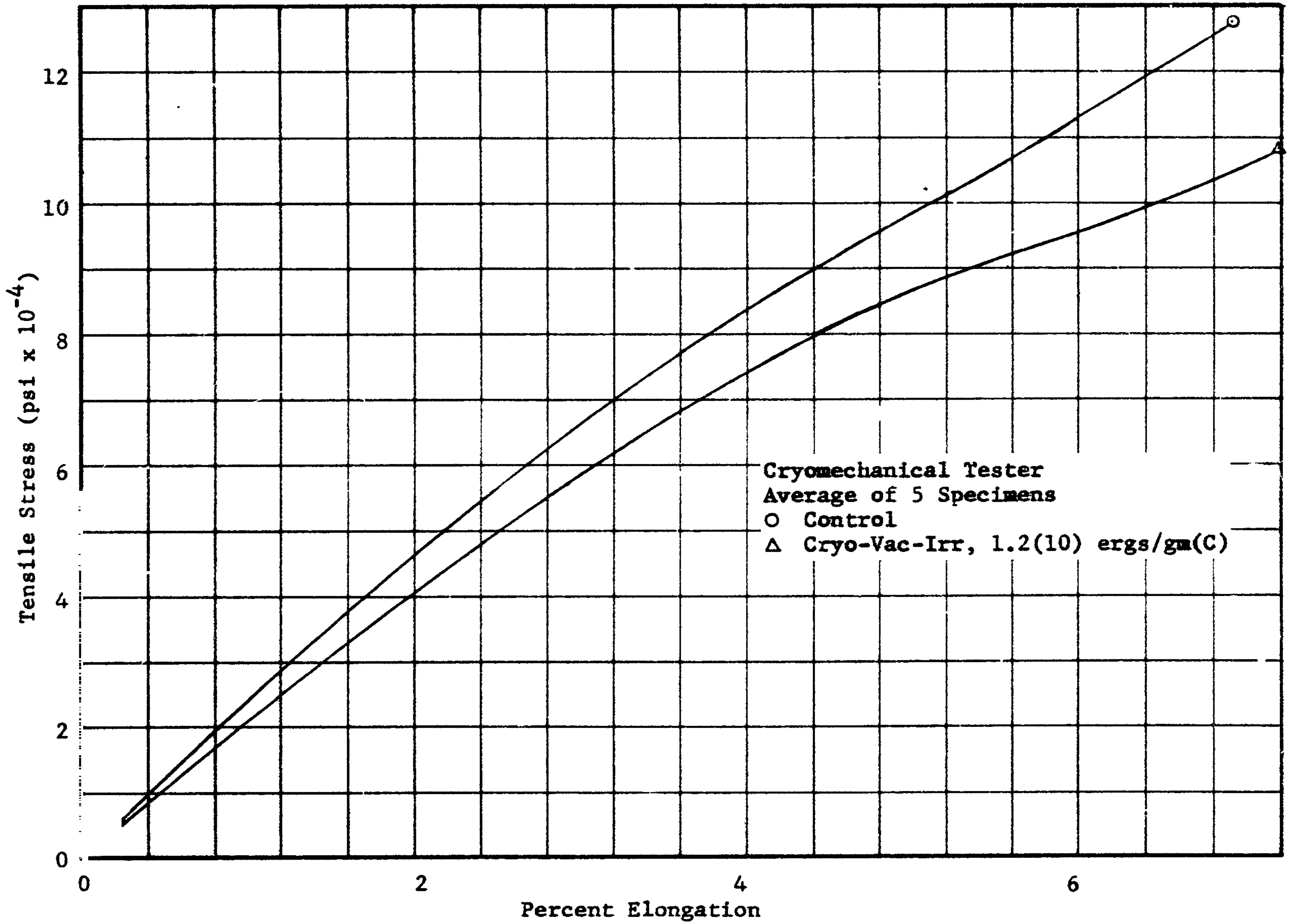


Figure 9.10 Lamicoid 6038E Stress-Strain Curves: Vacuum/LN_2 Irradiation; Dynamic Tests

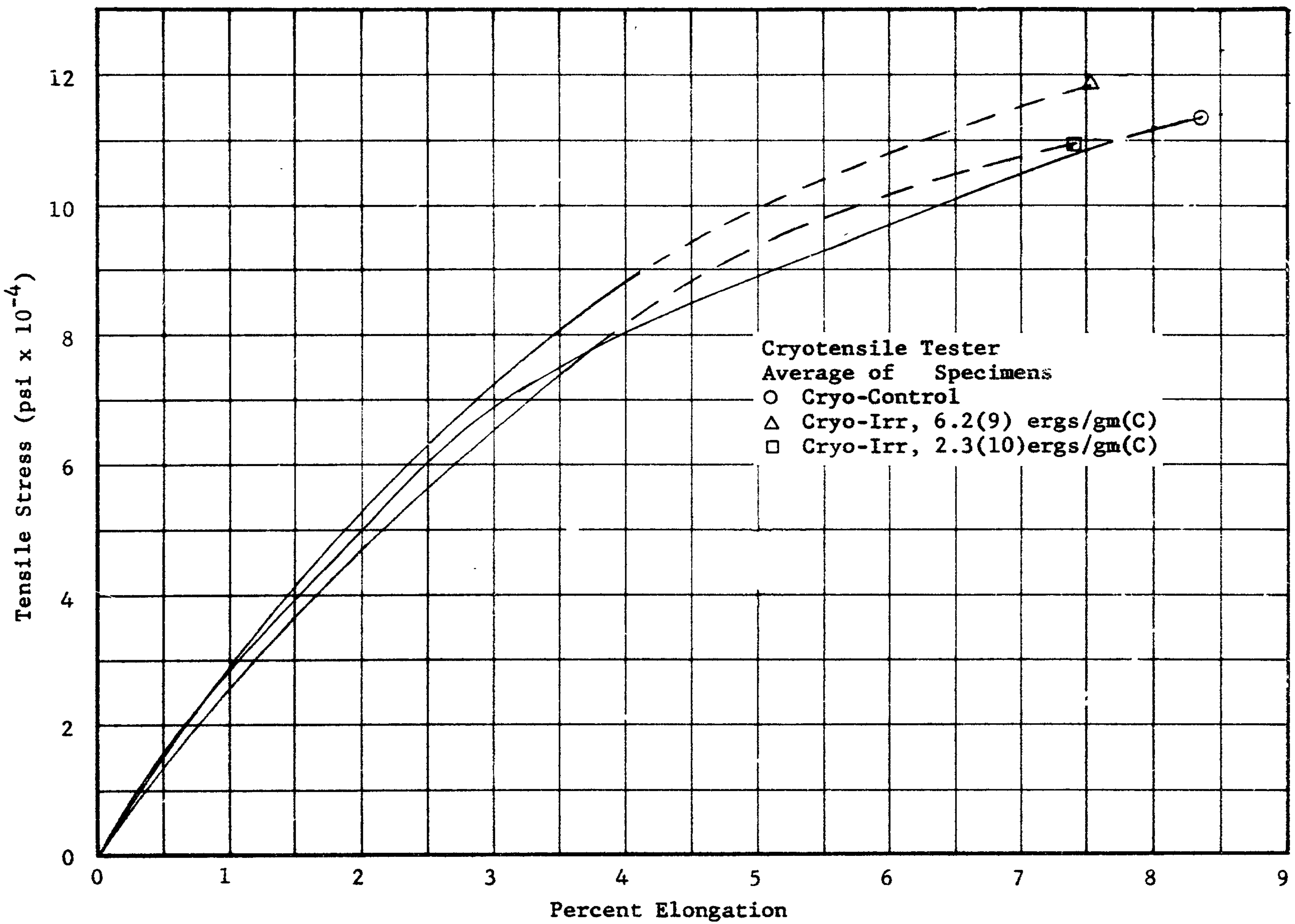


Figure 9.11 Lamicoid 6038E Stress-Strain Curves: LH_2 Irradiation; Dynamic Tests

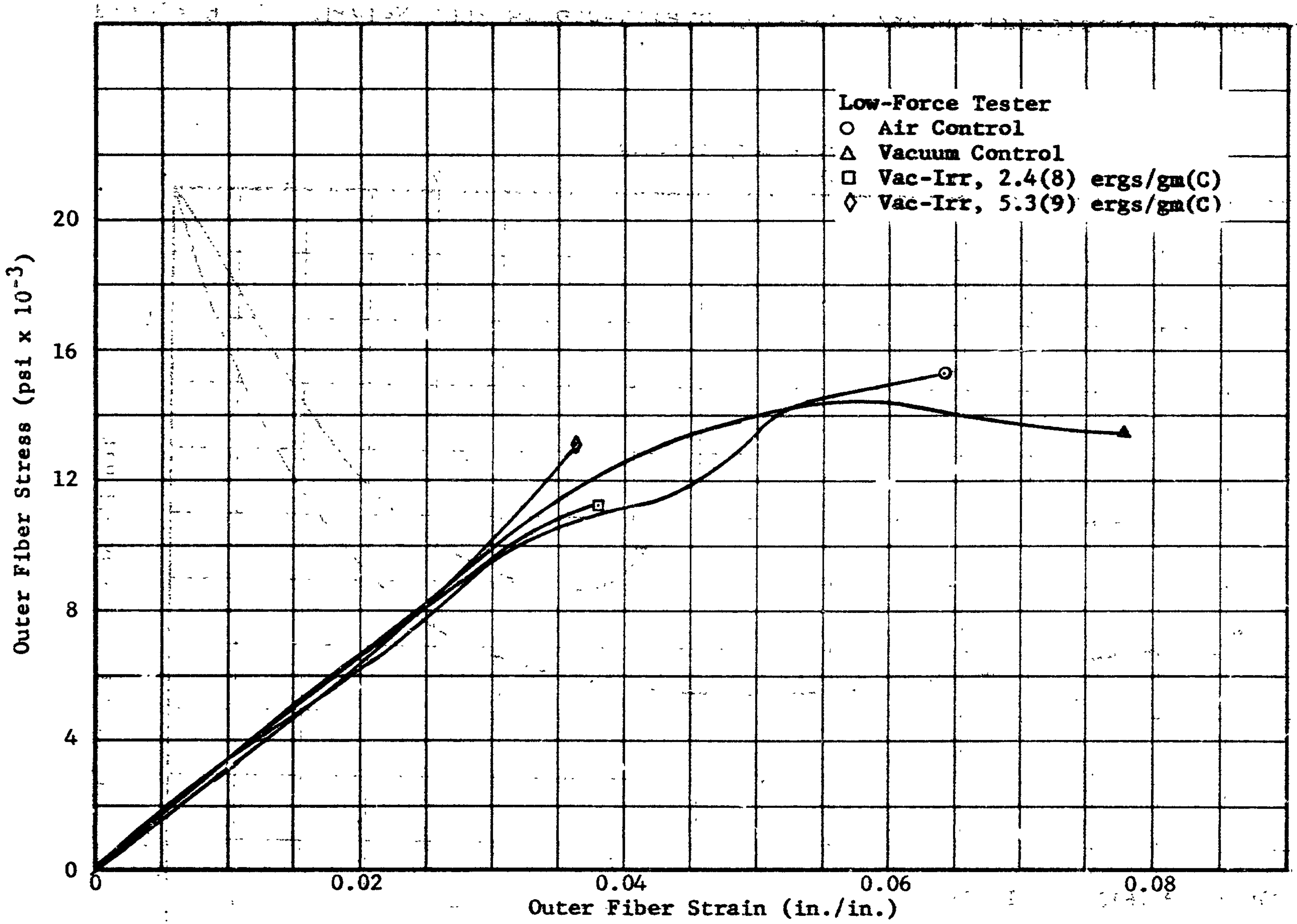


Figure 9.12 Lexan Stress-Strain Curves: Vacuum Irradiation; Dynamic Test

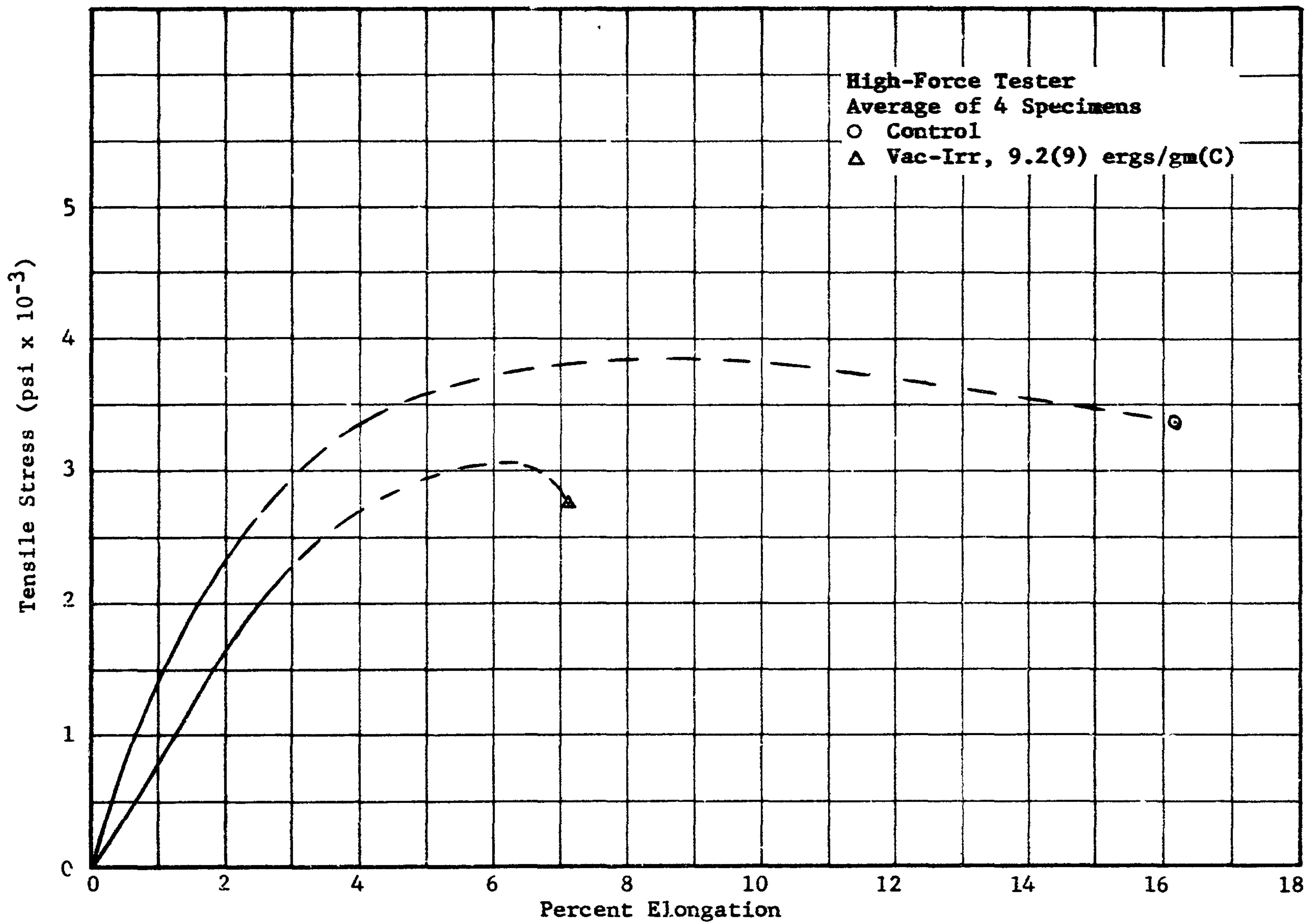


Figure 9.13 Marlex 6002 Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

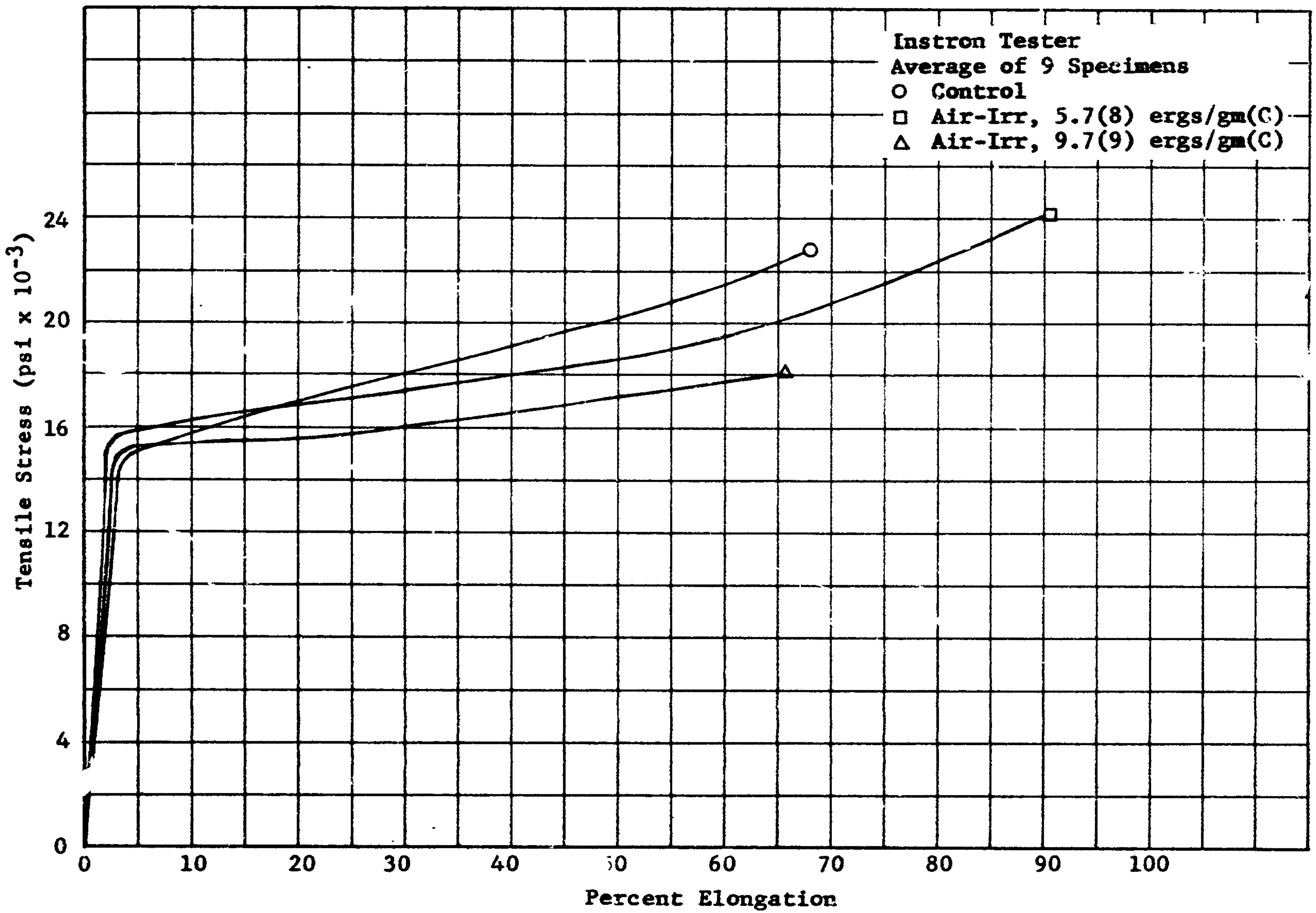


Figure 9.14 Mylar 100C Film Stress-Strain Curves: Air Irradiation; Static Tests

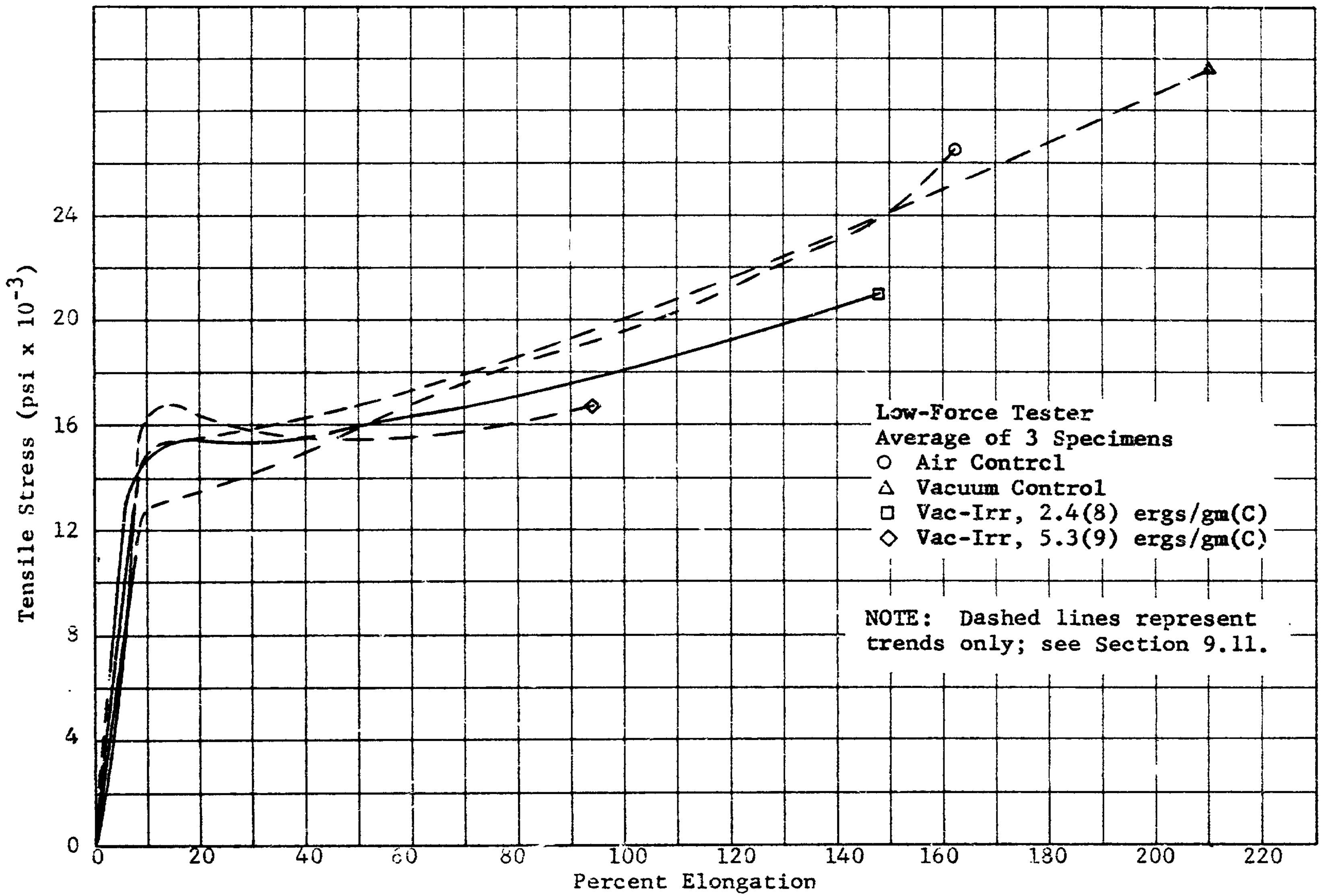


Figure 9.15 Mylar 100C Film Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

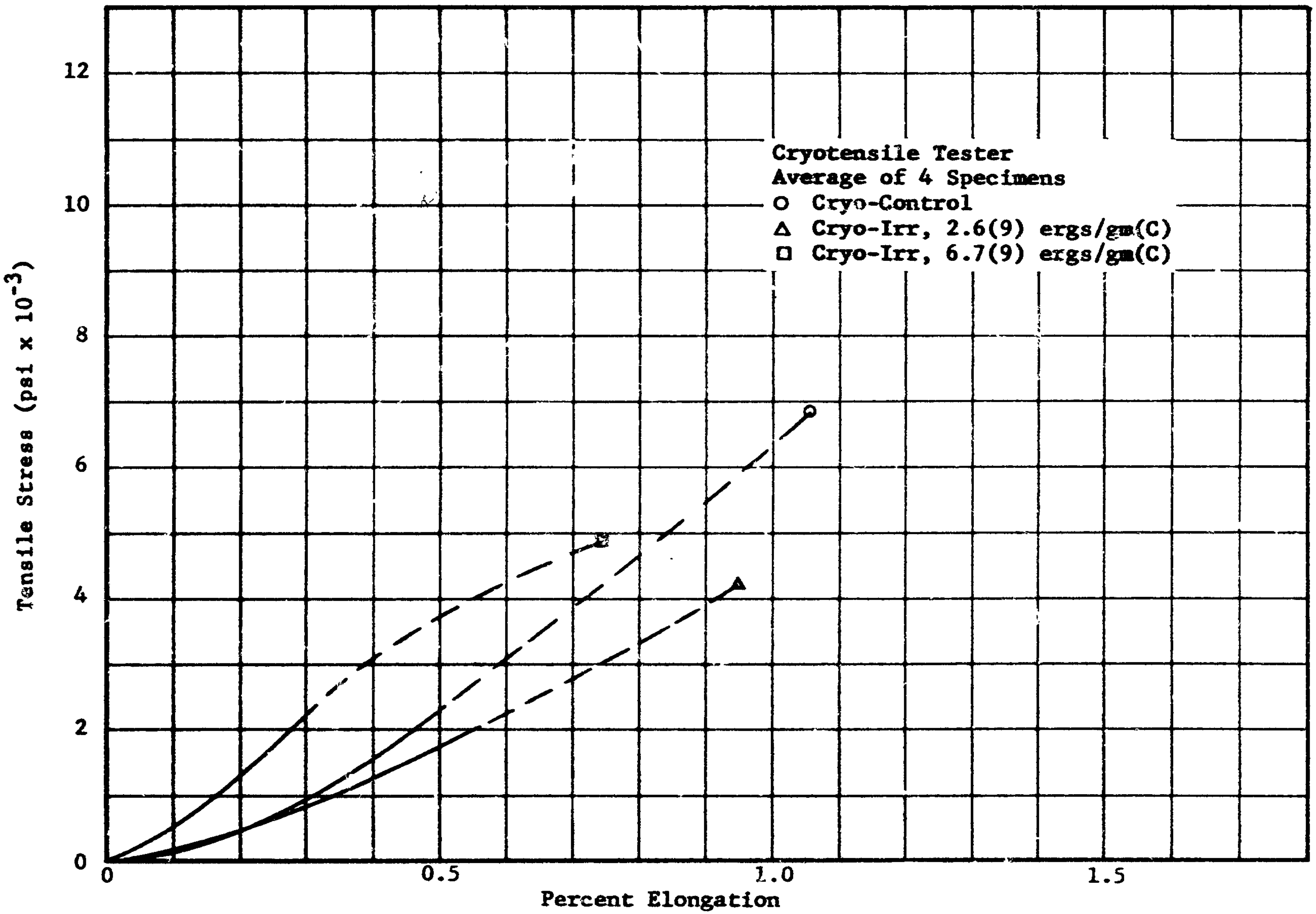


Figure 9.16 Silastic 950 Stress-Strain Curves: LN_2 Irradiation; Dynamic Tests

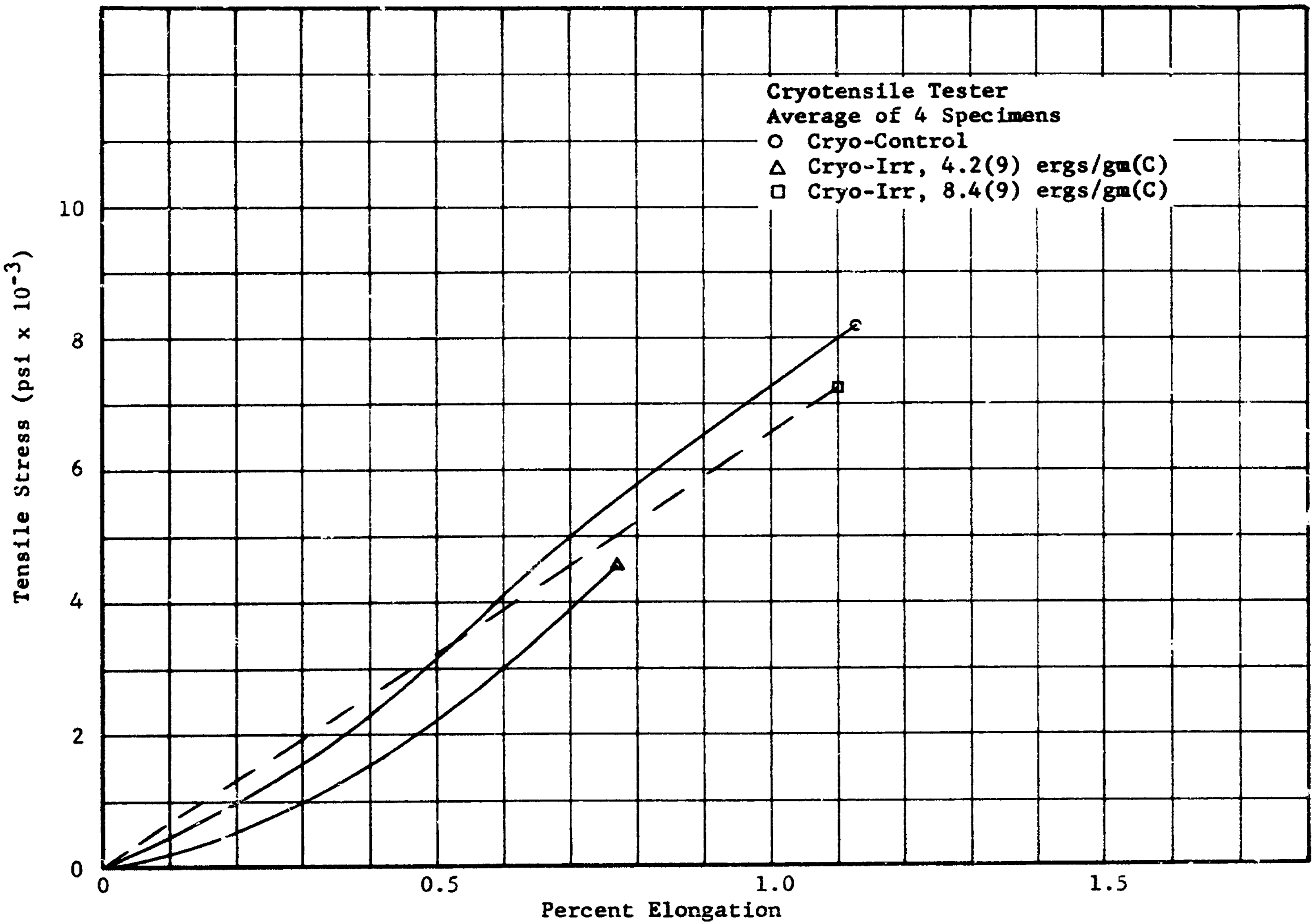


Figure 9.17 Silastic 1410 Stress-Strain Curves: LN_2 Irradiation; Dynamic Tests

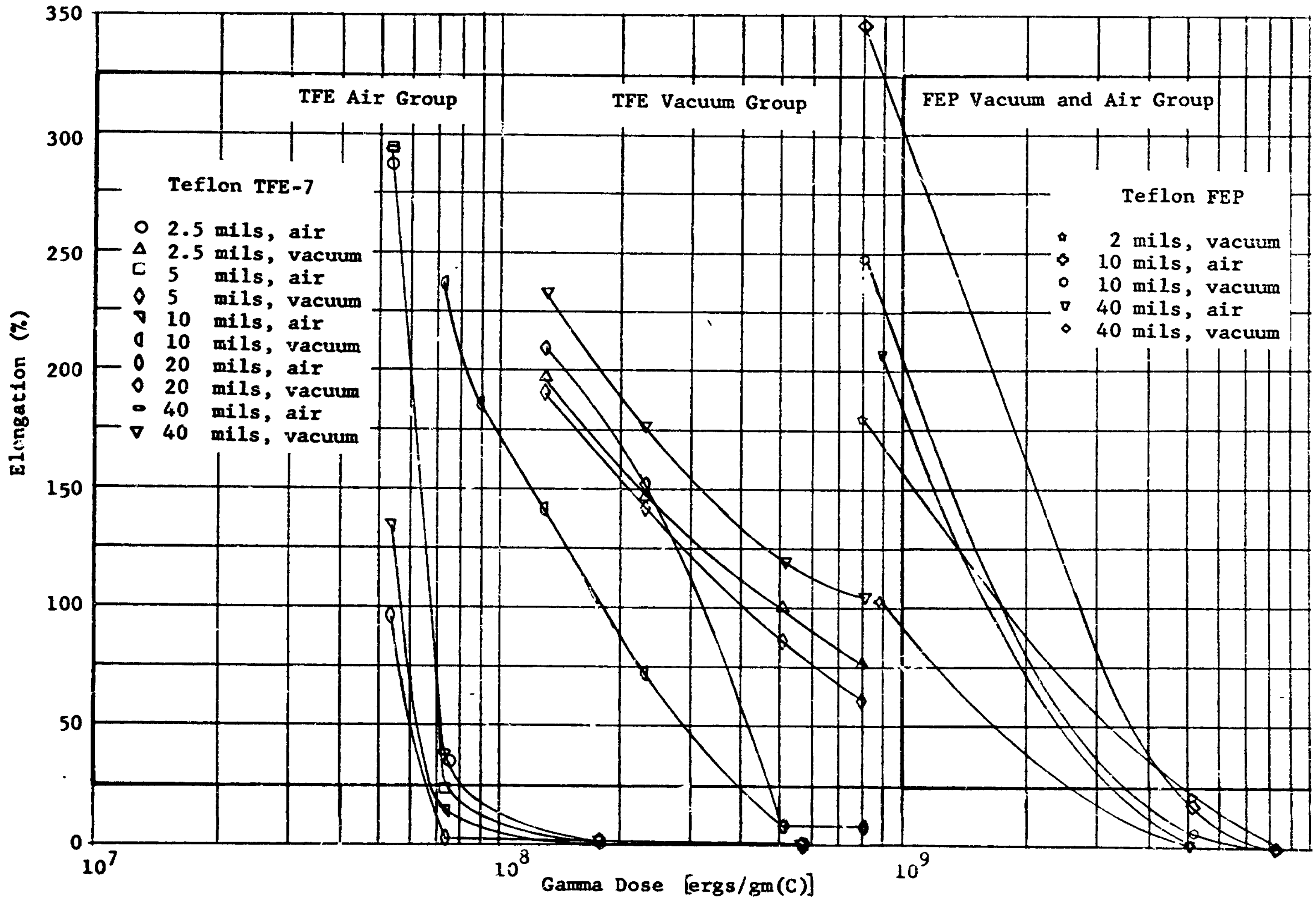


Figure 9.18 Comparison of Ultimate Elongation Values of Various Thicknesses of Teflon TFE and FEP Irradiated in Vacuum and Air

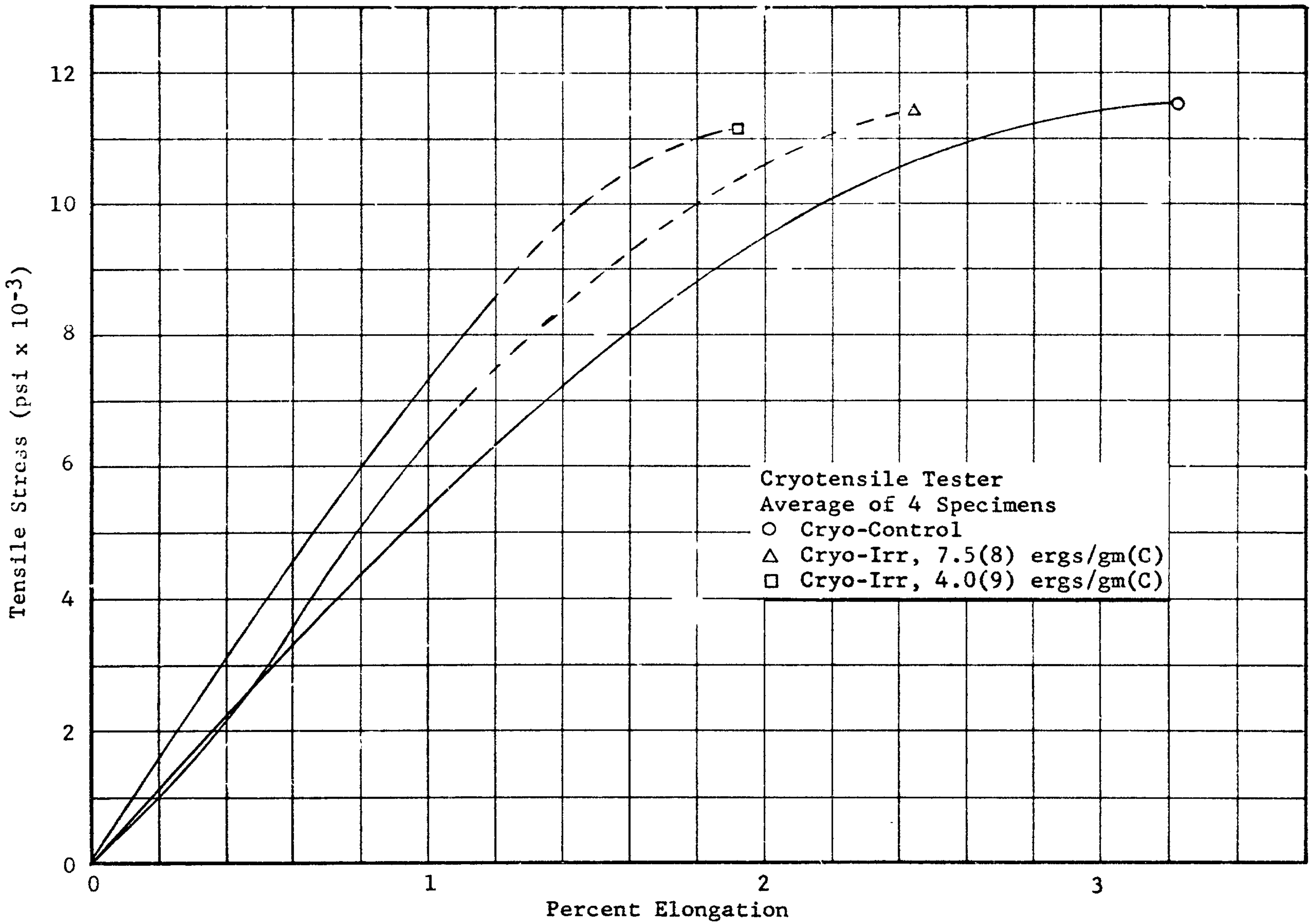


Figure 9.19 Teflon TFE-7 (125-mil) Stress-Strain Curves: LH_2 Irradiation; Dynamic Tests

X. THERMAL-INSULATION TEST METHODS AND TEST RESULTS

Table 10.1

Outline of Thermal Insulation Tests

Material	Type of Test	Irradiation Environment	Nominal Gamma Dose [ergs/gm(C)]	Materials Tester	Test Method		Test Data
					ASTM	Other	
CPR 200-2	Dynamic	Vacuum	5(8)	Low-Force	D-1621-59T Mod.		Load-Deflection Compressive Stress-Strain Curves
		Air	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
		LN_2	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
		LH_2	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
CPR-1021-2	Dynamic	Air	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
		LN_2	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
		LH_2	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
EFS-175	Dynamic	Vacuum	5(8),3(9)	Low-Force	D-1621-59T Mod.		Load-Deflection Compressive Stress-Strain Curves
		Air	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
		LN_2	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
		LH_2	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
Stafoam H-1502	Dynamic	Vacuum	5(8)	Low-Force	D-1621-59T Mod.		Load Deflection Compressive Stress-Strain Curves
		Air	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
		LN_2	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity
		LH_2	5(9),1(10)	T/C Units		GD/FW	Thermal Conductivity

X. THERMAL-INSULATION TEST METHODS AND TEST RESULTS

Four thermal-insulation materials were tested in the current period. The properties of thermal conductivity, load deflection, and compressive stress-strain were determined. The materials tested, environments, and test methods are shown in Table 10.1 on the facing page. Detailed analyses of the test methods and test results are shown below.

10.1 Test Methods

10.1.1 Thermal-Conductivity Test

The technique for making a thermal-conductivity measurement involved submerging the test unit (see Section 2.10) in cryogen (or exposing it to circulated room air) and applying a regulated dc voltage to the test heater sufficient to establish a differential temperature of approximately 50 Fahrenheit degrees between the inner and outer rows of thermocouples. After temperature stabilization had taken place in the system (two to four hours from time of application of power to the heater), voltage and current values to the heater were recorded along with thermocouple EMFs. The EMFs were converted to ^{o}F, and an average of readings was determined for the six inner and the six outer thermocouples. These average readings, along with the calculated heater power and known diametrical spacing of the thermocouples, were then substituted into the equation

$$k = \frac{q \left[\ell n \ (D_2/D_1)\right]}{2\pi h(T_1 - T_2)}$$

where

q is the heater power in Btu/hr

D_1 is the diametrical distance between the two outer thermocouples

D_2 is the diametrical distance between the two inner thermocouples

T_1 is the average of the six inner temperatures in ^oF

T_2 is the average of the six outer temperatures in ^oF

h is the length of the heater in ft

The value of k is given in units of

$$\frac{\text{Btu-in.}}{\text{hr-ft}^2\text{-F}^o}$$

A derivation of the above equation is given in the last annual report (Ref. 4, App. C).

As was mentioned in Section 2.10, a vacuum of approximately 2000 microns was maintained inside both the room-temperature and cryotemperature test units during operation. This was necessary for units submerged in cryogens (see Section 2.10) and allowed data obtained from the room-temperature-air units to be more accurately correlated with the data obtained at cryotemperatures. Figure 10.1 demonstrates the effect that varying degrees of vacuum within the test units had on thermal-conductivity data. As can be noted, the effect was practically negligible down to absolute pressures of 2000 microns. For pressures below this, however, the measured k-value began to rise rapidly. The actual thermal conductivity of the foam would, of course, be expected to decrease with decreases in pressure beyond 2000 microns, so an investigation of the phenomenon was conducted which led to several observations. First, accuracy of the k-value measurements depends upon the efficiency of heat transfer from the foam materials and gases within the cells to the test thermocouple junction; and with only a portion of the junction, on the average, being in direct contact with solid foam material, the conduction of heat from cell gases to the junction becomes significant. Second, if the combined partial pressures of these gases are reduced beyond a certain point (and a pressure of 2000 to 3000 microns is the critical level), then heat will be conducted away from the thermocouple junction (through its lead-in wire) at a rate approaching that at which it is being deposited. The temperature determined from the inner thermocouple readings will then begin to approach that determined from the outer thermocouples, ΔT will become smaller, and the calculated value of k will increase. Pressure within units tested in air and in LN_2 was therefore maintained between 2000 and 3000 microns, which provided good thermocouple readings and prevented the formation of excess condensate. It should be emphasized, incidentally, that when these foam materials are used in sealed systems to insulate cryogens, some condensation (and some reduction in cell-gas pressure) will take place. So experimental conditions in these tests, from this standpoint, more closely simulate actual application conditions than if no vacuum had been maintained in the units.

10.1.2 Compression Test

The rigid, organic, foam materials CPR 200-2, EFS-175, and Stafoam H-1502 were fabricated as compression buttons and subjected to the gamma-dose exposures in vacuum given in Table 10.1. The irradiated specimens were tested in the Low-Force tester while still in vacuum. Specimens were also tested under vacuum-control (unirradiated) conditions.

The test specimens were 1.129-in.-diam by 0.5-in.-high cylinders. During testing, the specimens were compressed at a rate of 0.05 in./min and the load existing at a compression level of 25% was recorded. This test procedure was a modification of ASTM D-1621-59T, since the existing compression test positions in the Low-Force Tester were not exactly adaptable to the specimens described in the standard. The reduced test-specimen size also indicated that in order to obtain more usable data it would be necessary to make the load measurements at 25% instead of the 10% compression specified by the standard.

10.2 Test Results

10.2.1 Thermal-Conductivity Test (CPR 200-2, CPR 1021-2, EFS-175, and Stafoam H-1502)

Data obtained from preirradiation (control) and postirradiation tests over a temperature range of from +90°F to -380°F are given in Table 10.2. The unirradiated control data did not compare closely with that reported by the manufacturers for the temperature range shown above, but the effect of radiation (demonstration of which was, of course, the prime objective of these tests) in this temperature range was established. As can be noted, the effect of irradiation to the maximum gamma dose level achieved $[\sim 3 \times 10^{10}$ ergs/gm(C)$]$ was small to insignificant for all materials tested.

Both the preirradiation (control) and postirradiation data obtained from units submerged in liquid hydrogen were considered questionable and were rejected completely as a result of conclusions reached concerning conditions within the units at temperatures approaching that of LH_2. As can be seen in Table 10.2, k-values obtained with the units submerged in LH_2 were, for all materials tested, significantly higher than those obtained at higher temperatures. Actually, they were a factor of 4 above that which would be expected from extrapolation of thermal-conductivity-versus-temperature curves obtained for higher temperature ranges.

A consideration of temperatures T_1 and T_2 that were recorded during the LH_2 tests leads to the conclusion that they were both below the condensation temperature of gases within the foam cells. This condition thus resulted in liquefaction of these gases, with consequent reduction of pressure in the units from the desired 2000 to 3000 microns. This reduced pressure would be at a level that would produce a k-value of about 0.40 on an exponential extrapolation of the LN_2 temperature curve shown in Figure 10.1. As stated above, the sharp up-turn of these k-value curves at low cell-gas pressures is believed to result from inefficient heat transfer from the foam material to the thermocouple junction, with a resultant lowering of T_1, a smaller value for $T_1 - T_2$, and a resulting higher value for the calculated thermal conductivity.

The experimental design and testing techniques used in preirradiation control-test conditions were duplicated for the irradiation and postirradiation tests so that data obtained in the latter would show clearly the effects of radiation on the materials. A review of the postirradiation data leads to the conclusion that within the temperature range of $+100^{\circ}F$ to $-280^{\circ}F$, radiation effects were slight to insignificant and that all four materials are qualified for use as thermal insulations in radiation environments to the highest gamma dose achieved in the tests, namely, 3×10^{10} ergs/gm(C).

Data obtained in the LH_2 tests, both control and post-irradiation, were considered unreliable. The measured values of thermal conductivity were in the vicinity of 0.35 to 0.45 instead of in the expected range of 0.10 to 0.13. The conclusion is reached that in the temperature range that existed in the test foam with the unit submerged in LH_2, all cell gases froze completely, resulting in partial pressure in the cells of considerably less than 2000 microns. Effects described in the above discussion concerning the data in Figure 10.1 would then predominate and result in errors in the measured values of thermal conductivity.

Although the absolute values of thermal conductivity obtained with the units submerged in LH_2 were unrealistically high, differences between the pre- and postirradiation data thus obtained were insignificant, which strongly suggests that gamma radiation to a level of 5×10^9 ergs/gm(C) had no effect on the thermal conductivity of the materials at temperatures in the vicinity of -400^oF.

A general conclusion is reached from the experiment that although the use of embedded thermocouple junctions for measuring temperatures in cel ar-foam materials has been the practice in many reported experiments, the approach is unsuitable except within temperature and cell-gas pressure ranges comparable to those maintained in these tests. A calorimetry test method, if compatible with other experimental conditions, would possibly be more reliable.

10.2.2 Compression Test (CPR 200-2, EFS-175, and Stafoam H-1502)

The results of compression tests on three thermal-insulation materials, CPR 200-2, EFS-175, and Stafoam H-1502, are given in Tables 10.3, 10.4, and 10.5; the stress-strain data are plotted in Figures 10.2, 10.3, and 10.4. Tests were conducted in the Low-Force Tester under both vacuum-control and vacuum-irradiation conditions.

An analysis of the data leads to the conclusion that, for all three materials, the compression strength was reduced as a result of exposure to a combination vacuum and radiation environment. This reduction was in contrast to data obtained in vacuum control tests.

The capabilities of the Low-Force Tester for testing compression specimens are limited. For example, 1.129-in.-diam compression buttons must be used as compared to ASTM-recommended 4-in.-sq blocks. This small specimen size limits the accuracy of data obtained from individual specimens. Also the number of specimens that can be tested in a single loading of the Low-Force Tester is limited, which serves to restrict statistical quality. Because of these factors, the data shown in the tables are considered to be of marginal reliability.

Table 10.2

Thermal Conductivity Test Data

Test Material	Test Environment	Average Temperature, $(T_1+T_2)/2$ (°F)	Thermal Conductivity (Btu-in./hr-ft^2-°F)			
			Preirr. Control Value	Irradiated Values [at doses shown in ergs/gm(C)]		
				5(9)	1(10)	3(10)
CPR-200-2	Room Air	+106	0.245	0.239	0.250	-
	LN_2	-275	0.167	0.176	0.176	0.179
	LH_2	-410	0.458	0.416	-	-
H-1502	Room Air	+103	0.251	0.240	0.255	-
	LN_2	-273	0.170	0.186	0.186	0.202
	LH_2	-404	0.427	0.388	-	-
EFS-175	Room Air	+104	0.234	0.214	0.235	-
	LN_2	-275	0.170	0.164	0.163	0.168
	LH_2	-403	0.379	0.261	-	-
CPR 1021-2	Room Air	+ 89	0.411	0.436	0.442	-
	LN_2	-271	0.175	0.175	0.175	0.179
	LH_2	-405	0.364	0.423	-	-

Table 10.3

CPR-200-2 Thermal Insulation (Compression Buttons)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Strength at 25% Compres-sion[a] (psi)	Avg. Temp. (F)	Avg. Press. (torr)
	Irrad-iation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)						
					$E < 0.48$ ev	$E > 2.9$ Mev	$E > 8.1$ Mev				
	-	Air	Low Force Tester at 0.05 in./min	0	0	0	0	-	31.8 31.25 31.5/0.5	75	760
	-	Vac	Low Force Tester at 0.05 in./min	0	0	0	0	-	39.5 41.2 40.4/1.5	75	1.0(-3)
	Vac	Vac	Low Force Tester at 0.05 in./min	2.4(8)	5.1(12)	4.4(13)	1.6(13)	-	36.8 37.2 37.0/0.4	80	5.0(-7)

[a]Values given as: average value/standard deviation on an individual basis.

Table 10.4

EFS-175 Thermal Insulation (Compression Buttons)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Strength at 25% Compression[a] (psi)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)						
					$E < 0.48$ ev	$E > 2.9$ Mev	$E > 8.1$ Mev				
	-	Air	Low Force Tester at 0.05 in./min	0	0	0	0	-	30.5 25.75 28.1/4.2	75	760
	-	Vac	Low Force Tester at 0.05 in./min	0	0	0	0	-	31.6 33.5 32.6/1.7	75	1.0(-3)
	Vac	Vac	Low Force Tester at 0.05 in./min	2.4(8)	5.1(12)	4.4(13)	1.6(13)	-	28.5 28.3 28.4/0.2	80	5.0(-7)
	Vac	Vac	Low Force Tester at 0.05 in./min	2.1(9)	4.5(13)	3.9(14)	1.4(14)	-	22.4 25.4 23.9/2.7	125	1.4(-6)

[a] Values given as: average value/standard deviation on an individual basis.

Table 10.5

Stafoam H-1502 Thermal Insulation (Compression Buttons)
Summary Table of Test Results

Specimen Number	Environment			Radiation Exposure				Time Until Test (days)	Strength at 25% Compression[a] (psi)	Avg. Temp. (F)	Avg. Press. (torr)
	Irradiation	Test	Tester	Gamma Dose [ergs/gm(C)]	Neutrons (n/cm^2)						
					E < 0.48 ev	E > 2.9 Mev	E > 8.1 Mev				
	-	Air	Low Force Tester at 0.05 in./min	0	0	0	0	-	40.5 36.9 38.7/3.2	75	760
	-	Vac	Low Force Tester at 0.05 in./min	0	0	0	0	-	53.0 46.5 49.7/5.76	75	1.0(-3)
	Vac	Vac	Low Force Tester at 0.05 in./min	2.4(8)	5.1(12)	4.4(13)	1.6(13)	-	38.0 45.7 41.9/6.8	80	5.0(-7)

[a]Values given as: average value/standard deviation on an individual basis.

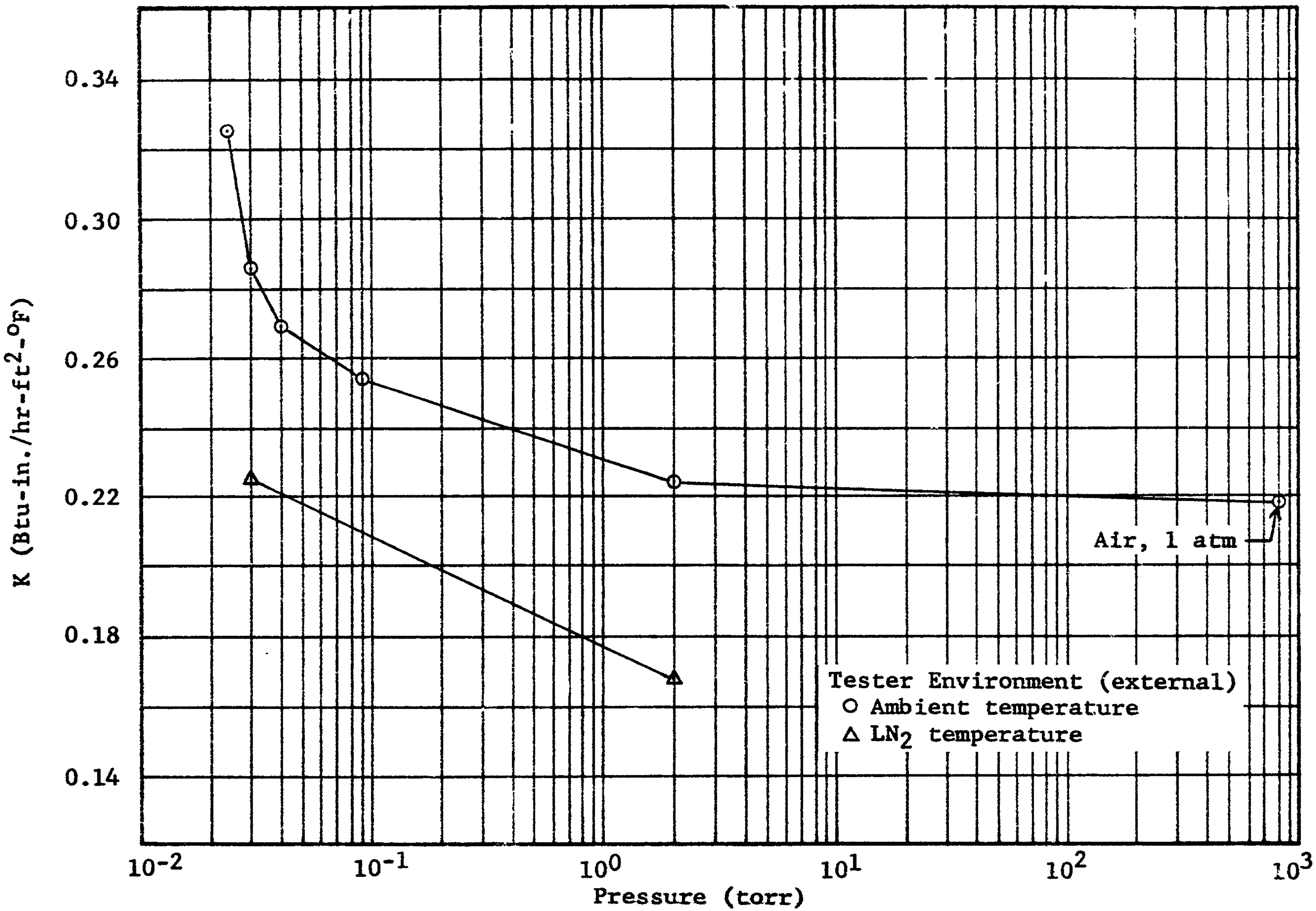


Figure 10.1 Thermal Conductivity of CPR-200-2 Foam at Various Internal Pressures and Temperatures

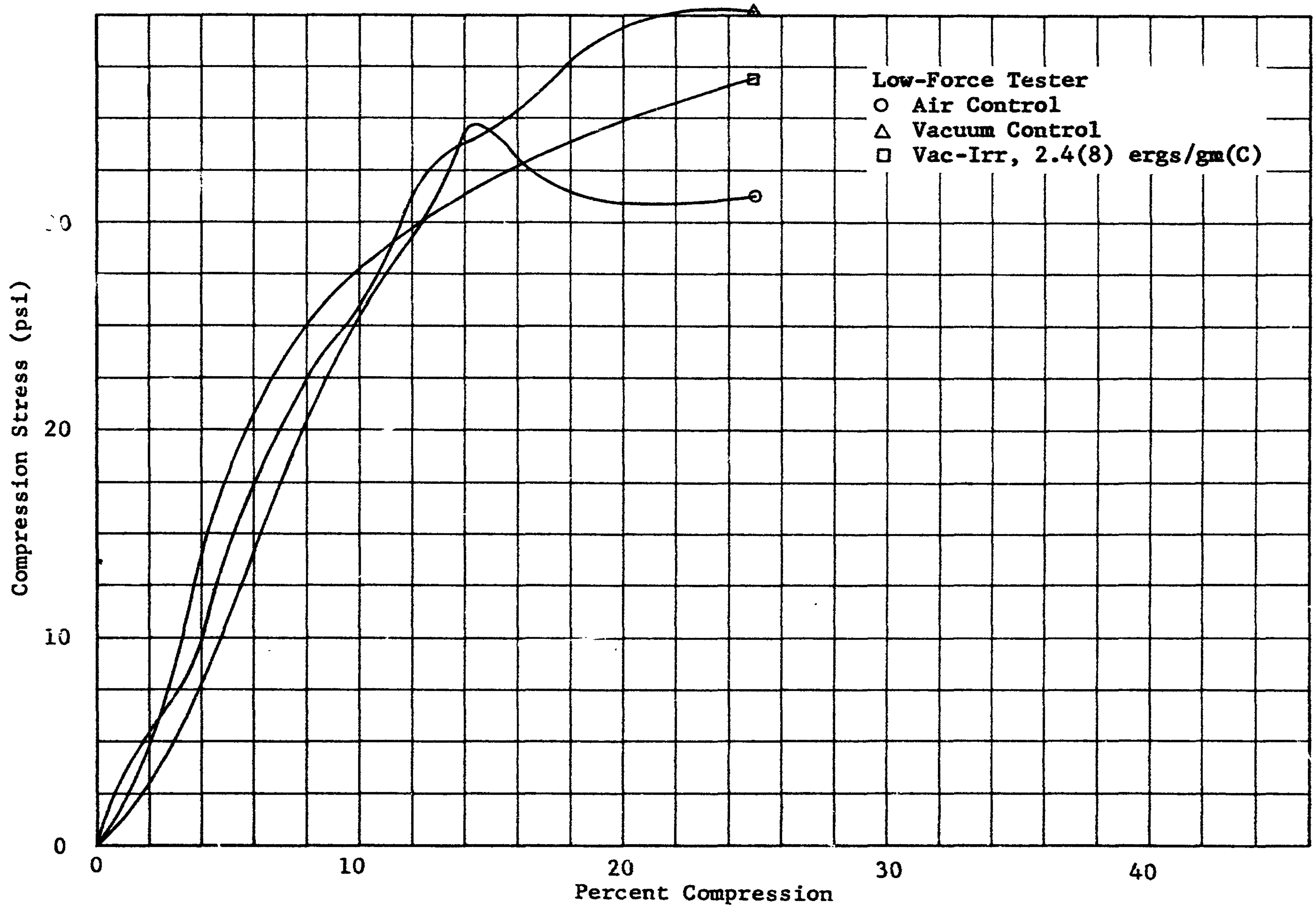


Figure 10.2 CPR-200-2 Compressive Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

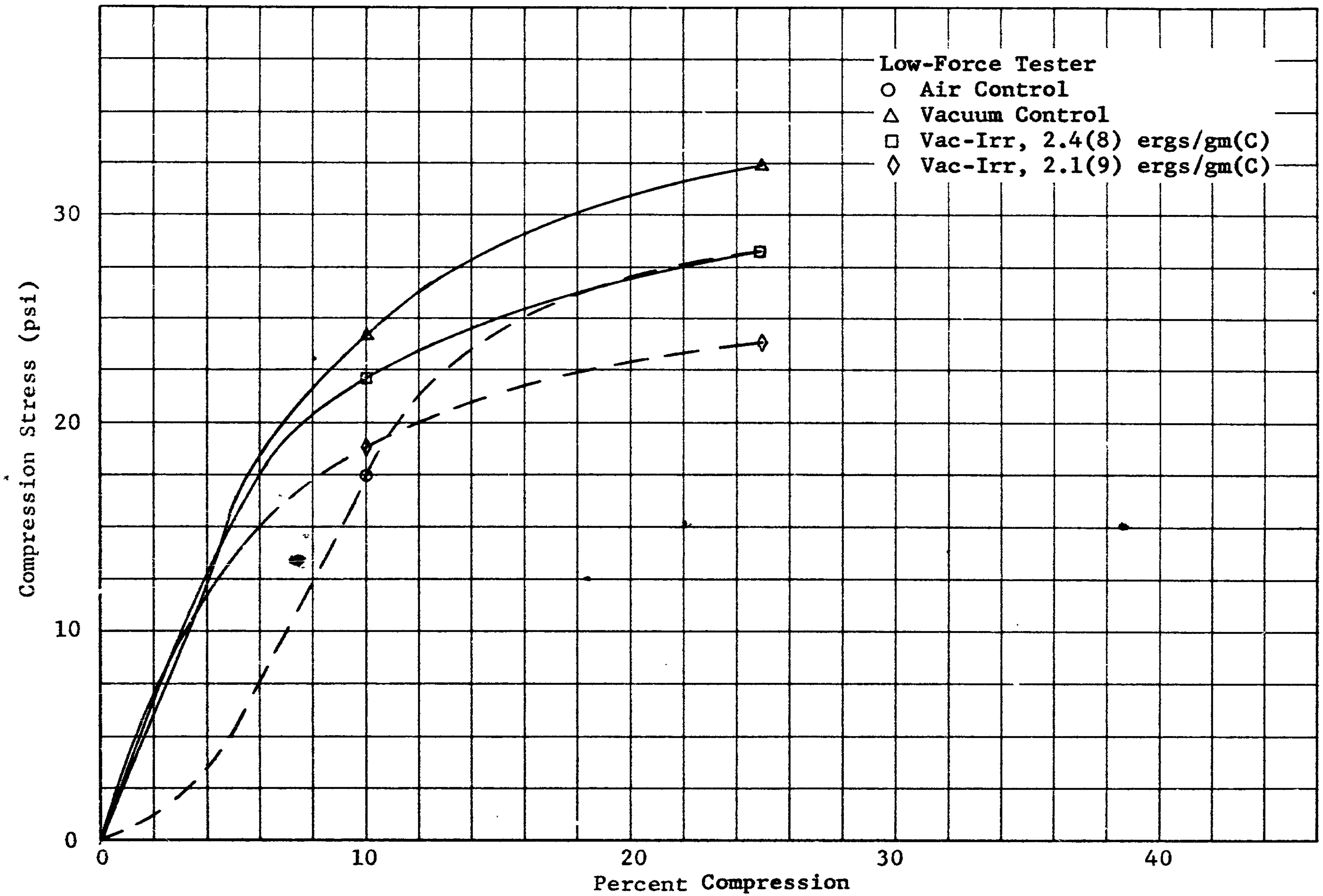


Figure 10.3 EFS-175 Compressive Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

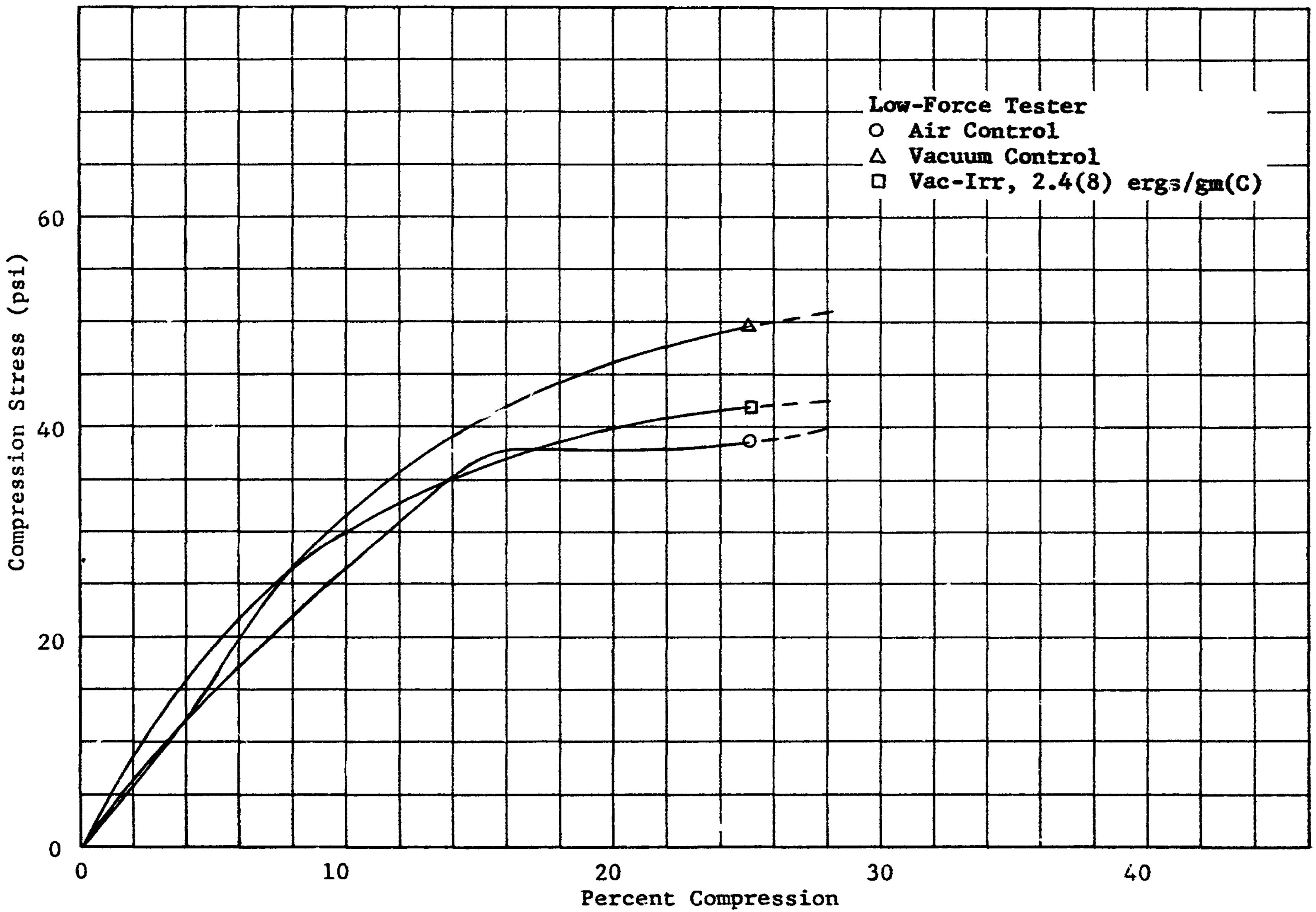


Figure 10.4 Stafoam H-1502 Compressive Stress-Strain Curves: Vacuum Irradiation; Dynamic Tests

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XI. LUBRICANT TEST METHODS AND RESULTS

Table 11.1

Outline of Lubricating Efficiency Tests[a]

Material	Type of Test	Environment	Nominal Gamma Dose [ergs/gm(C)]	Motor Speed and Power Input
Almasol SFD-238	Dynamic	Vacuum Control Air Irradiated Vacuum Irradiated	 Continuous to 1(10) Continuous to 1(10)	6000 rpm Low Power Input 6000 rpm Low Power Input 6000 rpm Low Power Input
DC-705	Dynamic	Vacuum Control Vacuum Control Vacuum Control Air Irradiated Vacuum Irradiated	 Continuous to 1(10) Continuous to 1(10)	6000 rpm High Power Input 3000 rpm High Power Input 6000 rpm Low Power Input 6000 rpm Low Power Input 6000 rpm Low Power Input
Durcid	Dynamic	Vacuum Control Vacuum Control		6000 rpm High Power Input 6000 rpm Low Power Input
Electrofilm 66-C	Dynamic	Vacuum Control Vacuum Control		6000 rpm High Power Input 6000 rpm Low Power Input
ETR-H	Dynamic	Vacuum Control Vacuum Control		6000 rpm High Power Input 6000 rpm Low Power Input
FS-1265	Dynamic	Vacuum Control Vacuum Control		3000 rpm High Power Input 6000 rpm Low Power Input
GE F-50	Dynamic	Vacuum Control Vacuum Control		6000 rpm High Power Input 6000 rpm Low Power Input
Kynar (filled)	Dynamic	Vacuum Control Vacuum Control Vacuum Control Air Irradiated Vacuum Irradiated	 Continuous to 1(10) Continuous to 1(10)	6000 rpm High Power Input 3000 rpm High Power Input 6000 rpm Low Power Input 6000 rpm Low Power Input 6000 rpm Low Power Input
Minapure	Dynamic	Vacuum Control Vacuum Control		3000 rpm High Power Input 6000 rpm Low Power Input
MLF-5	Dynamic	Vacuum Control Vacuum Control		6000 rpm High Power Input 6000 rpm Low Power Input
OS-124	Dynamic	Vacuum Control Vacuum Control Vacuum Control Air Irradiated Vacuum Irradiated	 Continuous to 1(10) Continuous to 1(10)	6000 rpm High Power Input 3000 rpm High Power Input 6000 rpm Low Power Input 6000 rpm Low Power Input 6000 rpm Low Power Input
Polymer SP-F	Dynamic	Vacuum Control Vacuum Control Vacuum Control Air Irradiated Vacuum Irradiated	 Continuous to 1(10) Continuous to 1(10)	6000 rpm High Power Input 3000 rpm High Power Input 6000 rpm Low Power Input 6000 rpm Low Power Input 6000 rpm Low Power Input

[a]General Dynamics developed bearing test method.

XI. LUBRICANT TEST METHODS AND RESULTS

Tests were conducted to determine the operational lubrication performance of several types of oils, greases, solid films, and retainers. The Program Summary table shown at the beginning of this report lists all of the bearing lubricants tested during the three contractual periods in the program (two annual and one biennial), and applicable reports covering each lubricant are referenced. Table 11.1 (facing page) contains a summary of the test conditions, environments, and doses for each lubricant tested under this category in the current period.

The essential parameters measured in the tests are operating time, motor coastdown time, and motor speed during coastdown. The bearings were examined with a binocular microscope after completion of the various tests.

A test plan, outlined below, was devised for each of the environmental conditions:

- Control Run in Vacuum, Low Power Input - The motors were operated in vacuum at the minimum electrical power required to sustain 6000 rpm during the total operating time of the lubricant. Several tests were required to evaluate all of the lubricants selected in the program. Not all lubricants were run to failure.

- Control Run in Vacuum, High Power Input - The motors were operated at full-rated power to phase 1 and minimum power to phase 2 to control the speed. This standard method, recommended by the vendor, proved to generate too much heat for good bearing service.

- Irradiation in Air, Low Power Input - The motors were operated in air for approximately 1¼ hr before irradiation, then for 11 hr in air while being irradiated. The reactor was operated at a power level of 500 kw for the first hour, then at 3 Mw for the remainder of the exposure, except when it was stopped for data cycles. After the irradiation, the motors were operated until bearing failure or for a maximum of 787 hr.

- Irradiation in Vacuum, Low Power Input - While in an uninterrupted vacuum environment, the motors were operated for 2 hr before irradiation, for 21 hr during reactor radiation, then for 620 hr after irradiation. The reactor was operated at a power level of 500 kw for 1¼ hr, then at 3 Mw for the remainder of the exposure, except when it was stopped for data cycles.

The vacuum was maintained at between 10^{-6} and 10^{-7} torr. The contractual requirement of operating the motors for a minimum of 250 hr during each run was exceeded in every case. The motors were operated to failure, or to the maximum time allowed in the ιadiation schedule.

The vacuum control tests were conducted on the same lubricant materials as were tested last year (Ref. 3). The same test method was also used. This method, recommended by the vendor of the motors, requires applying full-rated power to phase 1 and adjusting the power to phase 2 to control the speed. This method provided good speed control, but the dissipation of approximately 25 watts of power in the motors generated too much heat. The test results presented in Tables 11.2 and 11.3 show that this power overheated the bearing and resulted in a very short operating life.

A control test was run at 3000 rpm to evaluate the effects of reduced speed on bearing life. These results are presented in the data tables.

The method of operating the motors for the remainder of the test program was altered to provide a lower power input. The voltages to each phase of the motors were set equal and lowered to a minimum value to operate the motors at the desired speed. This method proved to be more efficient, and the motors could be operated at approximately 5 watts. As can be seen in Table 11.2, this increased the operating life of the lubricants.

The results of the bearing-lubricant tests are shown in Figures 11.1 through 11.49 and Tables 11.2 and 11.3. All tests were conducted at low-power input at 6000 rpm, unless otherwise indicated. Bearing failures were considered to have occurred when the servomotors stopped the first time.

A post-test calibration check of the motor field currents reported in Reference 3 showed the meter readings to be in error. The original and corrected values are shown in Table 11.4.

11.1 Almasol SFD-238

11.1.1 Vacuum Irradiation

One set of bearings lubricated with Almasol operated for 21 hr in a vacuum-radiation environment and for an additional 23 hr in vacuum before failure. Another set of bearings lubricated with Almasol failed prior to irradiation. In Figure 11.1 , the very significant decrease in coastdown time prior to failure is evident in the 43-hr-operating-time curve. The temperature rise of the bearings was not significant, but the current required for operation of the servomotors at 6000 rpm almost tripled in value.

Post-test examinations of the bearings revealed the following:

- The bearings were full of debris.
- The bearings were binding in their races.
- The races were worn and pitted.
- Most of the lubricant was worn off.

11.1.2 Air Irradiation

One set of bearings operated for 10 hr in an air-radiation environment and for an additional 335 hr in air before failure.

The other set of bearings operated during irradiation, but only for about 60 hr after irradiation. Figures 11.2 and 11.3 show the speed during coastdown for the two sets of bearings. No significant changes in temperature were observed, but the coastdown times of Motor 11 decreased significantly prior to failure.

Post-test examinations of the bearings revealed the following:

- Considerable debris was in the bearings of Motor 10; one of the bearings was locked; and the retainer was worn in half.

- The bearings from Motor 11 were clean, but the retainers showed considerable wear.

11.1.3 Vacuum Control

One set of bearings (in Motor 9) operated for 410 hr in vacuum before failure, but the other set (in Motor 10) failed after 35 hr (Figs. 11.4 and 11.5). The mode of failure of Motor 9 consisted of a decrease in coastdown time, followed by an increase in coastdown time prior to failure. Examination of both sets of bearings showed that:

- The bearings were considerably worn.

- There was no evidence of a lubricant coating remaining.

- The balls and races were pitted.

11.2 DC-705

11.2.1 Vacuum Irradiation

One of the two sets of bearings operated satisfactorily during a 21-hr vacuum irradiation, but failed after only 38 hr of postirradiation operation in vacuum. It was possible, however, to restart this motor (No. 5) and the bearings operated for the duration of the test (644 hr) with only two additional stops. The other set of bearings (in Motor 6) operated without failure during the 21-hr vacuum irradiation, then for 623 hr in vacuum. The curves showing speed during coastdown are given in Figures 11.6 and 11.7. A 622-hr coastdown curve is not shown for Motor 5. It is comparable to the one shown for Motor 6, but had a coastdown time of 2.6 min.

Post-test examination of the bearings revealed the components of all the bearings to be bright and shiny with no signs of wear. Sufficient oil remained in all bearings, but it had turned from the original water-clear color to a straw color. No cause of the operating discrepancy between the two bearing sets was apparent; it is possible that one of the bearings in Motor 5 was a little tight.

11.2.2 Air Irradiation

Both sets of bearings operated without failure for 11 hr in an air-radiation environment, then for 787 hr in air. The speed-during-coastdown curves are shown in Figures 11.8 and 11.9.

Post-test examination of the bearings showed them to be in good condition with sufficient oil remaining and no signs of bearing wear.

11.2.3 Vacuum Control

Both sets of bearings operated for 750 hr in vacuum without failure. The speed-during-coastdown curves, presented in Figures 11.10 and 11.11, show that little change occurred.

Post-test examination of the bearings showed them to be in very good condition with a sufficient amount of lubricant remaining.

11.2.4 Vacuum Control, High Power to Phase 1

Bearing operation was unsatisfactory during tests conducted at 6000 rpm and 3000 rpm with high power to phase 1 of the motors. The two sets of bearings operating at 6000 rpm failed after 22 and 64 hr, and the set operating at 3000 rpm failed after only 2.5 hr.

It is believed that the failures were caused by excessive bearing temperatures that resulted from a rise in the motor temperatures due to inefficient motor operation (high power to phase 1) and from poor heat transfer due to vacuum insulation. Post-test examination of the bearings showed that:

- Black, carbon-like deposits were on the inside of the shields, races, and retainers.
- The lubricant had a dark color.
- The bearing races showed excessive wear and the balls and races were pitted.

11.3 Duroid

11.3.1 Vacuum Irradiation, High Power to Phase 1

These tests were cond' cted in the previous period (Ref. 3). The results are summarized in Table 11.2 of this report.

11.3.2 Air Irradiation, High Power to Phase 1

These tests were conducted in the previous period (Ref. 3). The results are summarized in Table 11.2 of this report.

11.3.3 Vacuum Control

These bearings, with Duroid retainers, were operated in vacuum for 437 hr without failure. Very significant increases in coastdown time can be seen from Figures 11.12 and 11.13. The motor field currents decreased from 30 ma to approximately 17 ma for 6000-rpm operation. Post-test examination of the bearings showed them to be in good condition.

11.3.4 Vacuum Control, High Power to Phase 1

These bearings, with Duroid retainers, failed after approximately 1 hr of operation. Significant increases in indicated bearing temperature were observed (75°F to about 140°F). This is in sharp contrast to the continuously cool (65°F) operation in vacuum with low power to the motors.

Post-test examination of the bearings showed some damage. Failure is believed to have been caused by a combination of wear and unequal expansion of the bearing parts as they became heated. After failure, the motor could be operated for short periods of time when allowed to cool.

11.4 Electrofilm 66-C

11.4.1 Vacuum Irradiation, High Power to Phase 1

These tests were conducted in the previous period (Ref. 3). The results are summarized in Table 11.2 of this report.

11.4.2 Air Irradiation, High Power to Phase 1

These tests were conducted in the previous period (Ref. 3). The results are summarized in Table 11.2 of this report.

11.4.3 Vacuum Control

One set of bearings operated for 437 hr in vacuum without failure, while the other set failed after 145 hr. The coastdown-speed-versus-time curves in Figure 11.14 of the bearings that failed show that the coastdown time initially increased, then progressively decreased to failure. The curves for the other set of bearings are shown in Figure 11.15. Because of instrumentation difficulties that precluded obtaining coastdown data during the latter portion of the test, curves of coastdown data taken in air before and after the operation-in-vacuum period are also presented in Figure 11.15.

Post-test examination of the bearings from the motor that failed revealed the following:

- One bearing would not turn.
- Retainers appear to have been dragging on the outer races and were severely worn.
- Severe wear in channels and loss of lubricant occurred in the inner and outer races.
- The balls were rough and pitted.

Post-test examination of the bearings from the motor that was stopped after running 437 hr revealed the following:

- Some wear was evident on the ball pockets of the retainer.
- The dry film was worn through in spots on the outer race.
- The balls showed slight surface roughness.

11.4.4 Vacuum Control, High Power to Phase 1

One set of bearings failed almost immediately in vacuum, and the other set failed after approximately 1 hr of operation.

A significant bearing temperature rise (75°F to about 140°F) was observed. The bearings would operate for a very short period after cooling off; after the test, operation was possible in an air environment. These bearings apparently failed from a combination of bearing wear and bearing seizure due to elevated temperature.

11.5 ETR-H

11.5.1 Vacuum Irradiation, High Power to Phase 1

These tests were conducted in the previous period (Ref. 3). The results are summarized in Table 11.1 of this report.

11.5.2 Air Irradiation, High Power to Phase 1

These tests were conducted in the previous period (Ref. 3). The results are summarized in Table 11.1 of this report.

11.5.3 Vacuum Control

The bearings lubricated with this Shell grease operated for 437 hr without failure. Only small changes in the coastdown characteristics occurred, as shown in Figures 11.16 and 11.17. Post-test examination of the bearings showed them to be in very good condition with plenty of grease remaining and no signs of wear.

11.5.4 Vacuum Control, High Power to Phase 1

Both sets of bearings operated for 270 hr without failure. ETR-H demonstrated the most satisfactory performance of all the lubricants tested under this condition. The speed-during-coastdown curves (Figs. 11.18 and 11.19) show an initial decrease followed by an increase in coastdown times. Post-test examination of the bearings showed them to be in good condition with no signs of wear.

11.6 FS-1265

11.6.1 Vacuum Control

The bearings lubricated with FS-1265 operated for 752 hr without failure. Increases in coastdown time with test duration are shown in Figures 11.20 and 11.21. Post-test examination of the bearings showed them to be in very good condition with sufficient lubricant remaining.

11.6.2 Vacuum Control, High Power to Phase 1

One set of bearings failed after 45 hr, and the other set of bearings failed after 22 hr of operation. Post-test examination showed signs of lubricant deterioration from excessive temperatures, as evidenced by black deposits on the shields and a darkened color of the lubricant.

11.7 GE F-50

11.7.1 Vacuum Irradiation, High Power to Phase 1

These tests were conducted in the previous period (Ref. 3). The results are summarized in Table 11.2 of this report.

11.7.2 Air Irradiation, High Power to Phase 1

These tests were conducted in the previous period (Ref. 3). The results are summarized in Table 11.2 of this report.

11.7.3 Vacuum Control, Phenolic Bearing Retainers

Of the two sets of bearings that contained phenolic retainers, one operated for 1000 hr without failure and the coastdown times progressively increased, as shown in Figure 11.22. The other set of bearings failed after operating for 514 hr; the decrease in coastdown time prior to failure is shown in Figure 11.23. Post-test examination of the bearings showed them to be in good condition with no appreciable wear. No cause of failure could be ascertained.

11.7.4 Vacuum Control, Standard Ribbon Retainers

Both sets of bearings operated for 437 hr without failure. Little change occurred in the speed-during-coastdown curves, as shown in Figures 11.24 and 11.25. Post-test examination showed the bearings to be in very good condition with sufficient lubricant remaining.

11.7.3 Vacuum Control, - High Power to Phase 1

Bearing failures occurred after 13 hr of operation for one set and after 23 hr of operation for the other set (Figs. 11.26 and 11.27). A significant bearing temperature rise (75°F to about 150°F) was observed during operation. After the failures, the bearings would operate for short periods of time after they had cooled. One of the bearing sets would operate satisfactorily in air after the test. Post-test examination of the bearings indicated that the probable cause of failure was a combination of lubricant deficiency and bearing seizure due to the elevated temperature.

Visual inspection of the motor that operated for 14 hr revealed that:

- A black carbon-like deposit was visible throughout the bearings.
- The balls were worn and pitted.

Visual inspection of the motor that operated for 23 hr revealed that:

- Very little lubricant was left in the bearings.
- The balls were clean and bright and showed no signs of wear.

11.8 Kynar (filled)

11.8.1 Vacuum Irradiation

One set of bearings with Kynar retainers operated for 644 hr without failure; this included 21 hr of initial operation in a radiation environment. The other set of bearings, however, failed after only 6 hr of postirradiation operation for a total of 27 hr. The speed-during-coastdown curves are shown in Figures 11.28 and 11.29.

Post-test examination of the bearings that failed revealed the following:

- Considerable debris was in the bearings.
- The outside races were pitted and worn.
- The inner races were worn, discolored, and rough.
- The balls were pitted, discolored, and covered with black film.

The bearings that did not fail were similar in appearance, but had suffered less damage. The indicated maximum bearing temperature of 100°F was not excessive.

11.8.2 Air Irradiation

One set of bearings operated without failure for 10 hr in an air-radiation environment followed by 788 hr of postirradiation operation. The other set of bearings operated during the 10-hr irradiation period, but failed after 383 hr of postirradiation operation. The speed-during-coastdown curves are shown in Figures 11.30 and 11.31. The field currents of the motor associated with the bearings that failed increased from an initial 43 ma to 57 ma prior to failure; this was in sharp contrast to a decrease of from 44 to 40 ma for the motor containing the bearings that did not fail. The maximum indicated bearing temperature was 99°F.

Post-test examination of the bearings that failed revealed the following:

- The bearings were full of debris.
- The races were worn and pitted.
- The balls had a surface roughness and dark-brown material adhering to them.

The bearings that did not fail appeared to be in fairly good condition in all respects.

11.8.3 Vacuum Control

One set of bearings operated for 2014 hr without failure, while the other set failed after 827 hr of operation. The curves of coastdown speed versus time are shown in Figures 11.32 and 11.33. Considerable variation in coastdown times is evident.

There is no evident cause of failure for the bearings retainers that operated for 827 hr. These bearings were worn to about the same degree as the set that operated for 2014 hr without failure. The wear in the retainers was in the ball pockets, the original round shape having been worn into an oval shape. The performance of the bearings that did not fail was better from the start than those that failed.

11.8.4 Vacuum Control, High Power to Phase 1

Both sets of bearings failed after only 1½ hr of operation. Cause of failure was attributed to excessive localized heating of the bearings, which caused the Kynar retainers to soften. The failure of the Kynar was very evident upon post-test examination of the bearings.

11.9 Minapure

11.9.1 Vacuum Control

Both sets of bearings operated for 1000 hr without failure. Typical speed-during-coastdown curves are shown in Figures 11.34 and 11.35. These curves show the increases in coastdown times as the test progressed. Post-test examination of the bearings showed them to be in very good condition with no evident loss of lubricant.

11.9.2 Vacuum Control, High Power to Phase 1

One set of bearings failed after 20 hr of operation, while the other set failed after 65 hr. Cause of failure is attributed to breakdown of the lubricant due to excessive localized heating of the bearings. Post-test examination of the bearings showed the lubricant to be very coarse in texture, resembling fine white sand.

11.10 MLF-5

11.10.1 Vacuum Irradiation

These tests were conducted in the previous period (Ref. 3). The results are summarized in Table 11.2 of this report.

11.10.2 Air Irradiation, High Power to Phase 1

These tests were conducted in the previous period (Ref. 3). The results are summarized in Table 11.2 of this report.

11.10.3 Vacuum Control

One set of bearings operated for 437 hr without failure, while the other set failed after 342 hr of operation. Typical speed-during-coastdown curves are shown in Figures 11.36 and 11.37. Because of instrumentation difficulties that occurred with Motor 6 during the latter half of the test in vacuum, curves of coastdown data taken in air before and after the vacuum run are also shown in Figure 11.36.

Initial operation of the bearings that failed was not as good as the other set of bearings, and the field currents of the motor (No. 5) containing the bearings that failed increased from

25 to 38 ma. Post-test examination of these bearings revealed the following:

- One of the bearings had seized.
- A considerable amount of debris was in the bearings.
- The races and retainers were slightly pitted.
- Most of the dry-film lubricant appeared to have worn off.
- The balls had a slight surface roughness.

11.10.4 Vacuum Control, High Power to Phase 1

One set of bearings failed after 4 hr of operation and the other set after 1 hr. The indicated bearing temperatures rose rapidly from 75°F to 150°F. After the failures, it was possible to operate the bearings for short periods of time after they had cooled. After the test, it was possible to operate the bearings in air.

The cause of the failures is attributed to bearing seizure caused by excessive localized heating and wear of the solid-film lubricant. Post-test examination of the bearings revealed the following:

- The bearings were full of debris.
- The balls were very rough.
- The outside races were rough.

11.11 OS-124

11.11.1 Vacuum Irradiation

This polyphenyl-ether lubricant demonstrated outstanding performance. Both sets of bearings operated for 644 hr without failure. The initial 21 hr of operation was in a vacuum-radiation environment followed by 623 hr in vacuum. Typical speed-during-coastdown curves are shown in Figures 11.38 and 11.39. Post-test examination of the bearings showed them to be in very good condition with sufficient lubricant remaining in the bearings.

11.11.2 Air Irradiation

Both sets of bearings operated for 10 hr in an air-radiation environment followed by 788 hr of operation in air without failure. Some typical speed-during-coastdown curves are shown in Figures 11.40 and 11.41. Post-test examination of the bearings showed them to be in very good condition with sufficient lubricant remaining in the bearings.

11.11.3 Vacuum Control

Both sets of bearings operated for 752 hr without failure. Typical speed-during-coastdown curves are shown in Figures 11.42 and 11.43. The coastdown times of Motor 3 were significantly higher than those of Motor 4; this is attributed, at least partly, to the larger quantity of lubricant remaining in the bearings of Motor 3. Post-test examination of the bearings showed them to be in very good condition.

11.11.4 Vacuum Control, High Power to Phase 1

Both sets of bearings operated satisfactorily for 92 hr at 6000 rpm, after which they were operated at 3000 rpm to failure. Failure occurred after 9 hr for one set and 16 hr for the other.

The cause of the failures is attributed to excessive localized heating and lubricant deterioration. The indicated bearing temperatures rose rapidly to approximately 150°F. Post-test examination of the bearings showed the existence of black deposits and a darkened color of the lubricant.

11.12 Polymer SP-F

11.12.1 Vacuum Irradiation

Both sets of bearings operated satisfactorily in a vacuum-radiation environment for about 22 hr. In vacuum, after the irradiation, one set of bearings failed after 119 hr and the other set failed after 47 hr of operation. Very significant decreases in coastdown time can be seen from the typical curves shown in Figures 11.44 and 11.45.

Post-test examination of the bearings revealed the following:

- The bearings were full of debris.
- The retainers were worn completely through.
- The races showed considerable wear and pitting.

Indicated bearing temperatures during the test were about 105°F or less.

11.12.2 Air Irradiation

Both sets of bearings operated for 798 hr without failure. The initial 11 hr was in an air-radiation environment, followed by 787 hr of postirradiation operation. Speed-during-coastdown curves are shown in Figures 11.46 and 11.47. Post-test examination of the bearings revealed the following:

- The bearings showed some wear.
- The bearings contained some debris.
- The races showed a small amount of pitting.

11.12.3 Vacuum Control

One set of bearings operated for 420 hr without failure, and the other set failed after 255 hr of operation. The speed-during-coastdown curves presented in Figures 11.48 and 11.49 show increases in coastdown times followed by decreases prior to failure. The maximum indicated bearing temperature was about 90°F. Post-test examination of the bearings revealed the following:

- The retainer ball pockets were severely worn by as much as three-fourths of the distance to the next pocket.

- The balls were only slightly pitted.

- The races were worn a negligible amount.

11.12.4 Vacuum Control, High Power to Phase 1

During the 6000-rpm operation, one set of bearings failed after 37 hr of operation, and the other set failed after 64 hr. During the 3000-rpm operation, one set of bearings failed after only 3½ hr, while the other set operated for 72 hr prior to failure.

Post-test examination of the bearings containing the Polymer SP-F retainers revealed the following:

- The ball pockets were heavily worn.

- Black powder was highly concentrated on the inner and outer races.

- The outer races were worn excessively.

- The balls were worn and the races were channeled.

- Plastic and copper adhered to the balls.

It is believed that the failures were caused by the flaking off of small pieces of the retainer, which finally jammed the bearing. The bearings experienced a significant temperature rise, from 75°F to about 140°F.

11.13 General Discussion of Results

The polyphenyl-ether lubricant OS-124 demonstrated outstanding performance. No failures occurred in either air or vacuum environments during or after irradiation to gamma doses of about 1×10^{10} ergs/gm(C). Test durations were approximately 800 hr in air and 650 hr in vacuum. A 750-hr control run in vacuum was also satisfactorily completed.

The bearings lubricated with the silicone fluid DC-705 demonstrated superior performance, even though one set of bearings failed shortly after the vacuum-radiation period. It was possible to restart the motor that failed and operate the bearings for the duration of the test. The other set of bearings operated without failure for about 650 hr and received a gamma dose of about 1×10^{10} ergs/gm(C). No failures occurred during or after air-environment testing to a gamma dose of about 1×10^{10} ergs/gm(C) and a postirradiation-test duration of about 800 hr. Two other sets of bearings operated for 750 hr without failure during a vacuum control run.

The vacuum control tests conducted with high power to phase 1 of the motors indicate that failures observed previously (Ref. 3) during vacuum-radiation tests were probably caused by excessive localized heating. With the exception of the Shell grease ETR-H, the bearing failure times for the vacuum control runs were all less than the vacuum-radiation failure times. The bearings lubricated with ETR-H probably failed from a combination of radiation damage and overheating of the motors. The bearings operated for 270 hr in vacuum without failure, but failed in approximately 25 hr during the vacuum-radiation test. Two sets of bearings also operated without failure for 200 hr during the air-radiation test. A similar situation occurred during tests of bearings with Polymer SP-F retainers, which were conducted with low power to phase 1 of the motors. These bearings operated in air for about 800 hr without failure after being irradiated, but failed after an average time of only 105 hr during the vacuum-radiation test. In addition, they failed after an average time of 337 hr during the vacuum control test.

Table 11.2

Bearing Lubricant Test Results

Lubricant	Operating Time (hr)				Gamma Dose[g] [ergs/gm(C)]	
	Vacuum Control		Air[f] Irradiated	Vacuum[f] Irradiated	Air Irradiated	Vacuum Irradiated
	High Input	Low Input				
Almasol SFD-238		410F 35F	345 F 70 F	0 F 44 F	6.7(9) 6.0(9)	0 6.8(9)
DC-705	22 F 67 F 2.5F[a]	752 752	798 798	59 F 644	6.7(9) 6.0(9)	7.6(9) 6.8(9)
Duroid	1 F 1 F	437 437	23.95F[b] 61.87F[b]	10.6F[b]	1.1(10) 1.1(10)	1.8(9)
Electrofilm 66-C	0 F 1 F	168F 437	26.48F[b]	7.3F[b] 7.4F[b]	1.1(10) 1.1(10)	6.3(8) 6.6(8)
ETR-H	270 270	437 437	200[b] 200[b]	29.6F[b] 21.1F[b]	1.1(10) 1.1(10)	1.1(10) 6.3(9)
FS-1265	45 F[a] 22 F[a]	752 752				
GE-F50	23 F 13 F	514F[e] 1000[e] 437 437	25.15F[b] 48.20F[b]	20.9F[b] 15.5F[b]	1.1(10) 1.1(10)	6.1(9) 3.0(9)
Kynar	1.5F 1.5F 0.9F[a]	2014[c] 827F	393 F 798	27 F 644	6.7(9) 6.0(9)	4.6(9) 6.8(9)
Minapure	20 F[a] 64.5F[a]	1000 1000				
MLF-5	[illegible] F 1 F	342F 437	75.67F[b] 82.51F[b]	21.0F[b]	1.1(10) 1.1(10)	6.2(9)
OS-124	9 F[d] 16 F[d] 92 92	752 752	798 798	644 644	6.7(9) 6.0(9)	7.6(9) 6.8(9)
Polymer SP-1	71.5F[a] 3.5F[a] 64 F 37 F	255F 420F	798 798	141 F 69 F	6.7(9) 6.0(9)	7.6(9) 6.8(9)

a Operated at 3000 rpm
b High power to phase 1
c Includes 300 hr. at 10,000 rpm
d Operated at 3000 rpm after 92 hr. at 6000 rpm
e Phenolic retainer
f Failure denoted by: F
g Total dose at failure or at end of irradiation

Table 11.3

Summary of Bearing Lubricant Test Data

Lubricant	Environment	Test Method	Spec. No.	Run Time (hr)[a]	Initial Coast-down Time (min)	Coast-down Time (min)[b]	Initial Current Ø1 (ma)	Initial Current Ø2 (ma)	Final Current[b] Ø1 (ma)	Final Current[b] Ø2 (ma)	Max. Temp (°F)	Radial Play in. x 10^{-4} Before Test	Radial Play in. x 10^{-4} After Test	End Play in. x 10^{-3} Before Test	End Play in. x 10^{-3} After Test
Almasol SFD-238	Vacuum Control	Low Power	1	410F	5.23	8.71	40	18	22	22	87				
	Vacuum Control	Low Power	2	35F	4.10	6.70	39	39	38	38	91				
	Vacuum Irradiated	Low Power	1	0		(Failed Prior to Irradiation)						17	4	3.8	1.7
	Vacuum Irradiated	Low Power	2	44F	4.87	1.51	24	24	56	60	95	3	3	3.1	1.3
	Air Irradiated	Low Power	1	345F	3.69	1.40	37	38	37	37	98	14	14	4.0	2.7
	Air Irradiated	Low Power	2	70F	3.73	3.63	40	41	41	41	92	18	3	4.1	3.0
DC-705	Vacuum Control	Low Power	1	752	1.33	1.32	71	71	78	78	93				
	Vacuum Control	Low Power	2	752	1.02	1.29	68	68	70	70	90				
	Vacuum Control	High Power	1	22F	2.00	2.69	156	29	156	31	89	2-5		2.0	
	Vacuum Control	High Power	2	67F	0.73	1.17	139	15	143	15	117	2-5		3.0	
	Vacuum Control	High Power	1[c]	2.5F	1.33	0.27	198	53	199	80	75				
	Vacuum Irradiated	Low Power	1	59F	2.20	1.66	43	56	40	56	99	7	8	3.2	3.6
	Vacuum Irradiated	Low Power	2	644	1.52	1.65	50	58	57	57	110	6	6	2.6	2.2
	Air Irradiated	Low Power	1	798	0.54	0.39	78	74	88	78	101	6	6	3.7	1.8
	Air Irradiated	Low Power	2	798	1.78	1.14	78	70	100	58	101	6	6	3.2	2.4
Duroid	Vacuum Control	High Power	1	1F	0.65	0.65	200	30	200	30	135	8	4.5		
	Vacuum Control	High Power	2	1F	0.40	0.40	200	37	200	37	137	9	6		
	Vacuum Control	Low Power	1	437	1.30	6.30	32	32	19	19	63	3.5	5		
	Vacuum Control	Low Power	2	437	2.20	10.20	31	31	16	16	63	7	4		
Electrofilm 66-C	Vacuum Control	High Power	1	0		(Failed Prior to Vacuum Run)					138	11	6.5	3.5	3.0
	Vacuum Control	High Power	2	1F	0.65	0.65	200	30	200	30	138	10	6	4.2	4.7
	Vacuum Control	Low Power	1	145F	2.45	1.13	35	35	52	52	63	5.5	10	3.4	5.0
	Vacuum Control	Low Power	2	438	2.85	5.53	34	34	24	24	86	5.5	12	3.5	5.7
ETR-H	Vacuum Control	High Power	1	270	1.60	1.65	200	30	200	32	146	8	10	3.4	3.7
	Vacuum Control	High Power	2	270	1.80	2.00	200	27	200	29	150	5.5	9	3.4	3.2
	Vacuum Control	Low Power	1	437	1.80	2.60	44	44	39	39	68	5.5	10	1.5	3.4
	Vacuum Control	Low Power	2	437	2.35	2.70	36	36	34	34	68	5.5	10	1.5	3.7
FS-1265	Vacuum Control	Low Power	1	752	0.90	0.80	95	92	113	113	113				
	Vacuum Control	Low Power	2	752	1.10	1.88	60	60	54	54	98				
	Vacuum Control	High Power	1	45F[c]	0.83	0.20	224	61	198	28	147				
	Vacuum Control	High Power	2	22F[c]	0.60	0.43	206	60	180	70	130				
GE-F50	Vacuum Control	Low Power	1[d]	514F	2.12	3.14	47	47	19	19	92				
	Vacuum Control	Low Power	2[d]	1000	1.41	5.65	41	41	16	16	93				
	Vacuum Control	High Power	1	25F	2.10	2.05	200	29	200	33	142	6	6	3.2	3.4
	Vacuum Control	High Power	2	14F	2.20	0.65	200	24	200	36	150	4	4	3.7	1.0
	Vacuum Control	Low Power	1	437	3.30	3.50	34	34	33	33	66	7	11	1.8	4.6
	Vacuum Control	Low Power	2	437	3.20	4.23	33	33	29	29	67	5	9	1.6	3.1

Table 11.3 (cont'd)

Lubricant	Environment	Test Method	Spec. No.	Run Time (hr)[a]	Initial Coast-down Time (min)	Coast-down Time (min)[b]	Initial Current ϕ_1 (ma)	Initial Current ϕ_2 (ma)	Final Current[b] ϕ_1 (ma)	Final Current[b] ϕ_2 (ma)	Max. Temp (°F)	Radial Play in. x 10^{-4} Before Test	Radial Play in. x 10^{-4} After Test	End Play in. x 10^{-3} Before Test	End Play in. x 10^{-3} After Test
Kynar	Vacuum Control	Low Power	1[e]	2014	2.13	15.45	21	21	11	11	87				
	Vacuum Control	Low Power	2	827F	3.06	5.81	25	25	20	20	87				
	Vacuum Control	High Power	1	1.5F	6.01	6.01	149	48	144	48	93	7-11			
	Vacuum Control	High Power	2	1.5F	1.23	1.23	142	48	138	48	94	7-11			
	Vacuum Irradiated	Low Power	1	27F	3.42	9.10	30	30	22	22	96	9	22		
	Vacuum Irradiated	Low Power	2	644	1.31	3.30	40	40	35	35	100	13	18		
	Air Irradiated	Low Power	1	393F	2.63	2.05	43	43	56	57	96	7	28		
	Air Irradiated	Low Power	2	798	1.59	2.88	44	44	40	40	99	20	15		
Minapure	Vacuum Control	Low Power	1	1000	3.20	3.45	32	33	50	50	93				
	Vacuum Control	Low Power	2	1000	2.59	2.73	41	40	55	55	89				
	Vacuum Control	High Power	1	20F[c]	0.83	1.03	210	54	176	19	94				
	Vacuum Control	High Power	2	65F[c]	0.93	0.67	211	54	187	19	98				
MLF-5	Vacuum Control	High Power	1	4F	3.05	3.05	200	35	200	35	153	12	12	4.1	6.5
	Vacuum Control	High Power	2	1F	4.10	4.10	200	28	200	28	75	9	9	4.2	6.8
	Vacuum Control	Low Power	1	342F	3.85	2.90	25	25	38	38	67	11	14	3.0	5.4
	Vacuum Control	Low Power	2	437	5.60	7.30	20	20	22	22	66	10	20	4.3	4.9
OS-124	Vacuum Control	Low Power	1	752	0.46	0.47	15	115	107	107	99				
	Vacuum Control	Low Power	2	752	1.22	0.77	.2	71	90	90	92				
	Vacuum Control	High Power	1[f]	101F	0.63	0.37	138	60	184	69	105	2-5		3.5	
	Vacuum Control	High Power	2[g]	108F	0.40	0.46	138	66	180	74	102	2-5		2.5	
	Vacuum Irradiated	Low Power	1	644	0.47	0.65	84	81	74	74	115	3	3	1	0.9
	Vacuum Irradiated	Low Power	2	644	0.76	1.10	61	62	65	65	115	7	6	3.2	2.5
	Air Irradiated	Low Power	1	798	0.50	0.29	86	86	110	110	97	5	7	3.8	3.4
	Air Irradiated	Low Power	2	798	0.38	0.52	94	94	80	88	101	8	7	4.1	3.6
Polymer SP-F	Vacuum Control	Low Power	1	255F	2.23	2.10	30	30	35	35	90				
	Vacuum Control	Low Power	2	419F	2.70	6.98	23	23	17	17	90				
	Vacuum Control	High Power	1[c]	72F	2.43	0.63	208	50	189	18	100	7-11			
	Vacuum Control	High Power	2[c]	3.5F	3.42	3.42	208	50	216	50	70	7-11			
	Vacuum Control	High Power	1	64F	0.59	0.60	138	30	139	15	81				
	Vacuum Control	High Power	2	37F	3.53	6.36	152	-	131	48	72				
	Vacuum Irradiated	Low Power	1	141F	3.00	0.97	36	36	52	52	101	5	24		
	Vacuum Irradiated	Low Power	2	69F	4.86	0.40	24	24	88	88	109	5	7		
	Air Irradiated	Low Power	1	798	3.10	2.52	44	44	38	38	95	10	18		
	Air Irradiated	Low Power	2	798	1.14	1.80	58	58	42	42	96	6	12		

[a]Failure denoted by: F
[b]Just before failure, or at end of test
[c]Operated at 3000 rpm
[d]Phenolic retainer

[e]Includes 300 hr at 10,000 rpm
[f]Last 9 hr of operation at 3000 rpm
[g]Last 16 hr of operation at 3000 rpm

Table 11.4

Field Current of Servomotors During a Bearing Lubricant Test

Run No. and Field Winding	Field Current (ma)									
	Motor No.									
	1	2	3	4	5	6	7	8	9	10
Run 7										
Phase I (Original)	120	132	150	132	132	132	129	---	156	---
Phase I (Corrected)	154	169	192	169	169	169	165	---	200	
Phase II (Original)	39	45	45	36	45	45	42	---	51	---
Phase II (Corrected)	50	58	58	46	58	58	54		65	
Run 9										
Phase I (Original)	138	150	141	135	150	150	144	147	162	150
Phase I (Corrected)	177	192	180	173	192	192	184	188	207	192
Phase II (Original)	51	54	54	45	51	54	54	51	57	54
Phase II (Corrected)	65	69	69	58	65	69	69	65	73	69

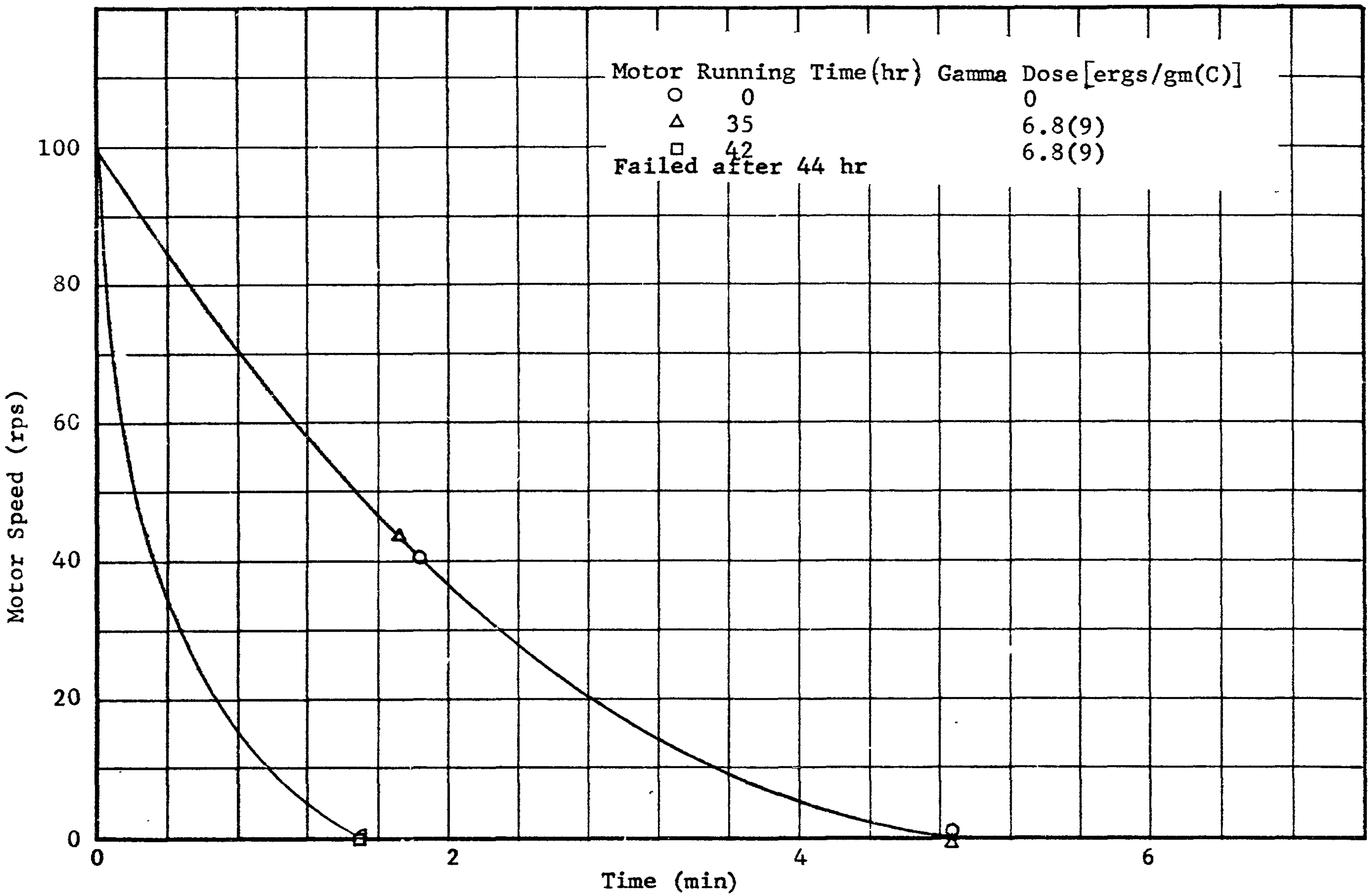

Figure 11.1 Speed During Coastdown of Motor 10 for Almasol SFD-238: Vacuum Irradiation (Low Power to Phase 1)

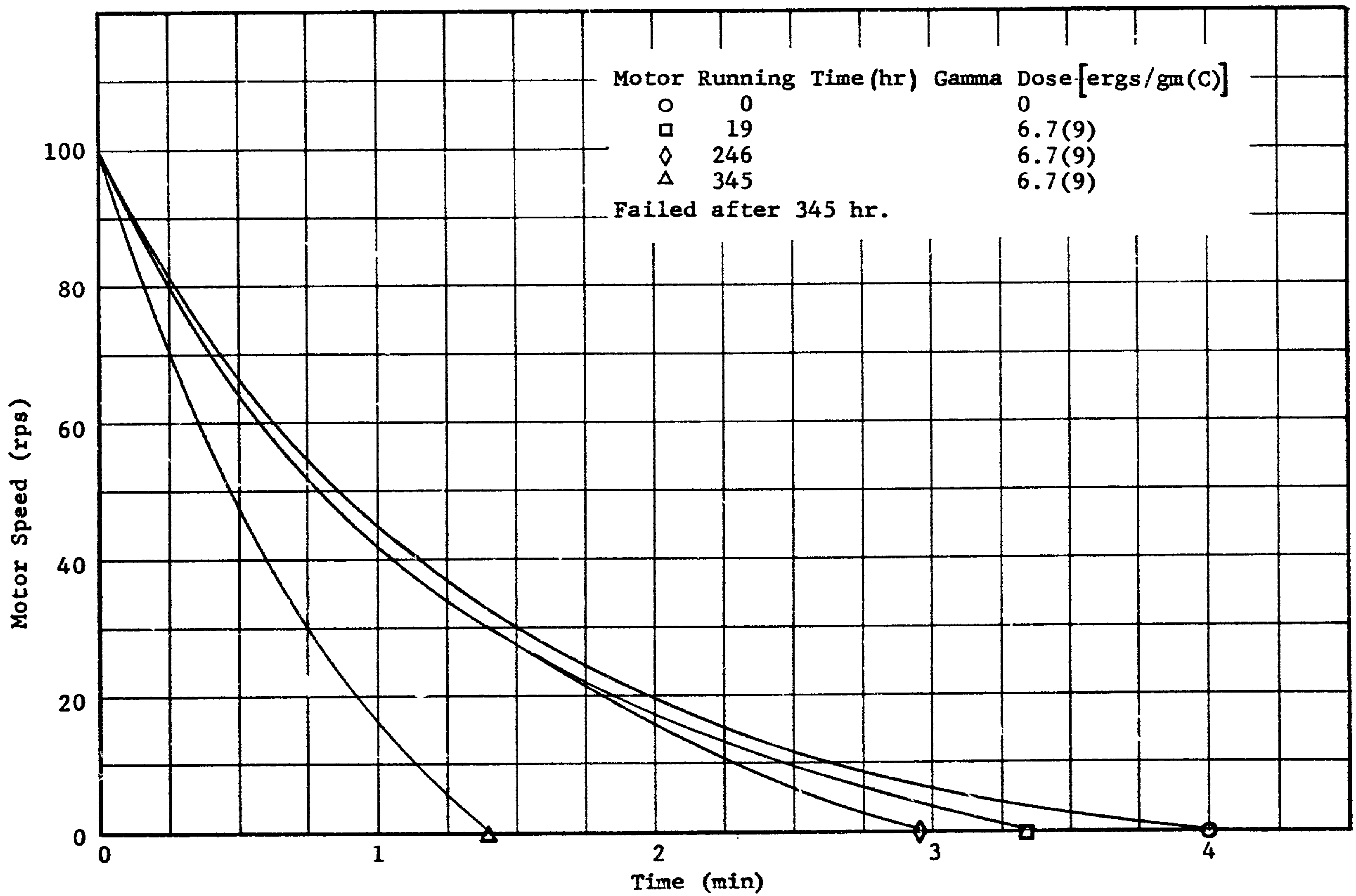

Figure 11.2 **Speed During Coastdown of Motor 11 for Almasol SFD-238: Air Irradiation (Low Power to Phase 1)**

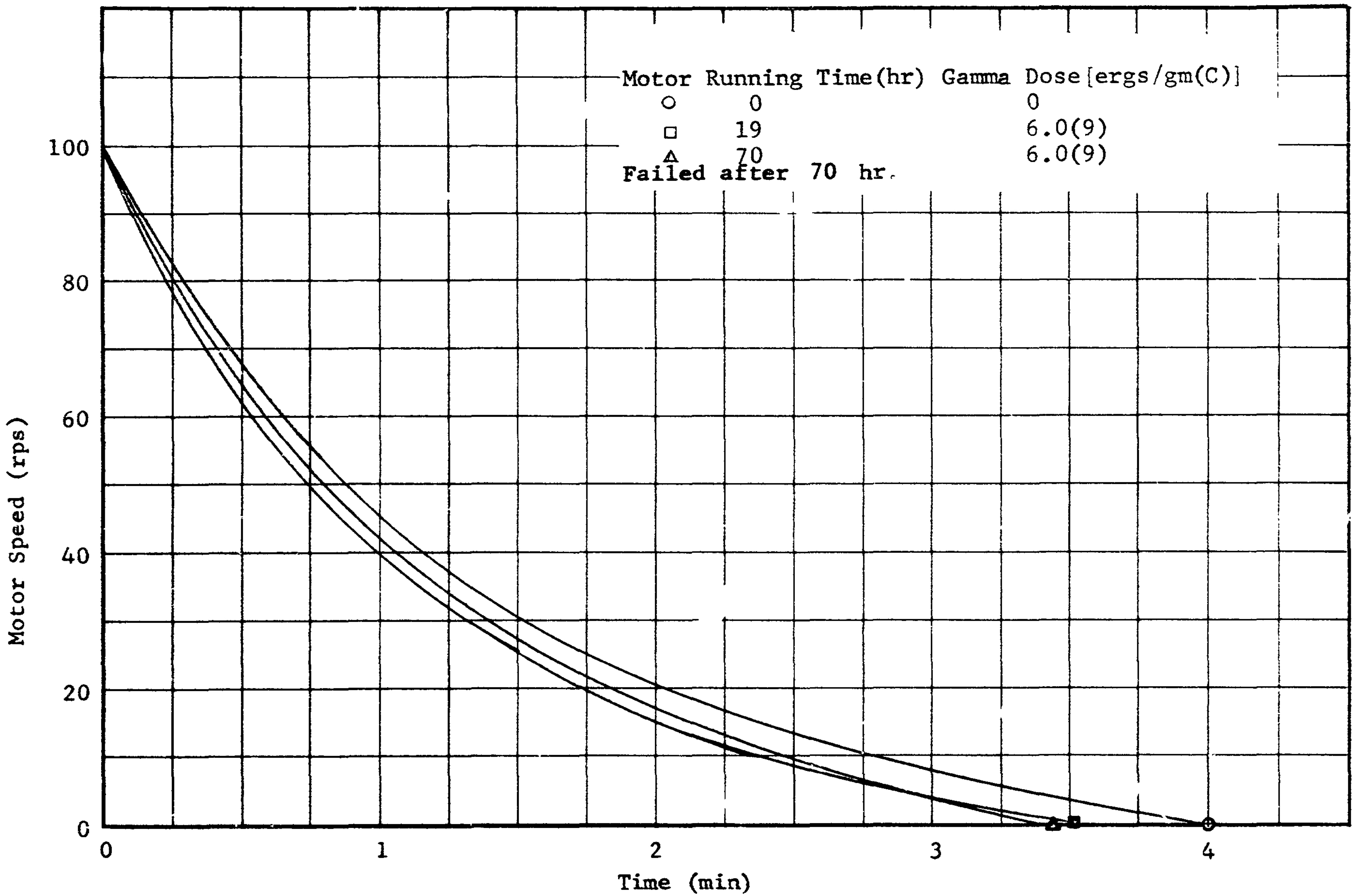

Figure 11.3 Speed During Coastdown of Motor 10 for Almasol SFD-238: Air Irradiation (Low Power to Phase 1)

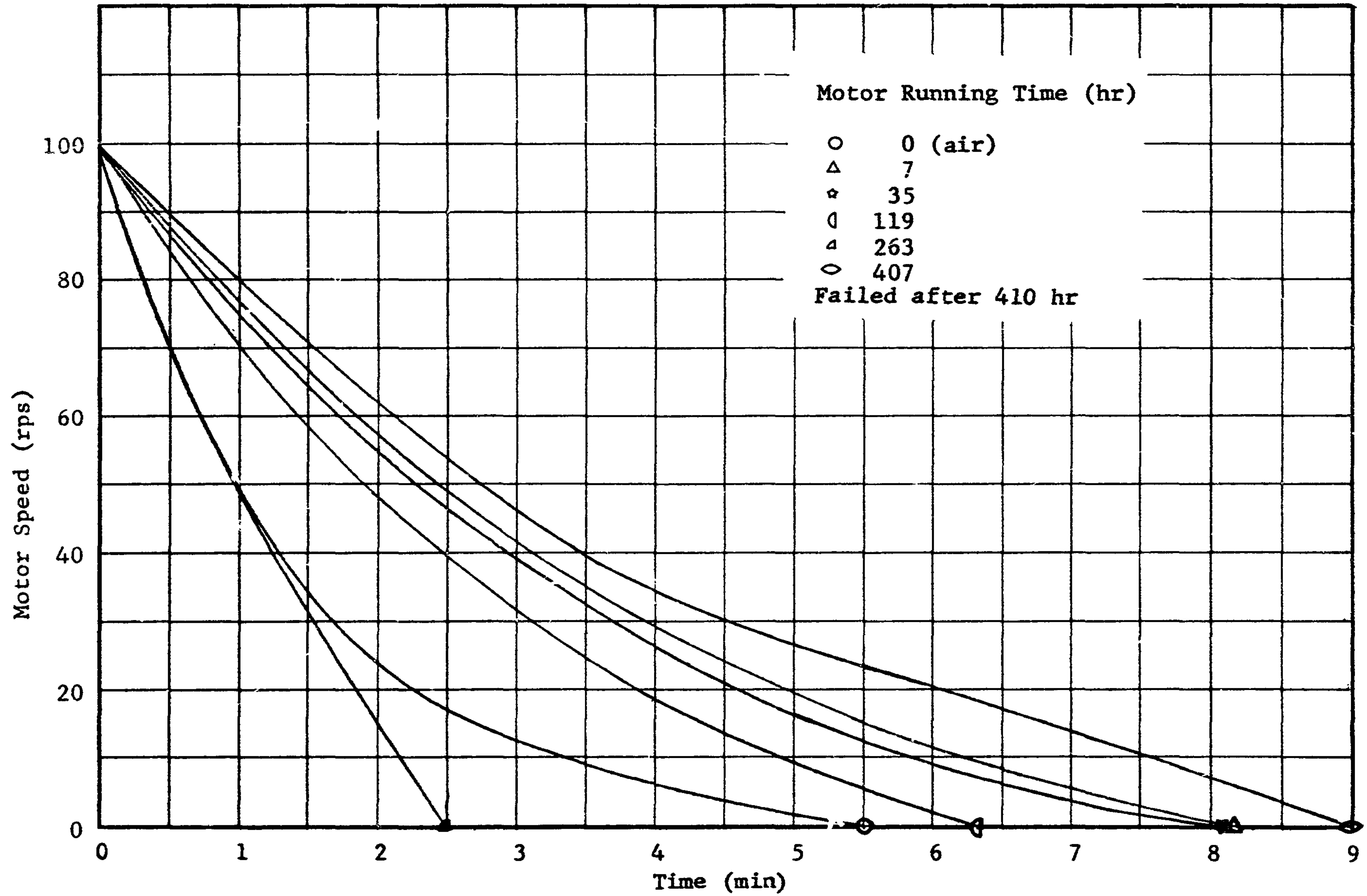

Figure 11.4 Speed During Coastdown of Motor 9 for Almasol SFD-238: Vacuum Control (Low Power to Phase 1)

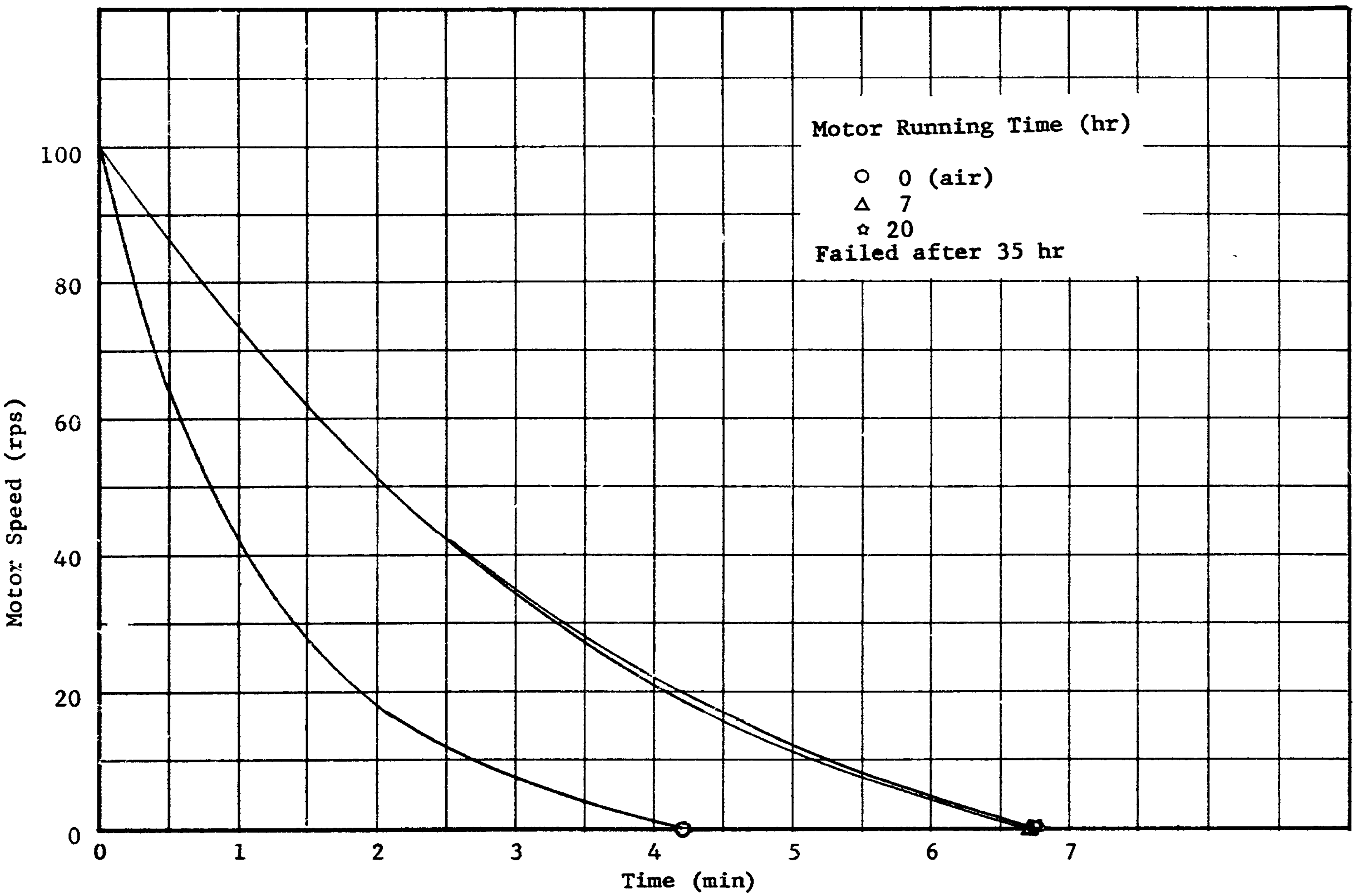

Figure 11.5 Speed During Coastdown of Motor 10 for Almasol SFD-238: Vacuum Control (Low Power to Phase 1)

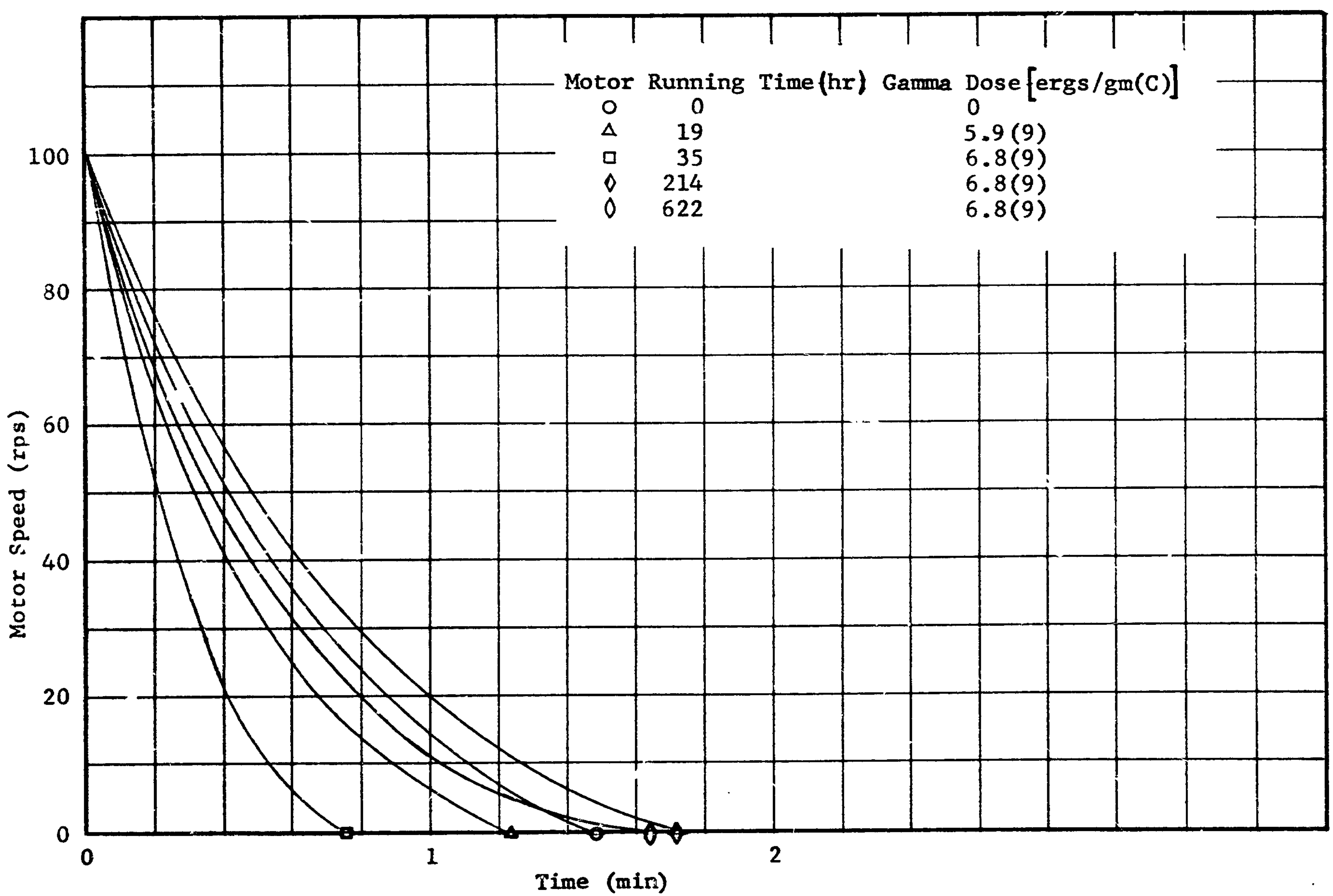

Figure 11.6 Speed During Coastdown of Motor 6 for DC-705: Vacuum Irradiation (Low Power to Phase 1)

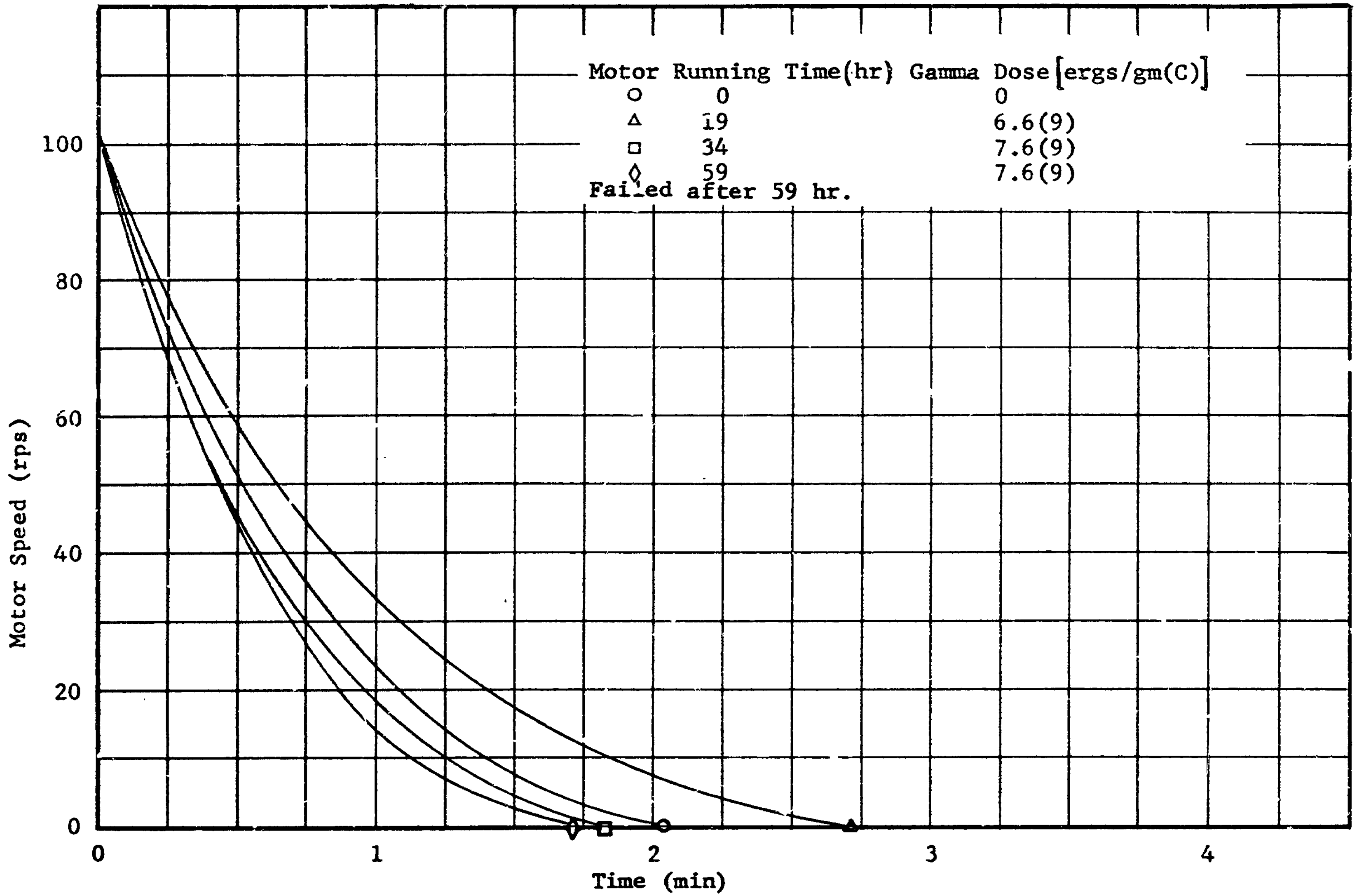

Figure 11.7 Speed During Coastdown of Motor 5 for DC-705: Vacuum Irradiation (Low Power to Phase 1)

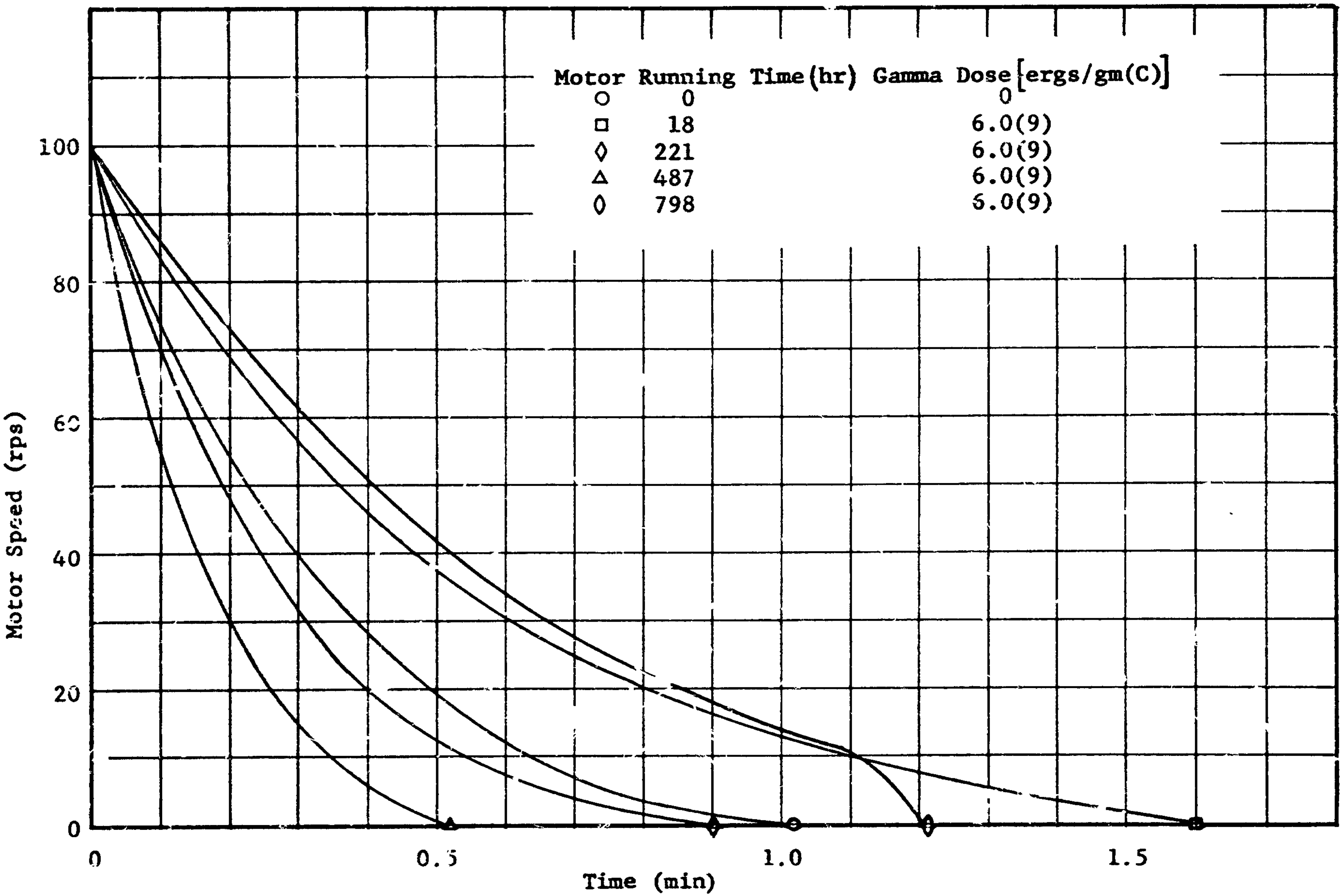

Figure 11.8 Speed During Coastdown of Motor 6 for DC-705: Air Irradiation (Low Power to Phase 1)

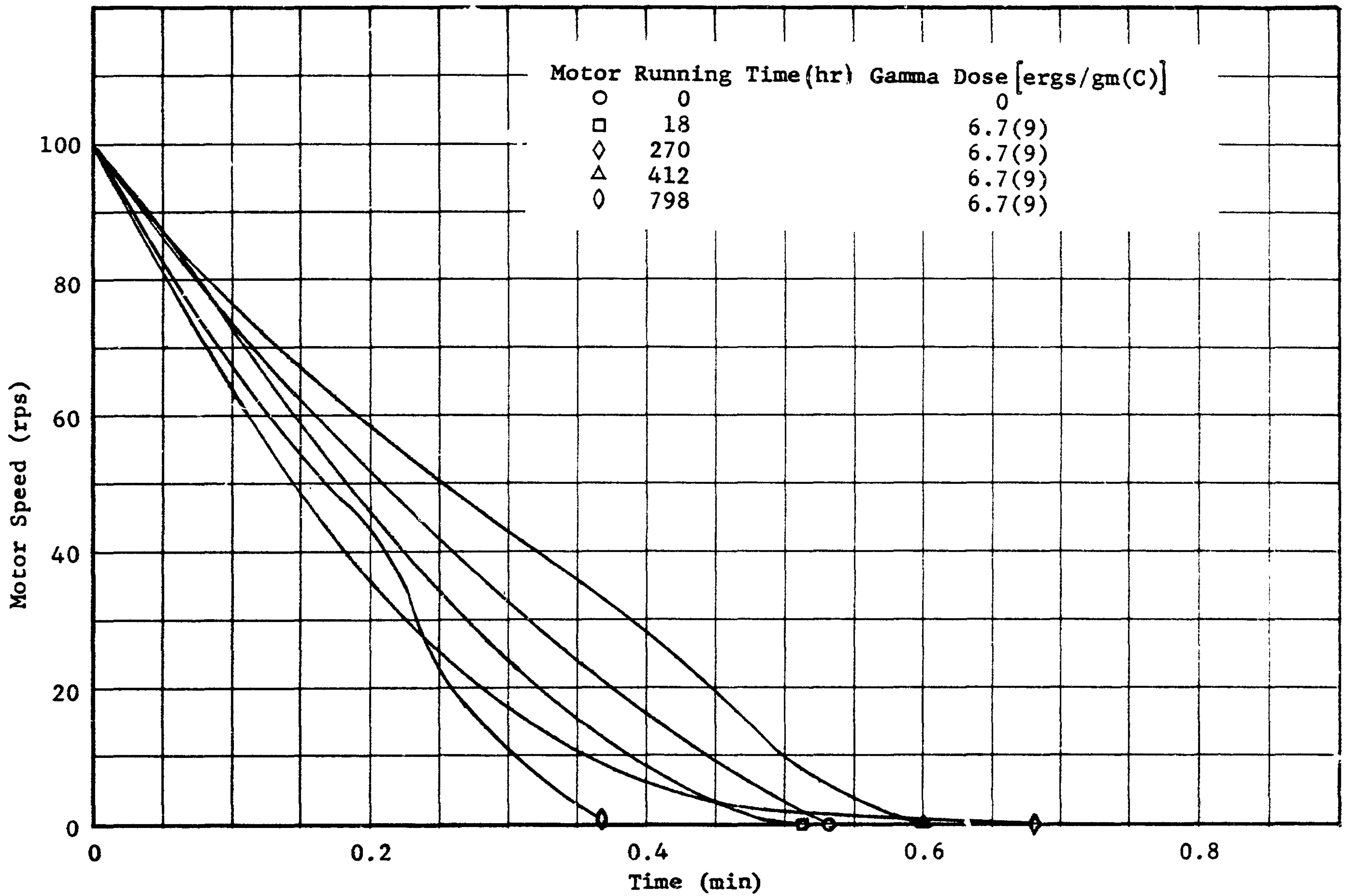

Figure 11.9 Speed During Coastdown of Motor 5 for DC-705: Air Irradiation (Low Power to Phase 1)

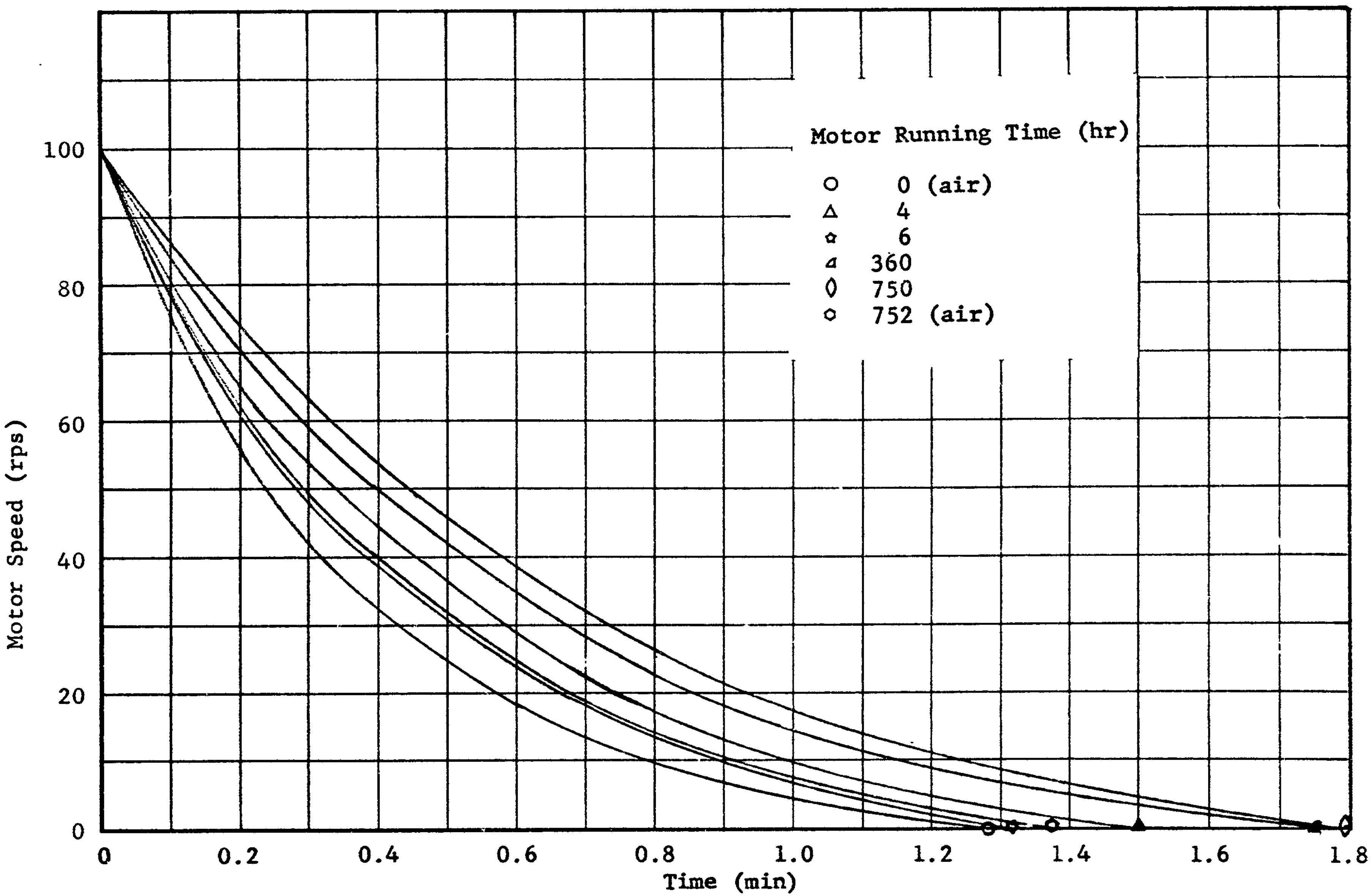

Figure 11.10 Speed During Coastdown of Motor 8 for DC-705: Vacuum Control (Low Power to Phase 1)

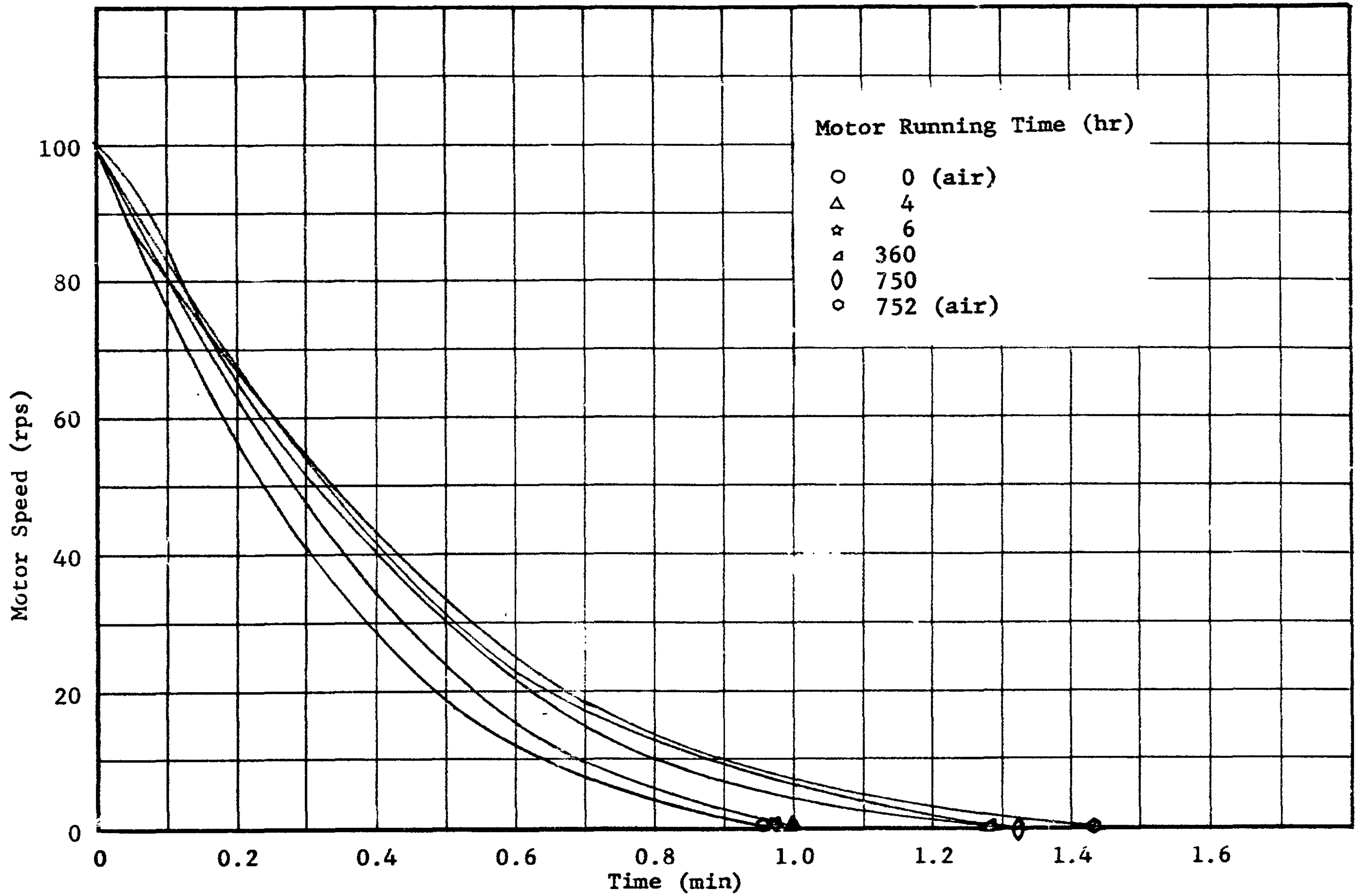

Figure 11.11 Speed During Coastdown of Motor 11 for DC-705: Vacuum Control (Low Power to Phase 1)

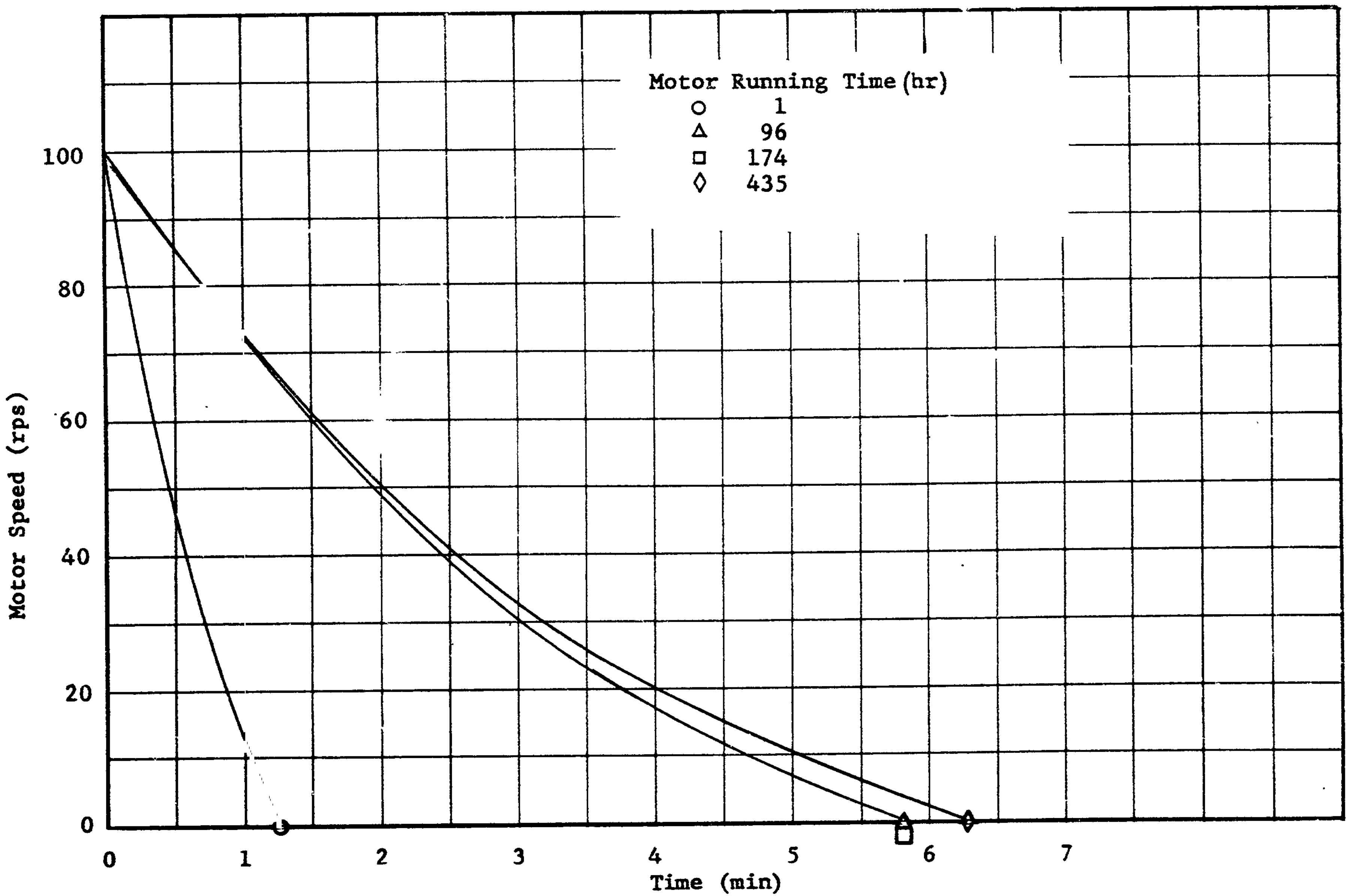

Figure 11.12 Speed During Coastdown of Motor 7 for Duroid: Vacuum Control (Low Power to Phase 1)

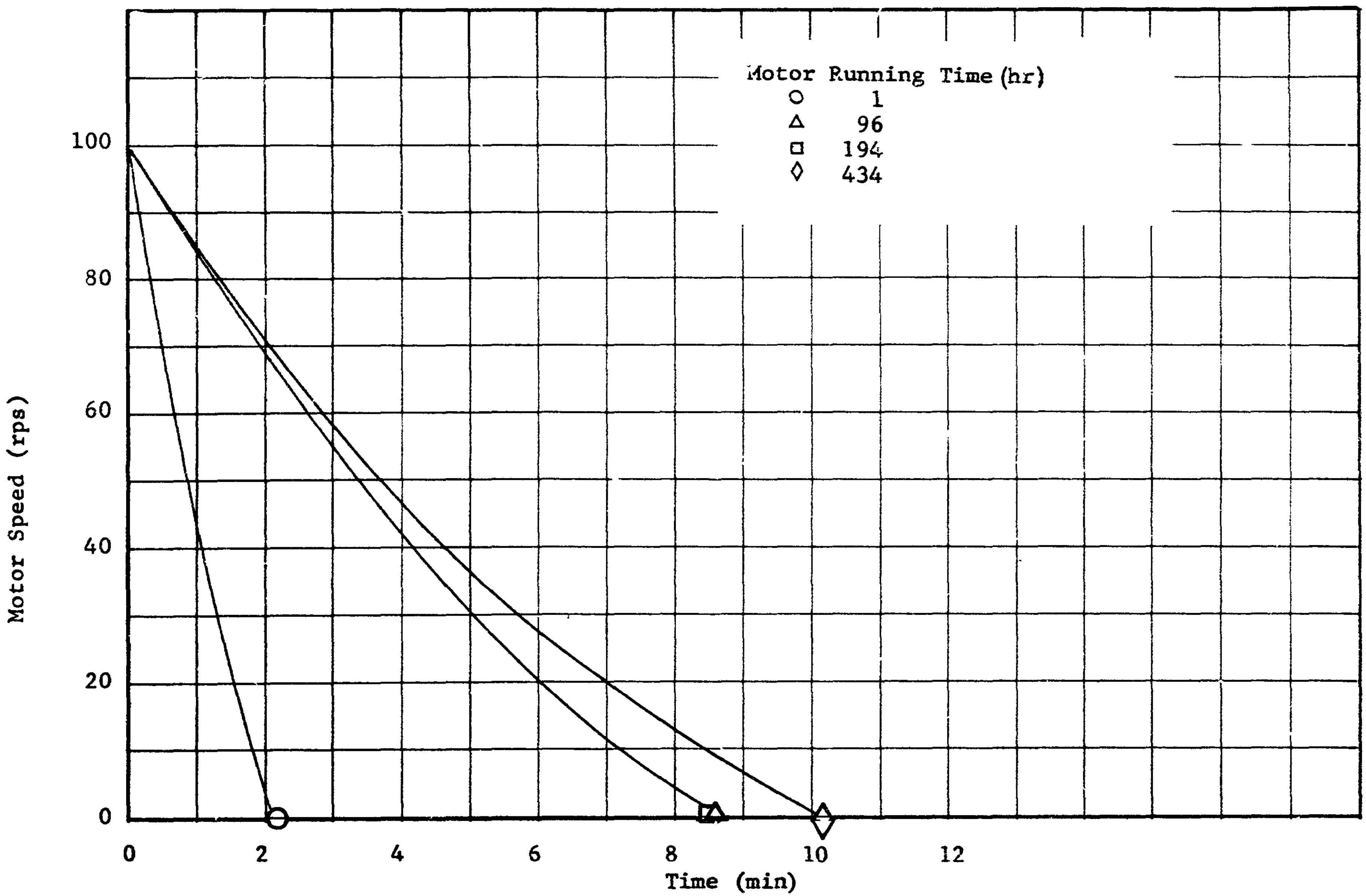

Figure 11.13 Speed During Coastdown of Motor 8 for Duroid: Vacuum Control (Low Power to Phase 1)

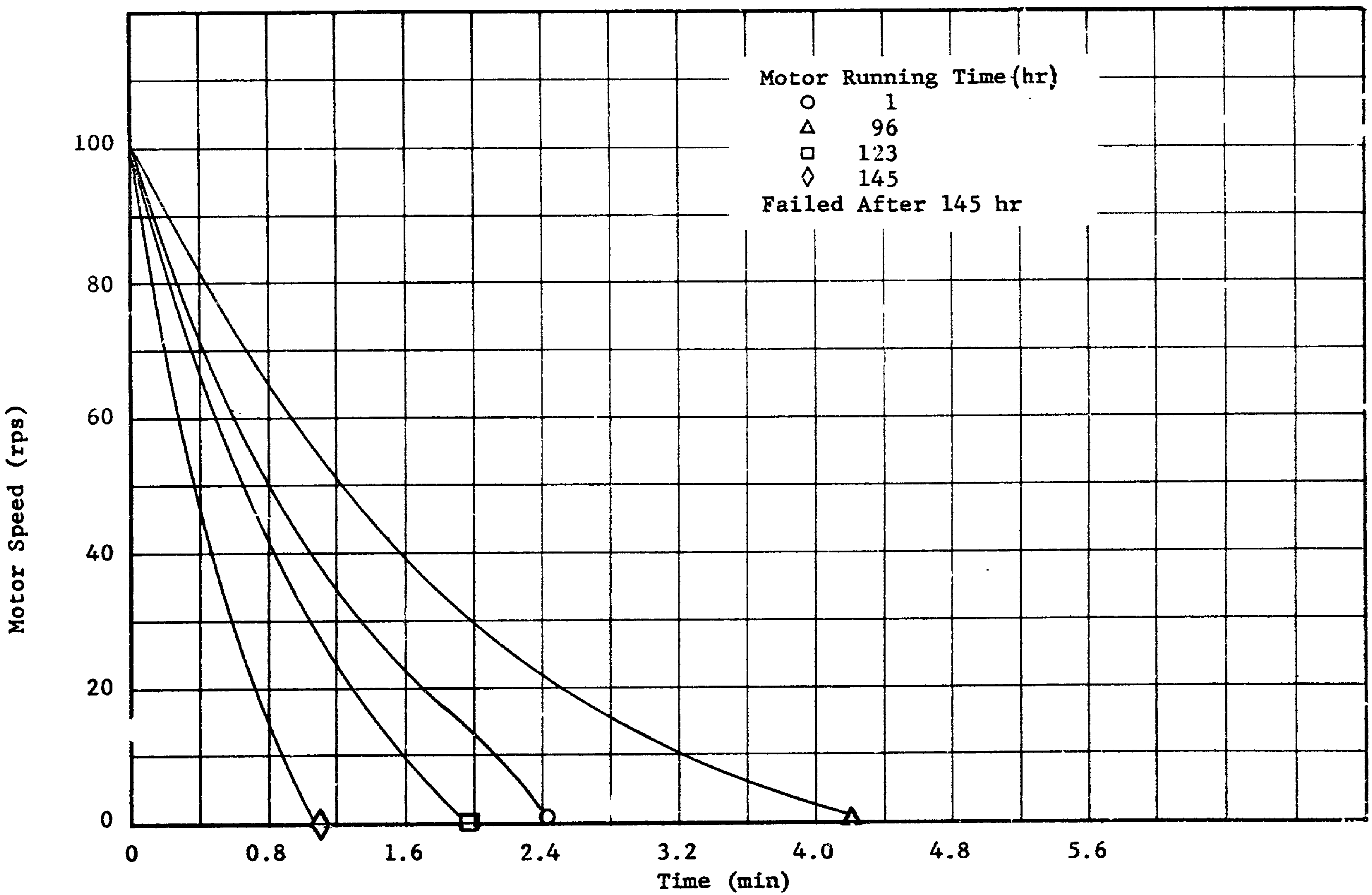

Figure 11.14 Speed During Coastdown of Motor 9 for Electrofilm 66-C: Vacuum Control (Low Power to Phase 1)

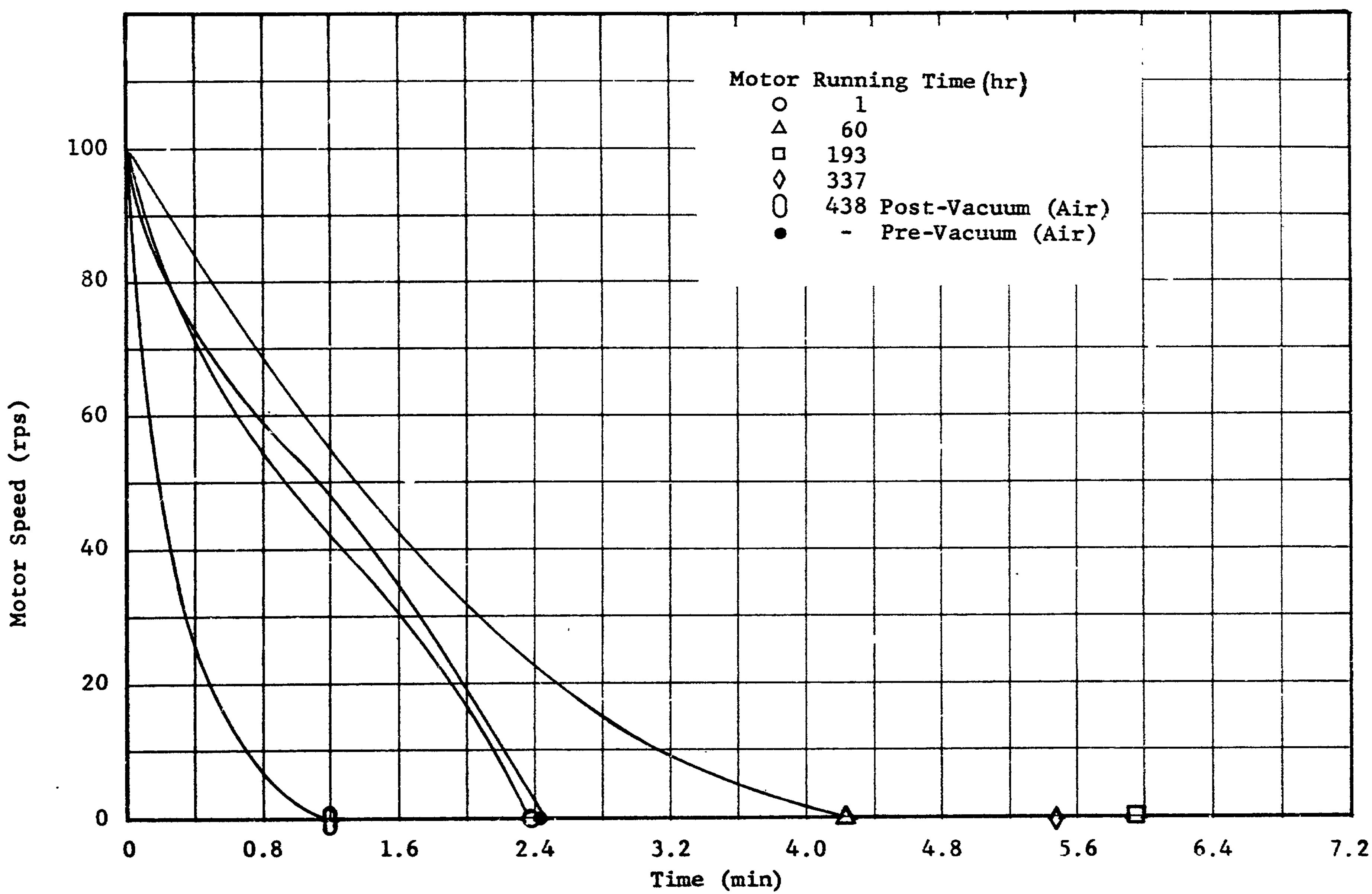

Figure 11.15 Speed During Coastdown of Motor 10 for Electrofilm 66-C: Vacuum Control (Low Power to Phase 1)

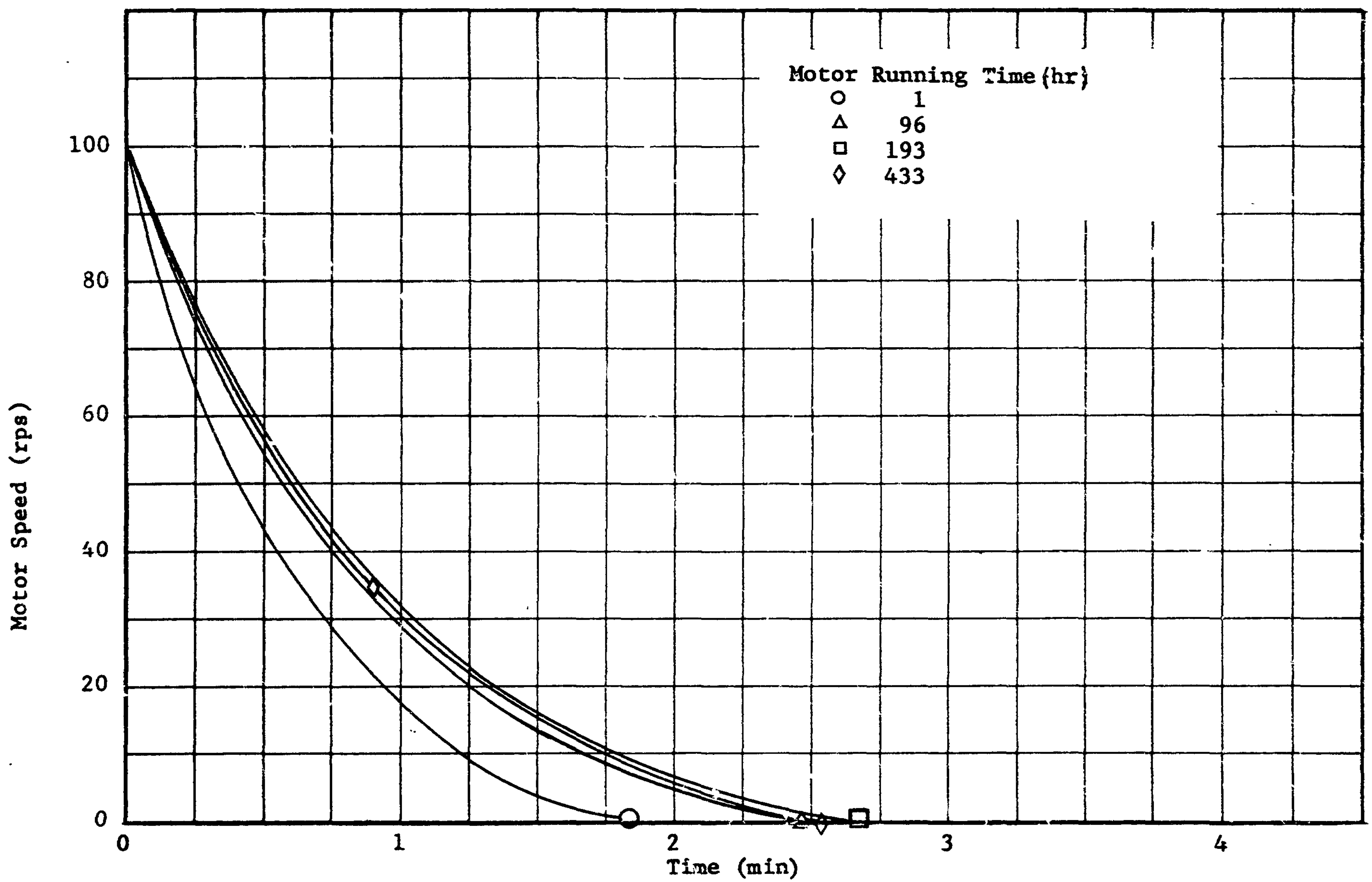

Figure 11.16 Speed During Coastdown of Motor 3 for ETR-H: Vacuum Control (Low Power to Phase 1)

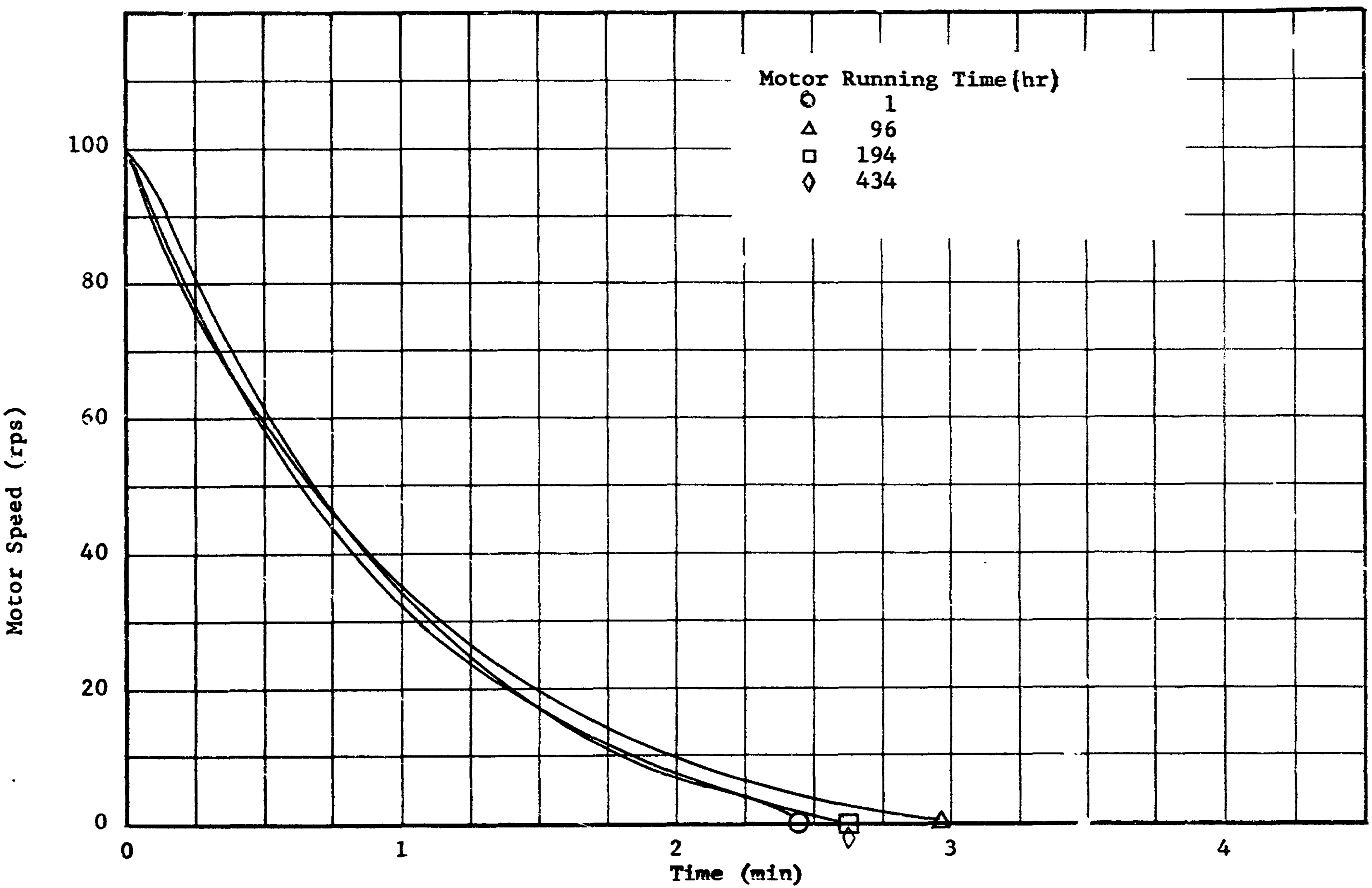

Figure 11.17 Speed During Coastdown of Motor 4 for ETR-H: Vacuum Control (Low Power to Phase 1)

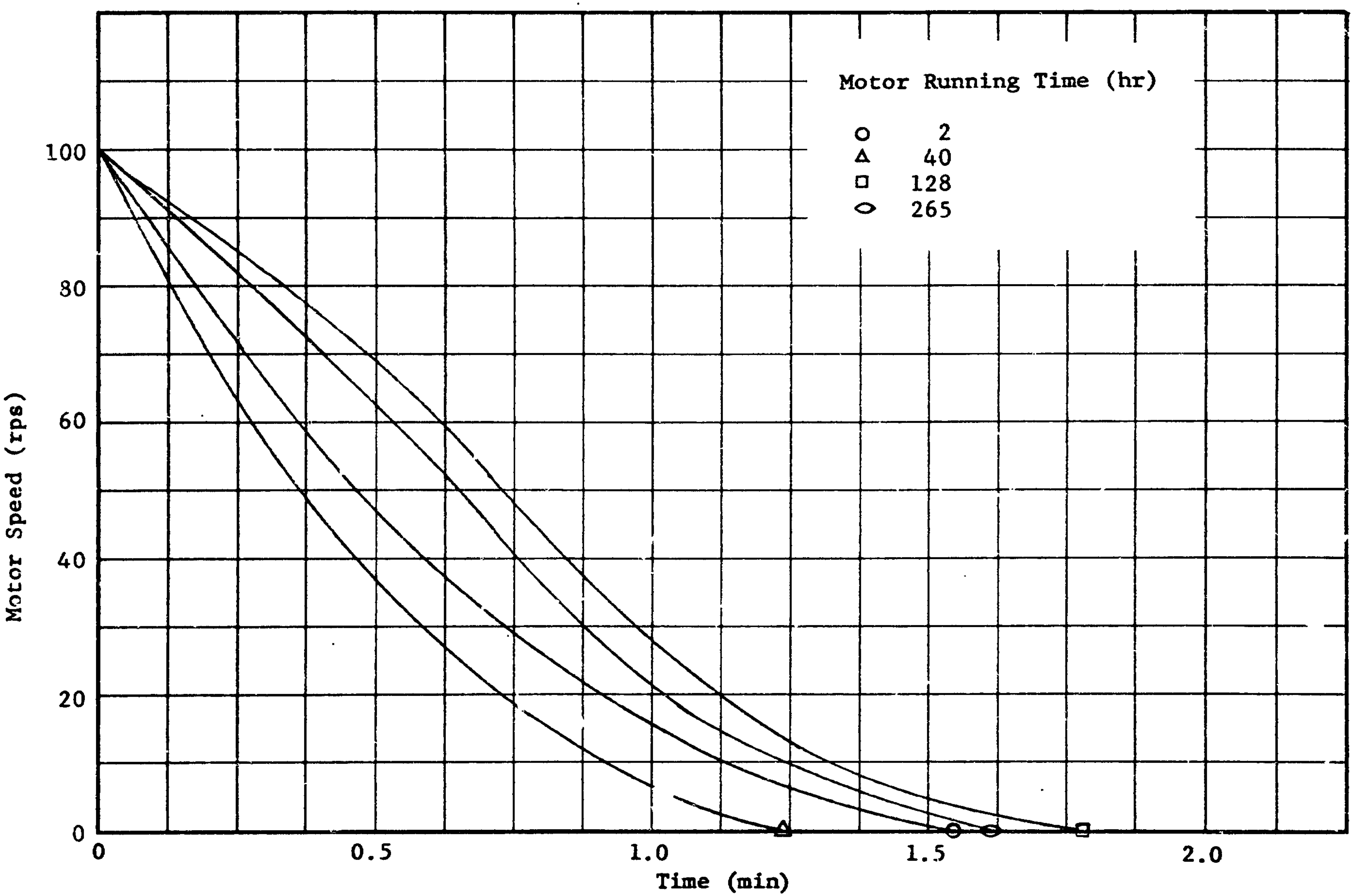

Figure 11.18 Speed During Coastdown of Motor 3 for ETR-H: Vacuum Control (High Power to Phase 1)

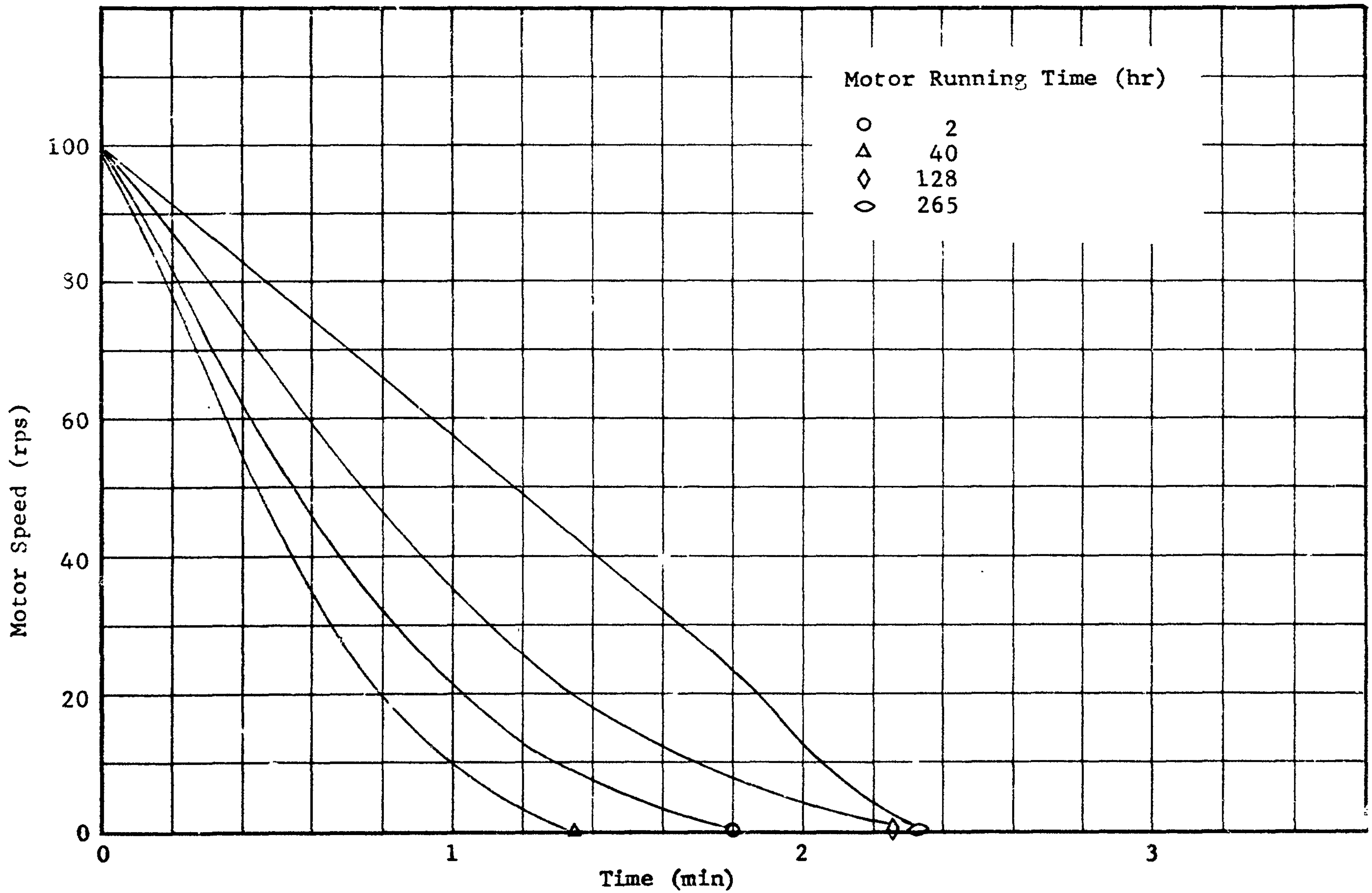

Figure 11.19 Speed During Coastdown of Motor 4 for ETR-H: Vacuum Control (High Power to Phase 1)

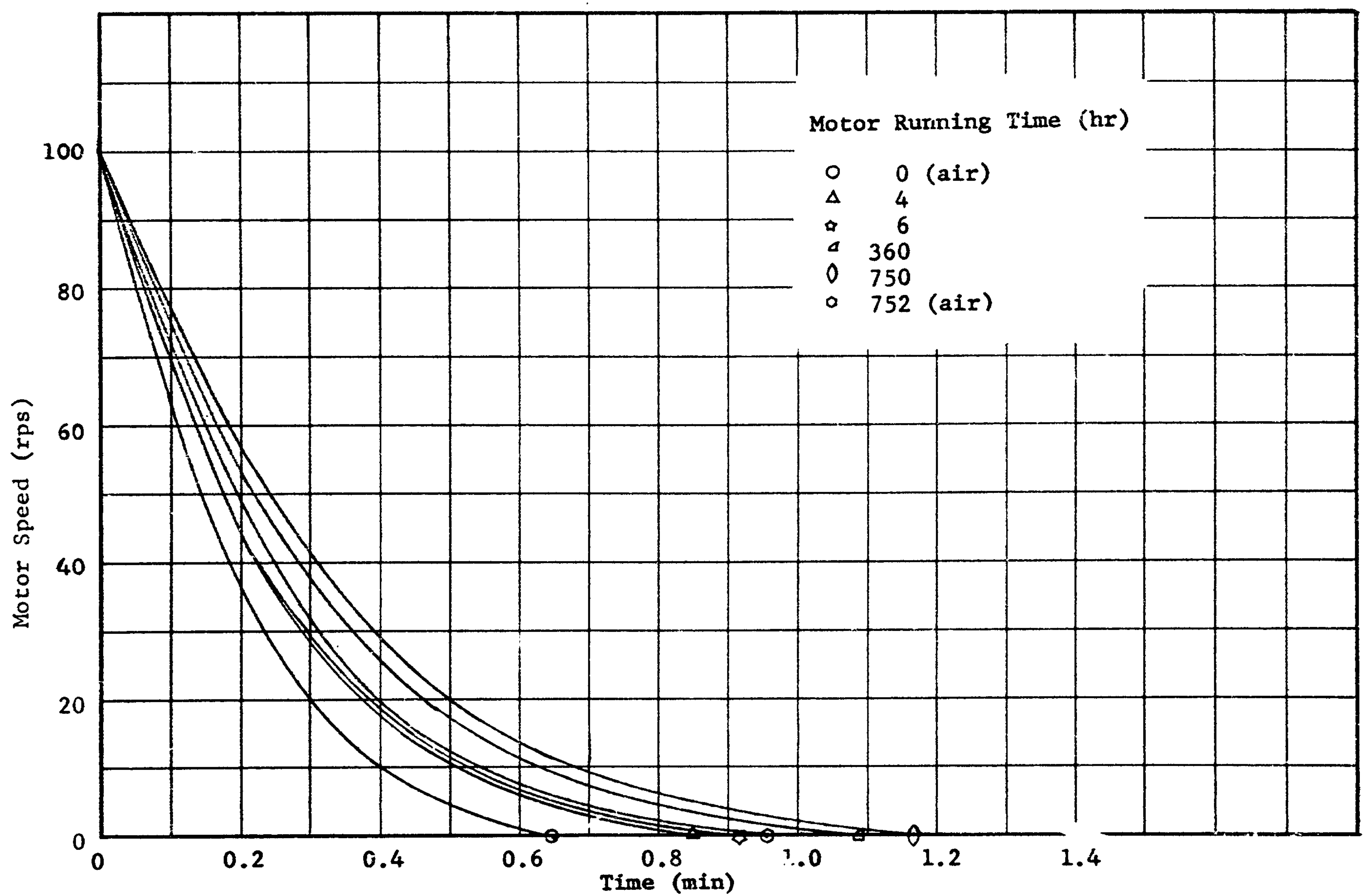

Figure 11.20 Speed During Coastdown of Motor 1 for FS-1265: Vacuum Control (Low Power to Phase 1)

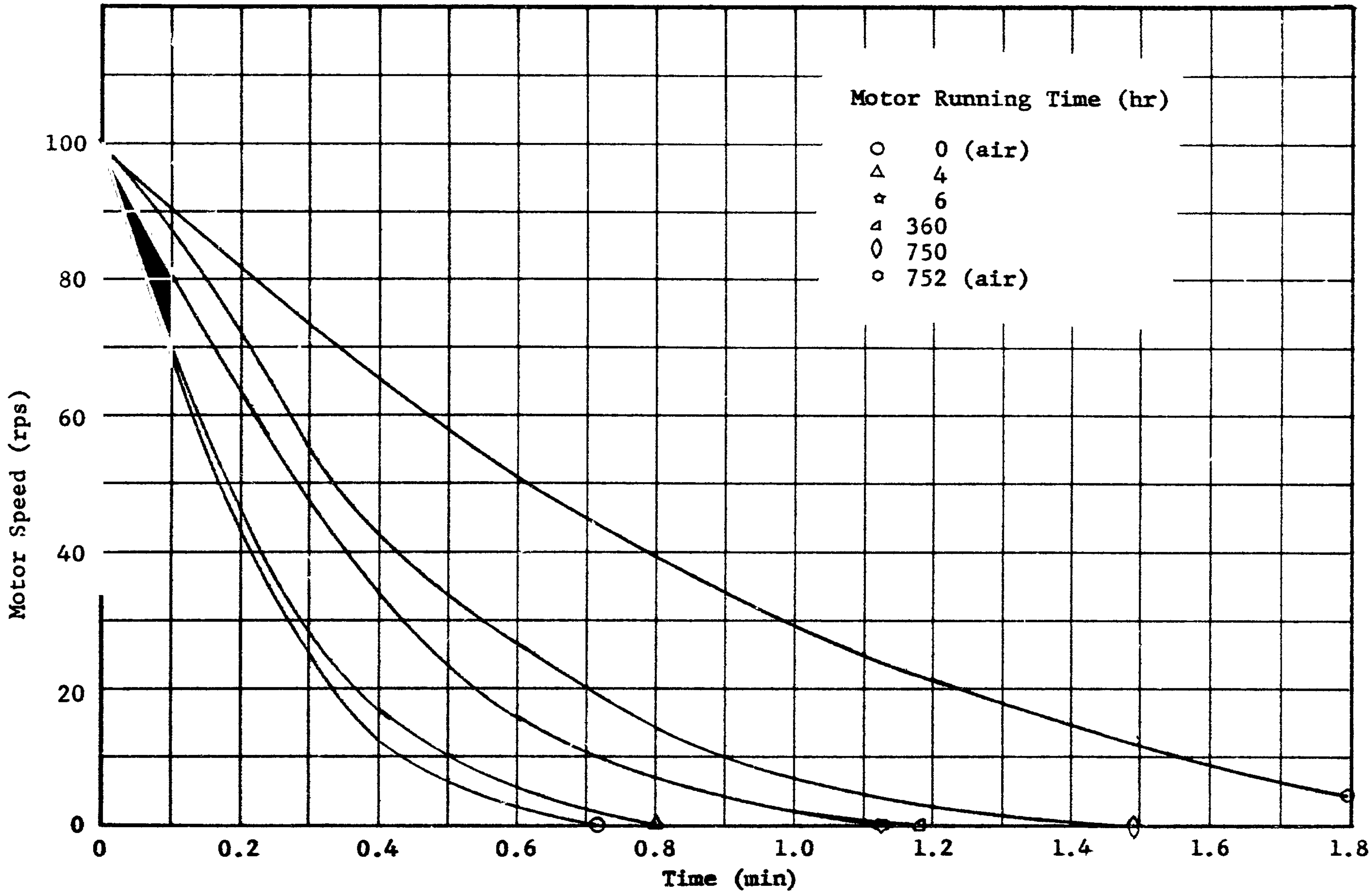

Figure 11.21 Speed During Coastdown of Motor 2 for FS-1265: Vacuum Control (Low Power to Phase 1)

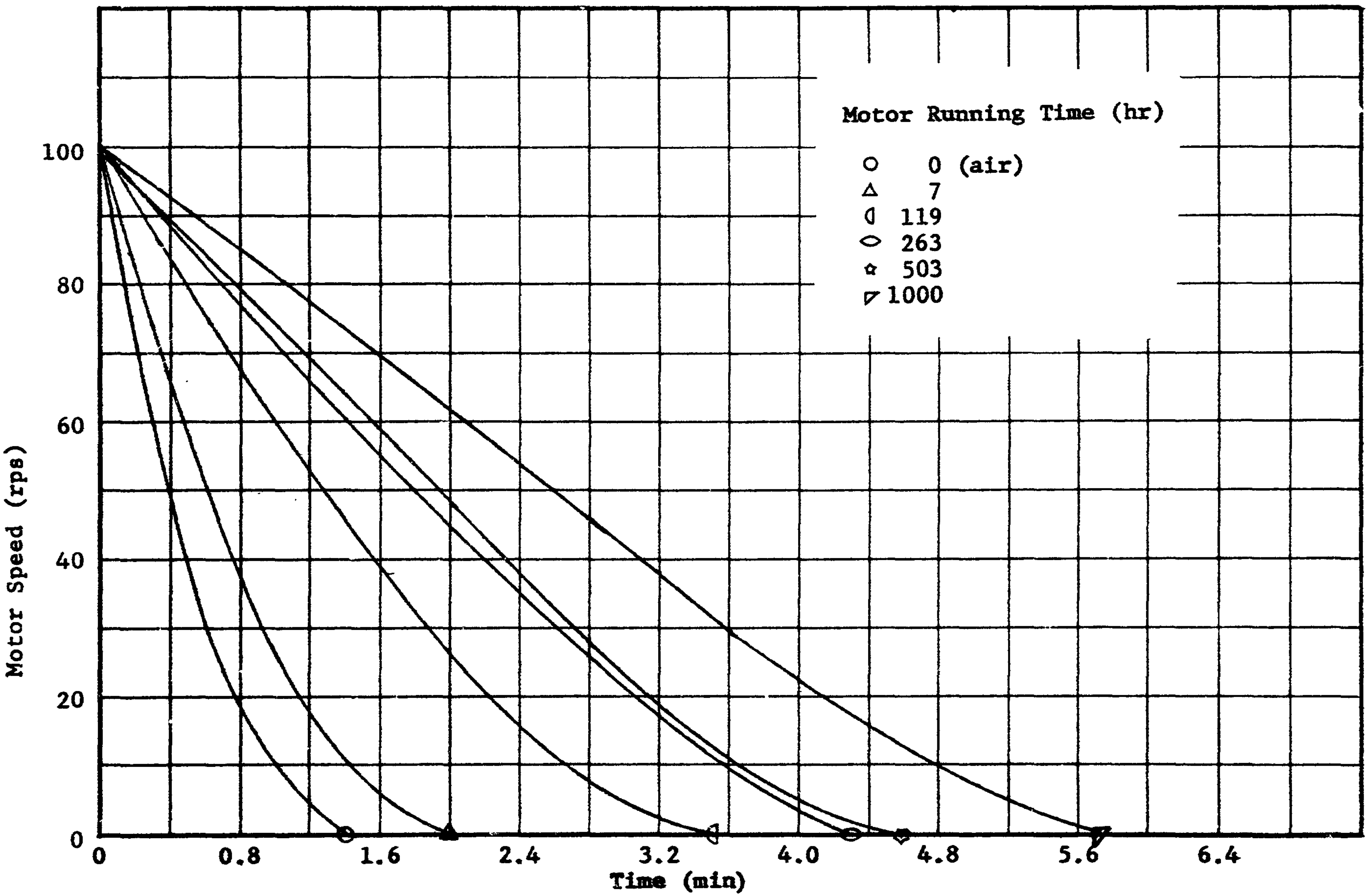

Figure 11.22 Speed During Coastdown of Motor 6 for GE F-50 (Phenolic Retainer): Vacuum Control (Low Power to Phase 1)

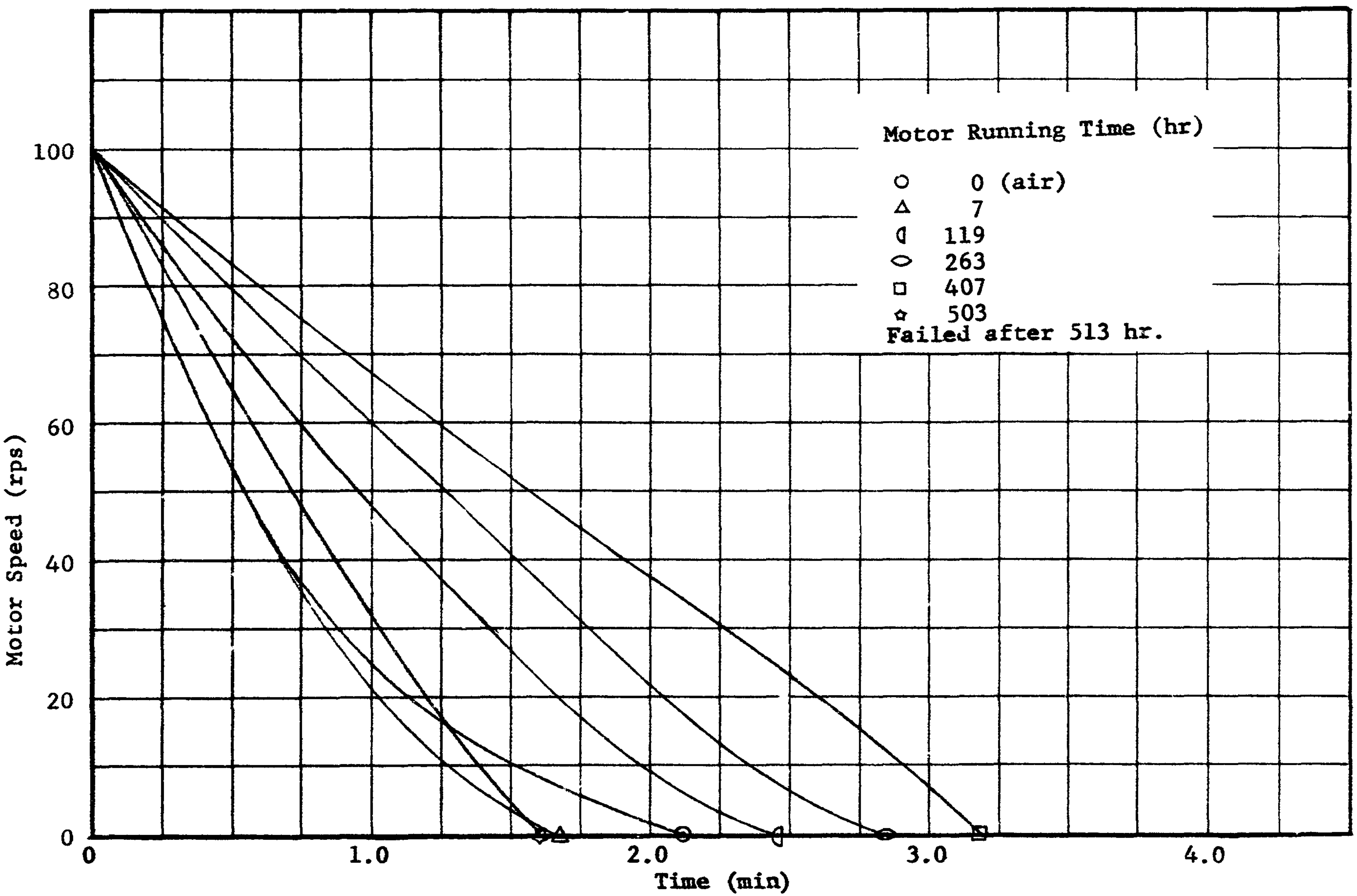

Figure 11.23 Speed During Coastdown of Motor 5 for GE F-50 (Phenolic Retainer): Vacuum Control (Low Power to Phase 1)

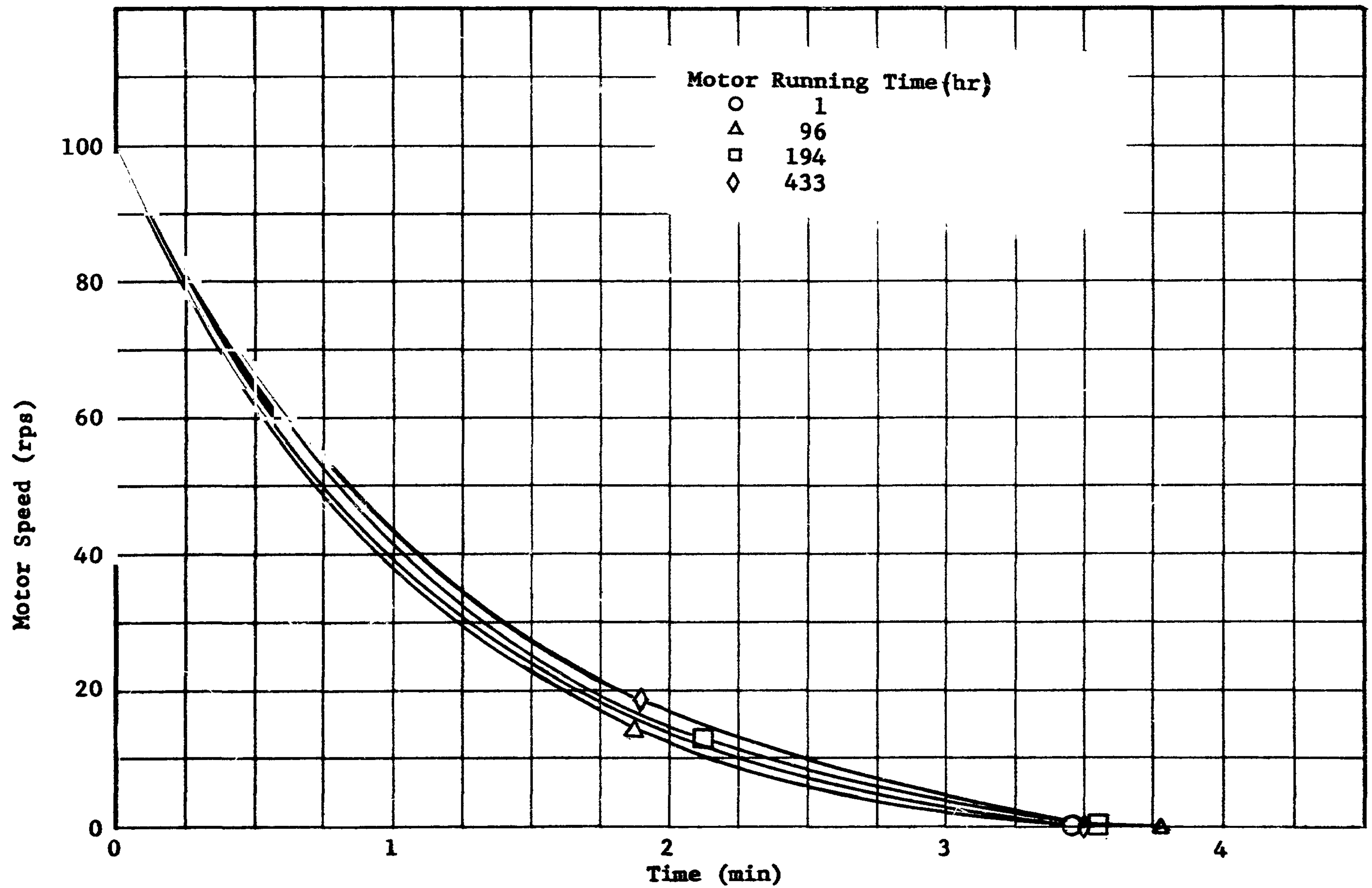

Figure 11.24 Speed During Coastdown of Motor 1 for GE F-50: Vacuum Control (Low Power to Phase 1)

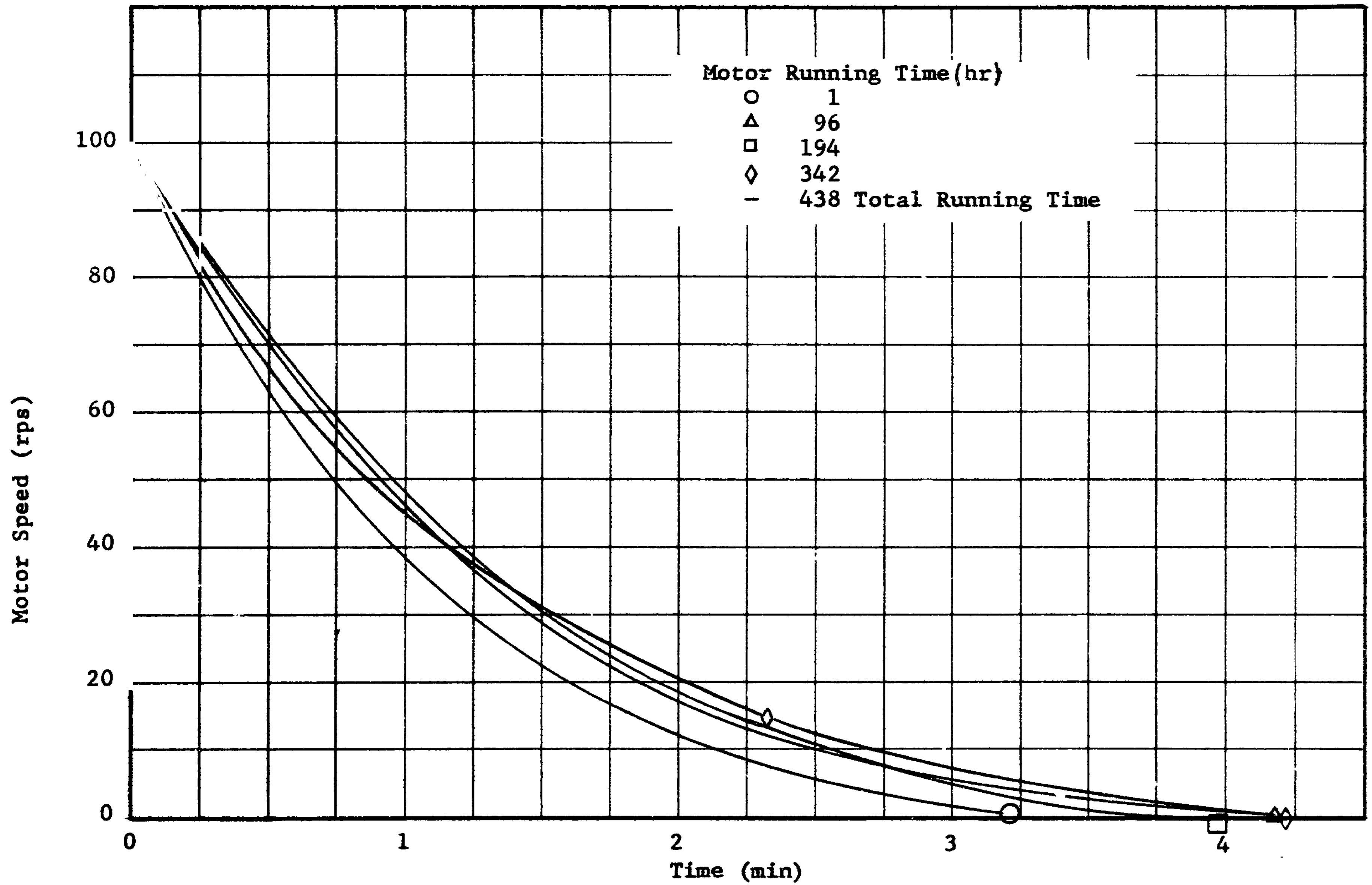

Figure 11.25 Speed During Coastdown of Motor 2 for GE F-50: Vacuum Control (Low Power to Phase 1)

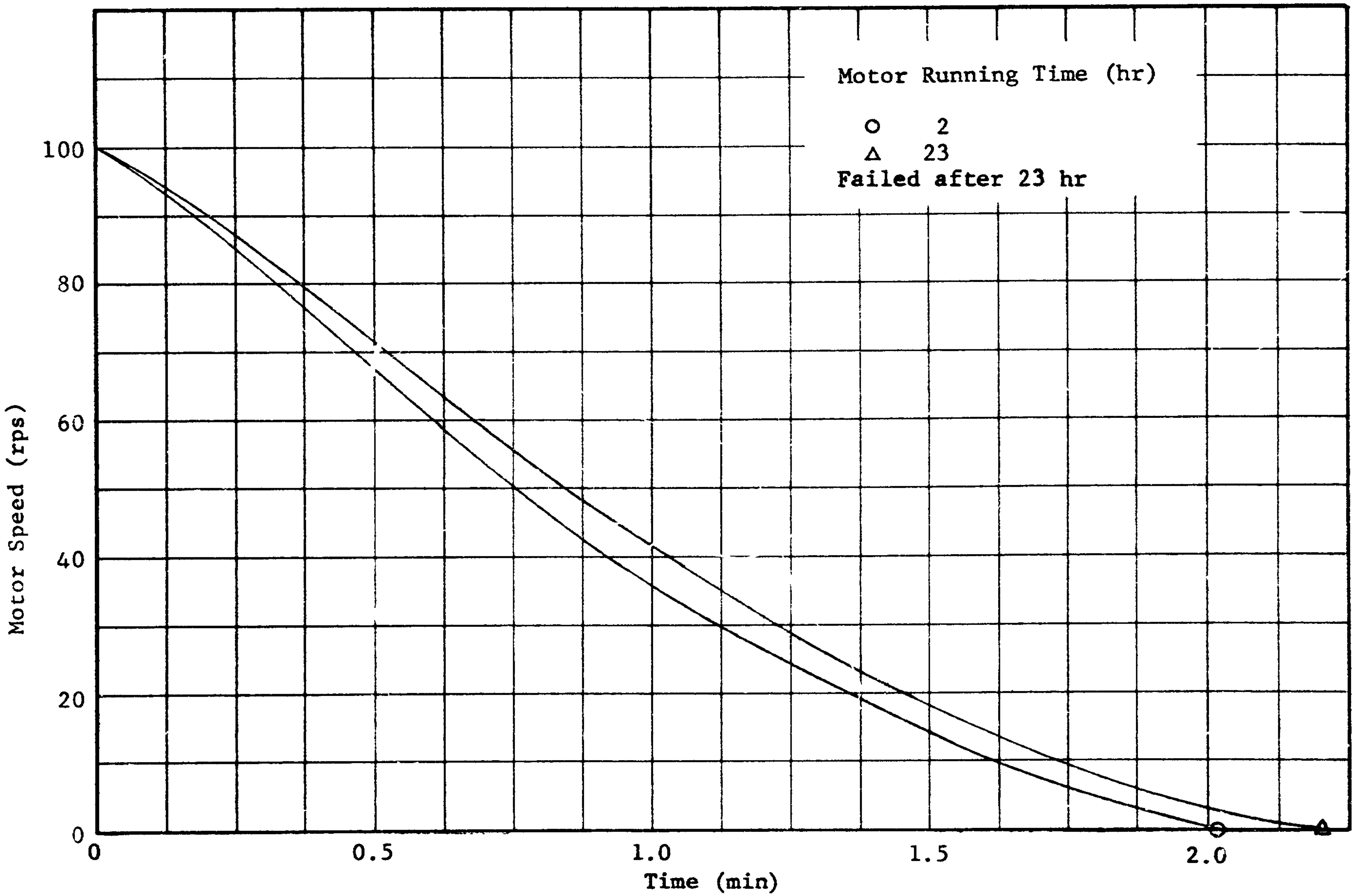

Figure 11.26 Speed During Coastdown of Motor 1 for GE F-50: Vacuum Control (High Power to Phase 1)

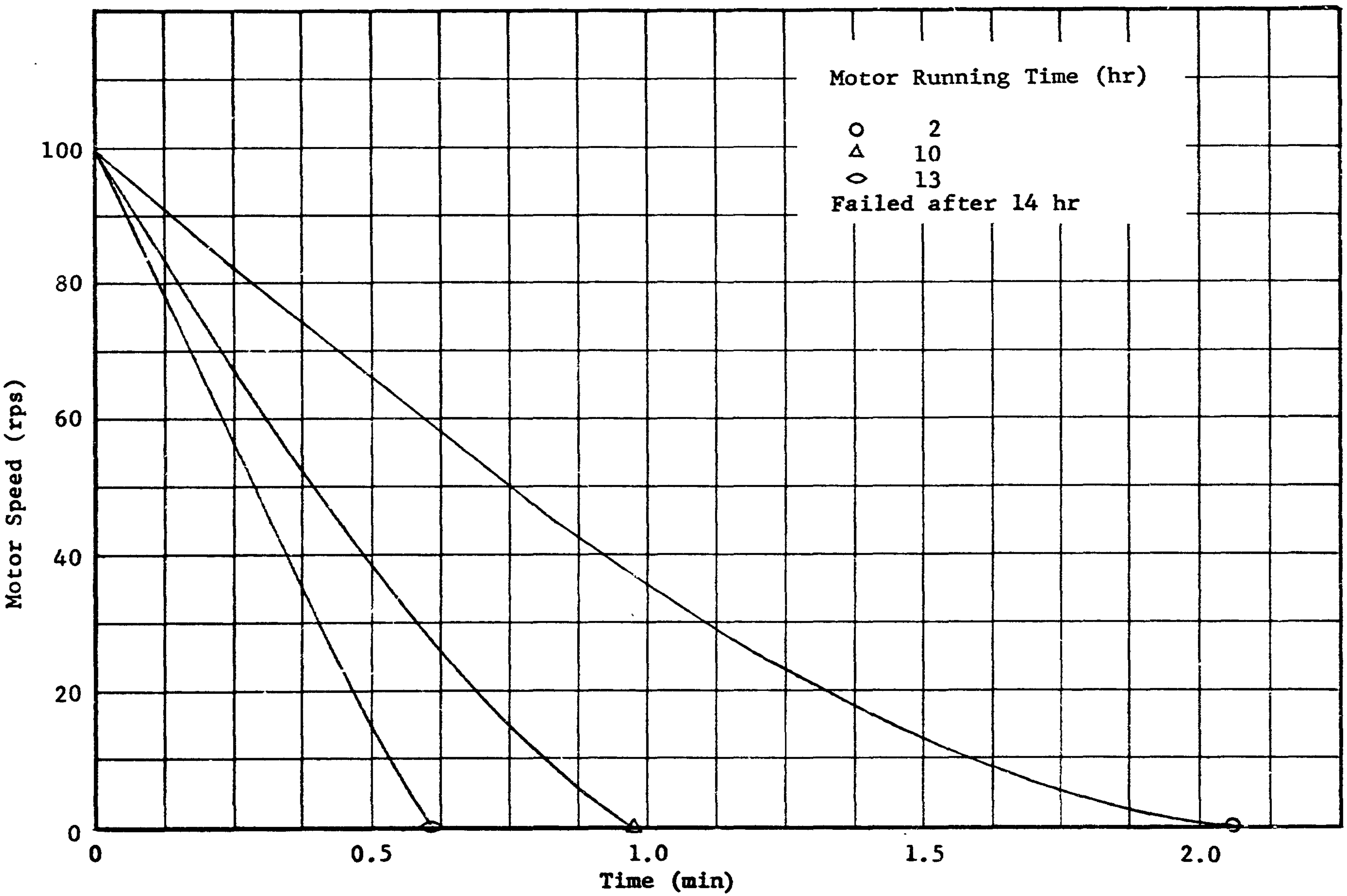

Figure 11.27 Speed During Coastdown of Motor 2 for GE F-50: Vacuum Control (High Power to Phase 1)

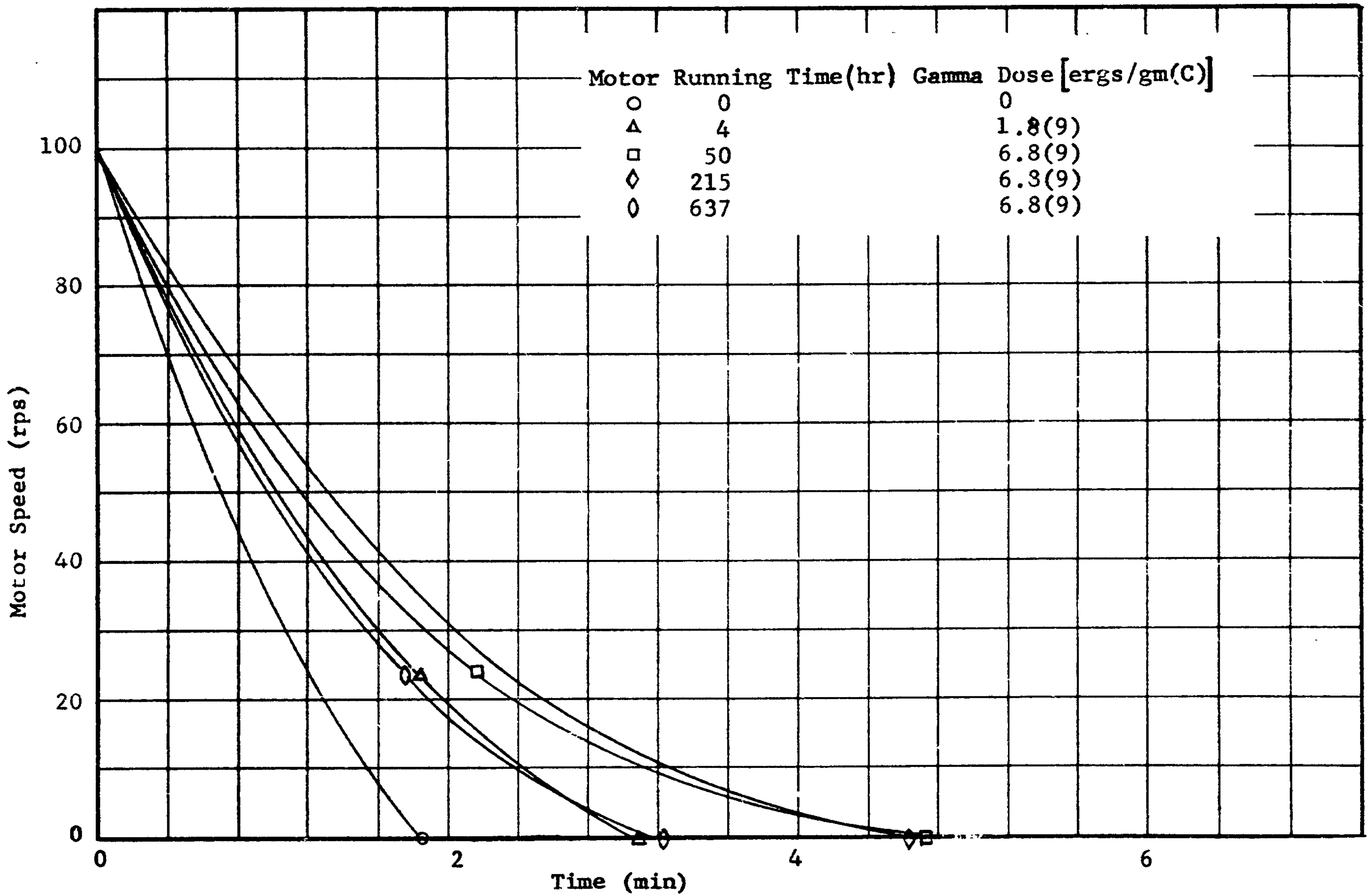

Figure 11.28 Speed During Coastdown of Motor 8 for Kynar: Vacuum Irradiation (Low Power to Phase 1)

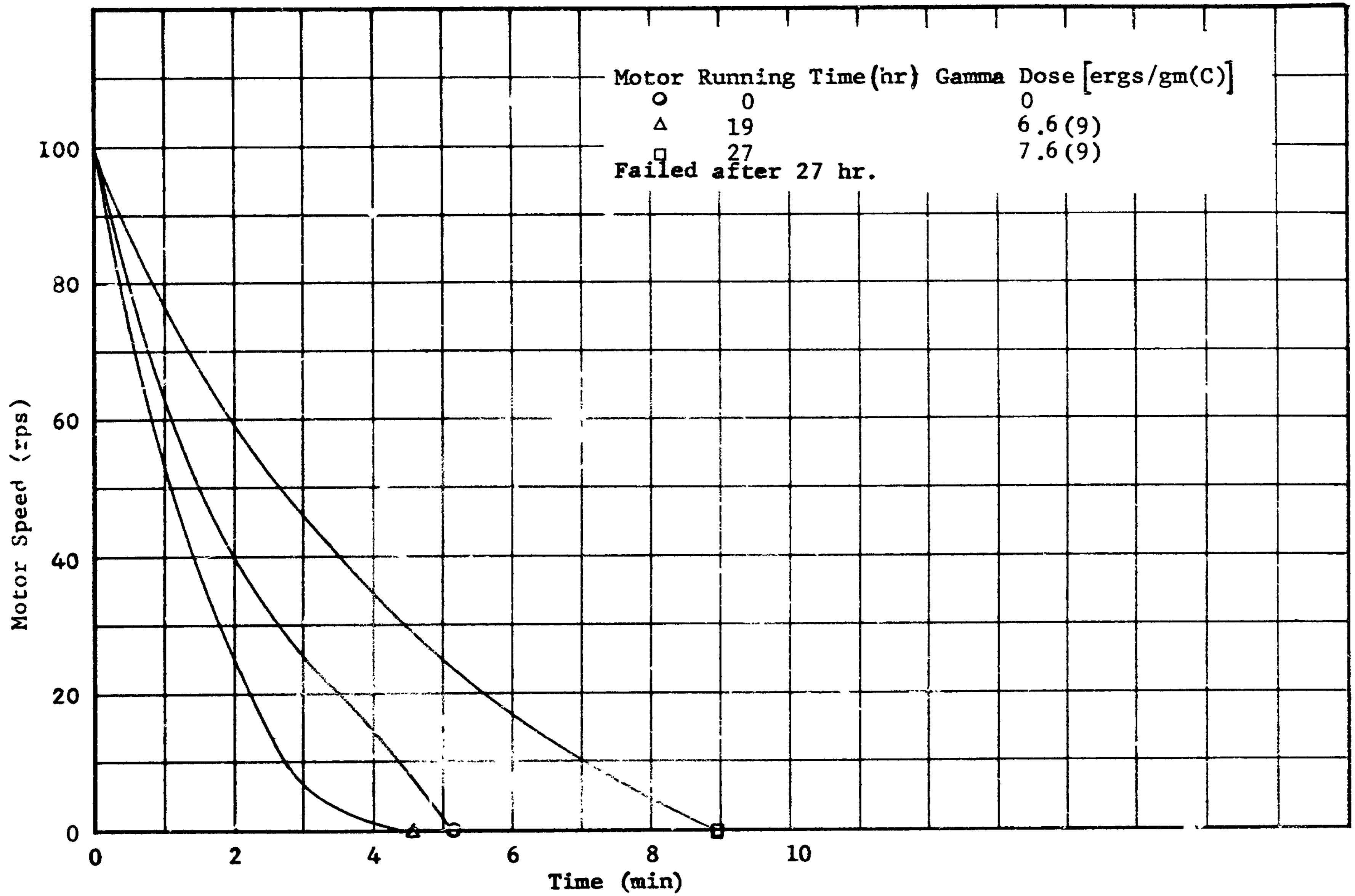

Figure 11.29 Speed During Coastdown of Motor 7 for Kynar: Vacuum Irradiation (Low Power to Phase 1)

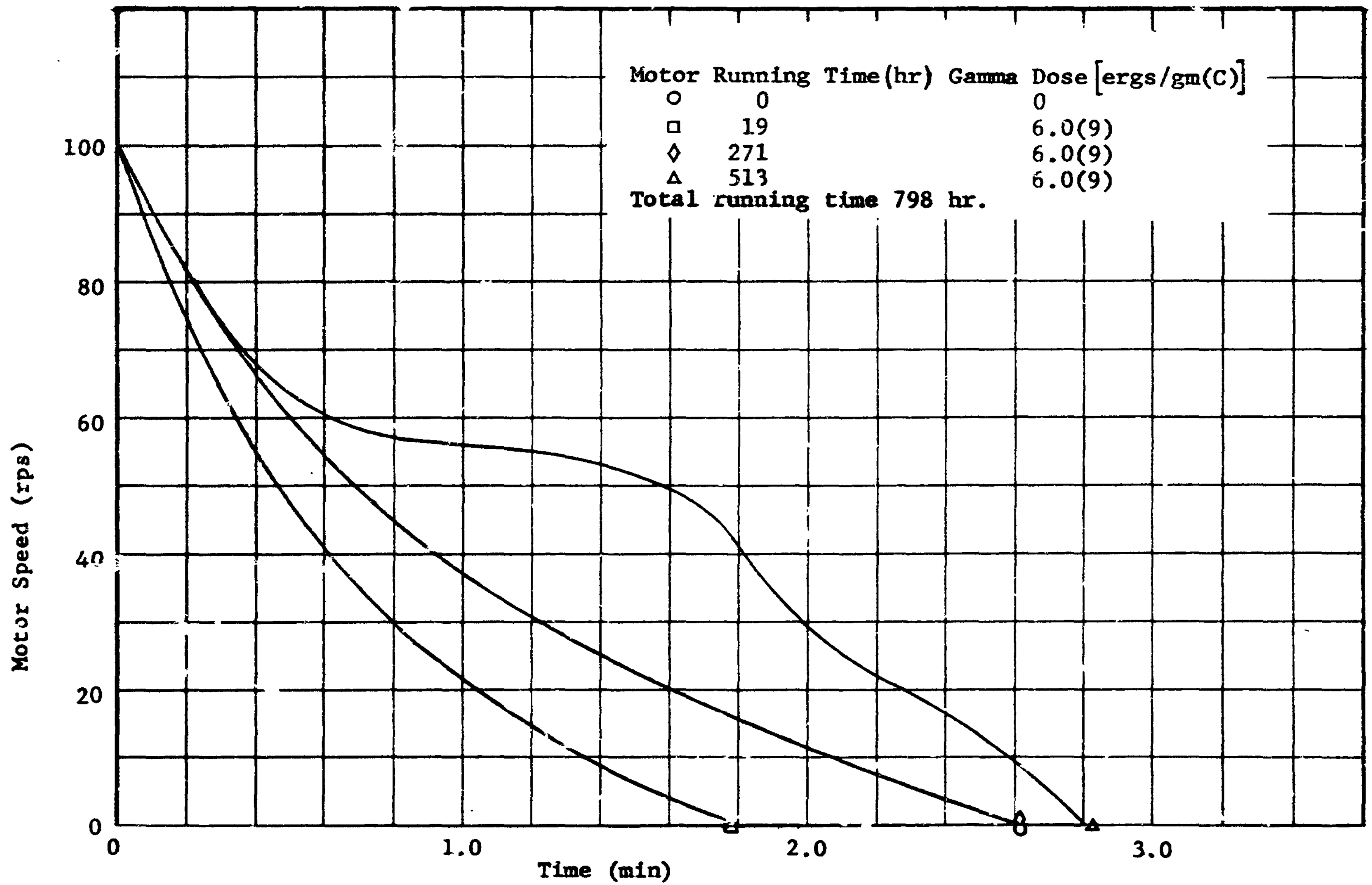

Figure 11.30 Speed During Coastdown of Motor 8 for Kynar: Air Irradiation (Low Power to Phase 1)

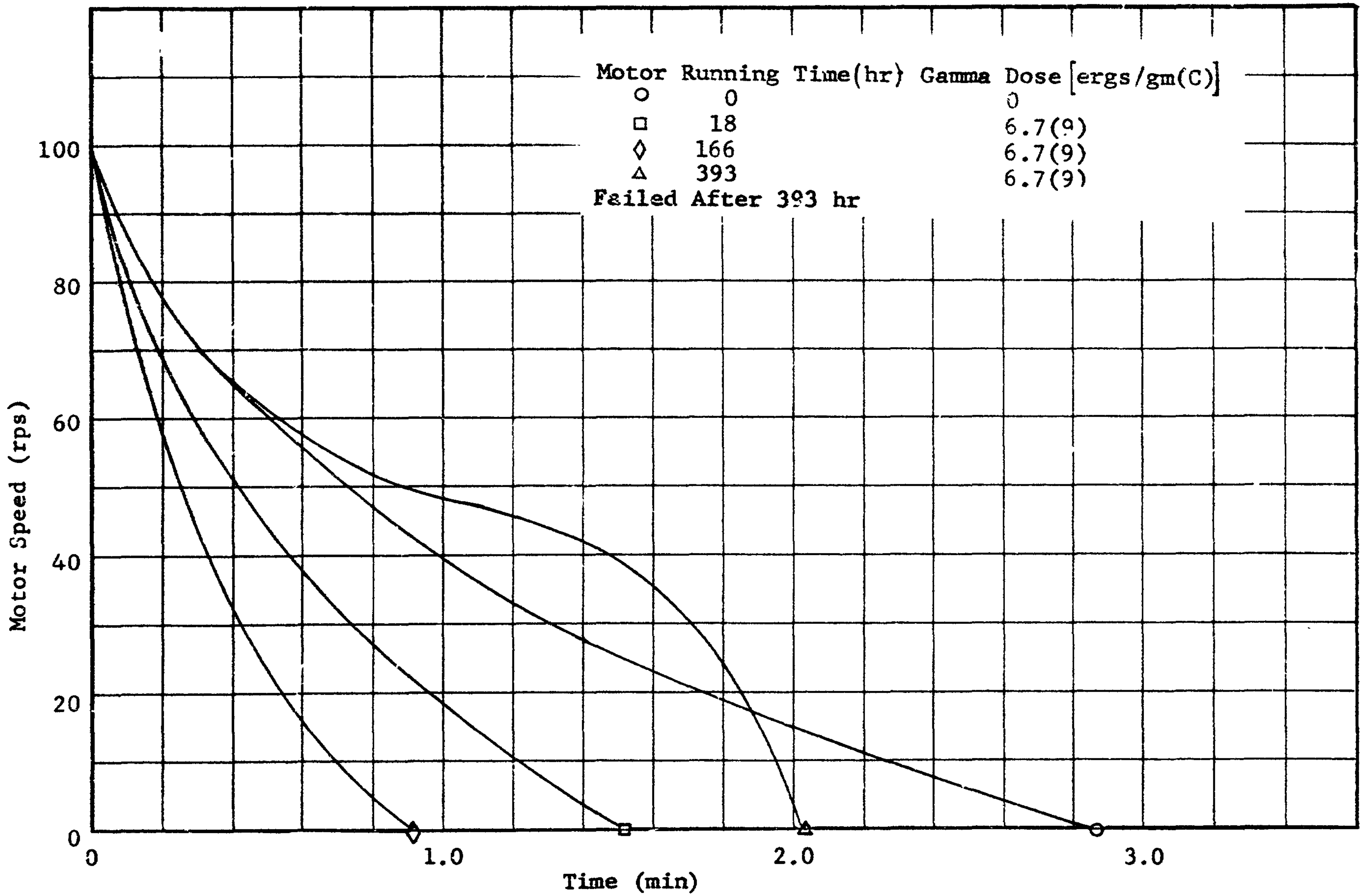

Figure 11.31 Speed During Coastdown of Motor 7 for Kynar: Air Irradiation (Low Power to Phase 1)

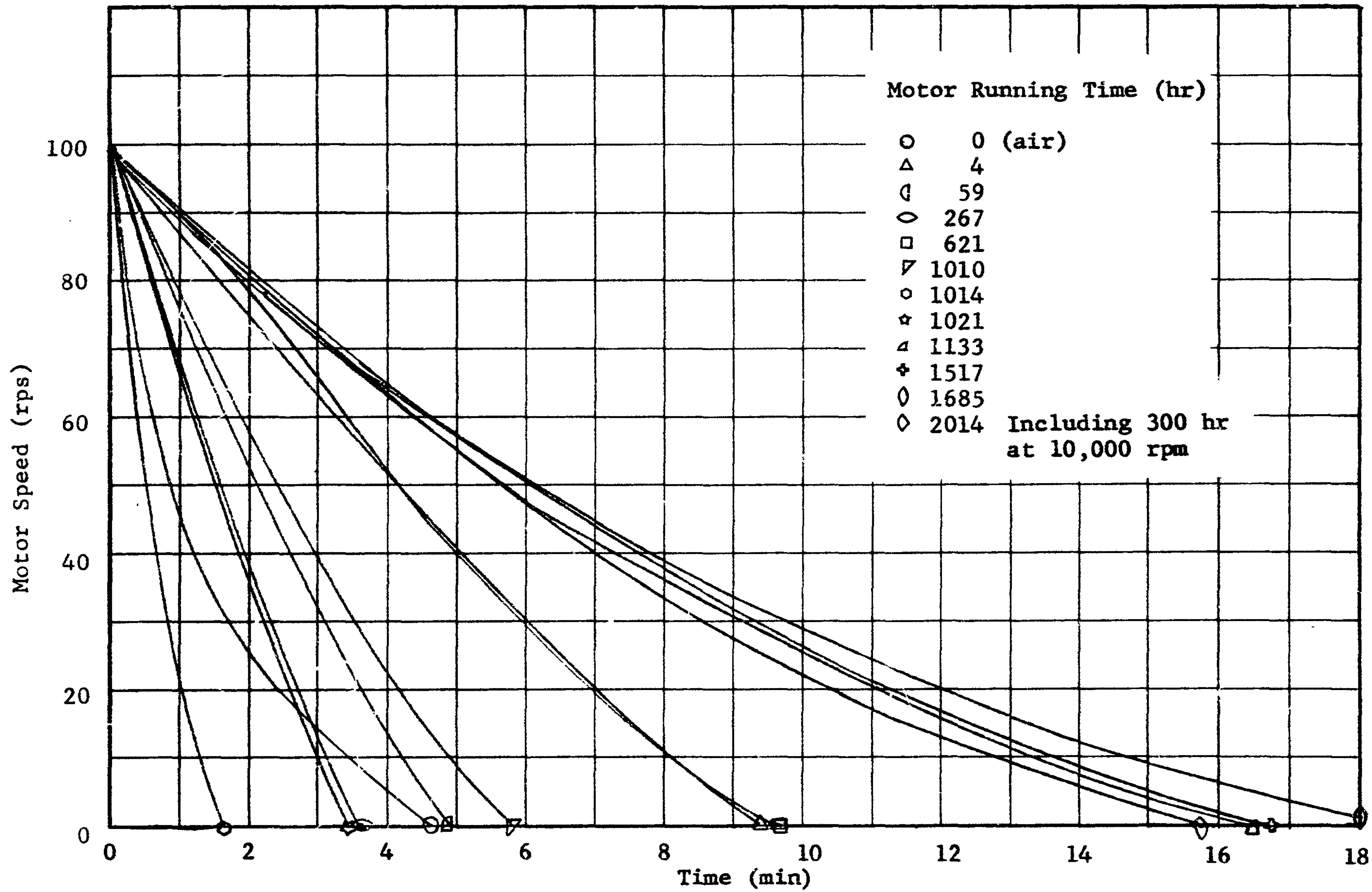

Figure 11.32 Speed During Coastdown of Motor 7 for Kynar: Vacuum Control (Low Power to Phase 1)

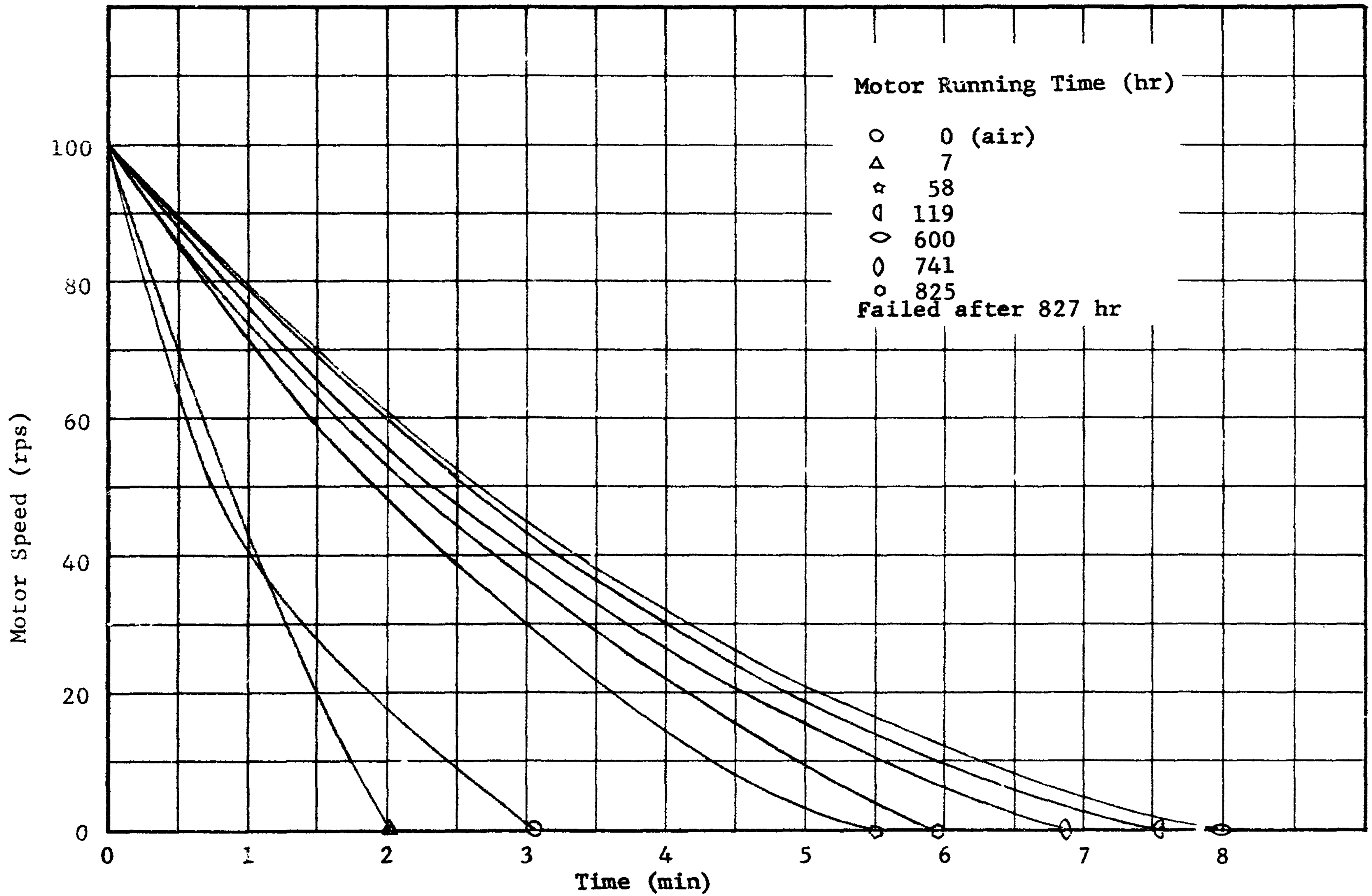

Figure 11.33 Speed During Coastdown of Motor 8 for Kynar: Vacuum Control (Low Power to Phase 1)

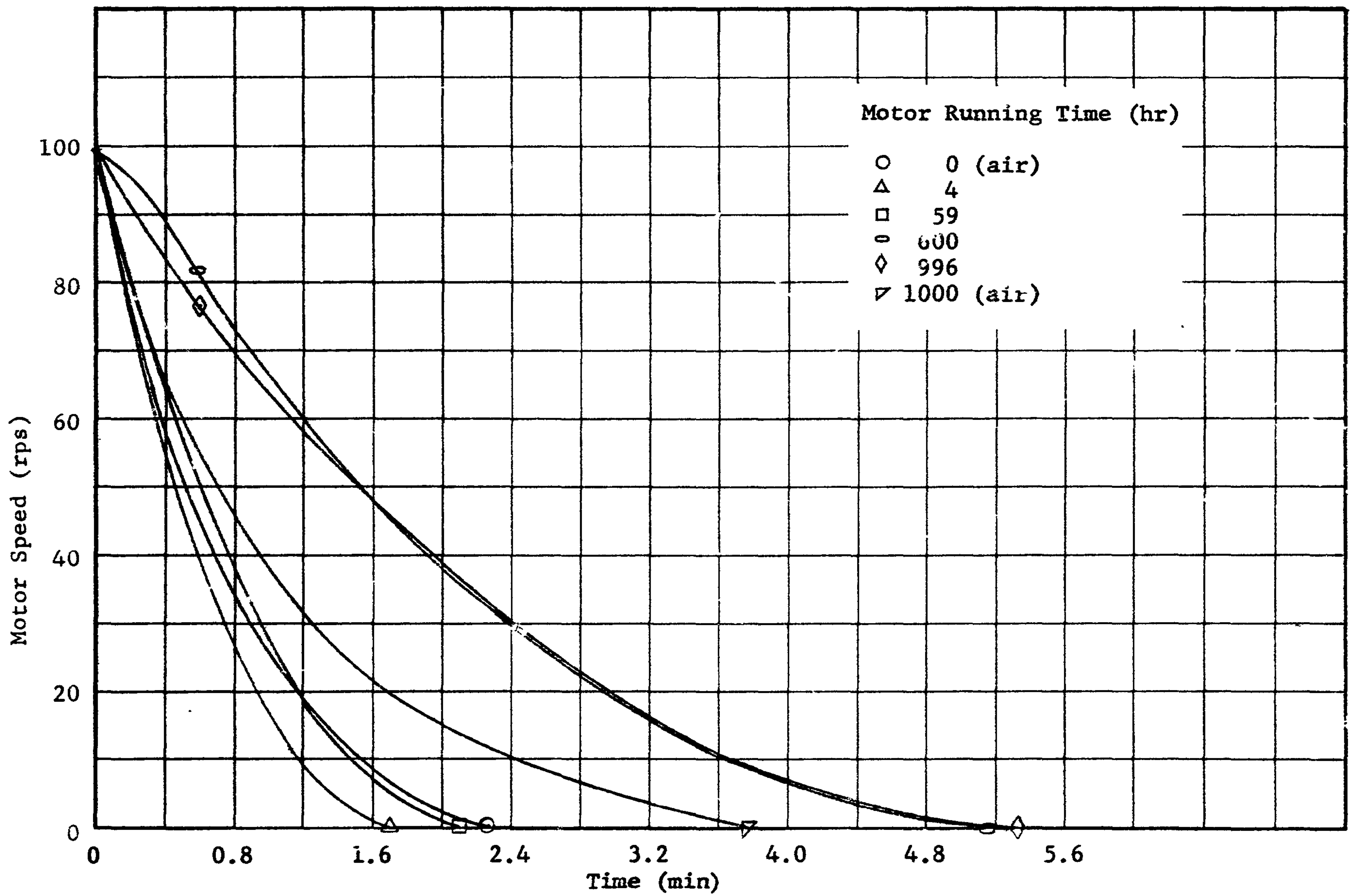

Figure 11.34 Speed During Coastdown of Motor 5 for Minapure: Vacuum Control (Low Power to Phase 1)

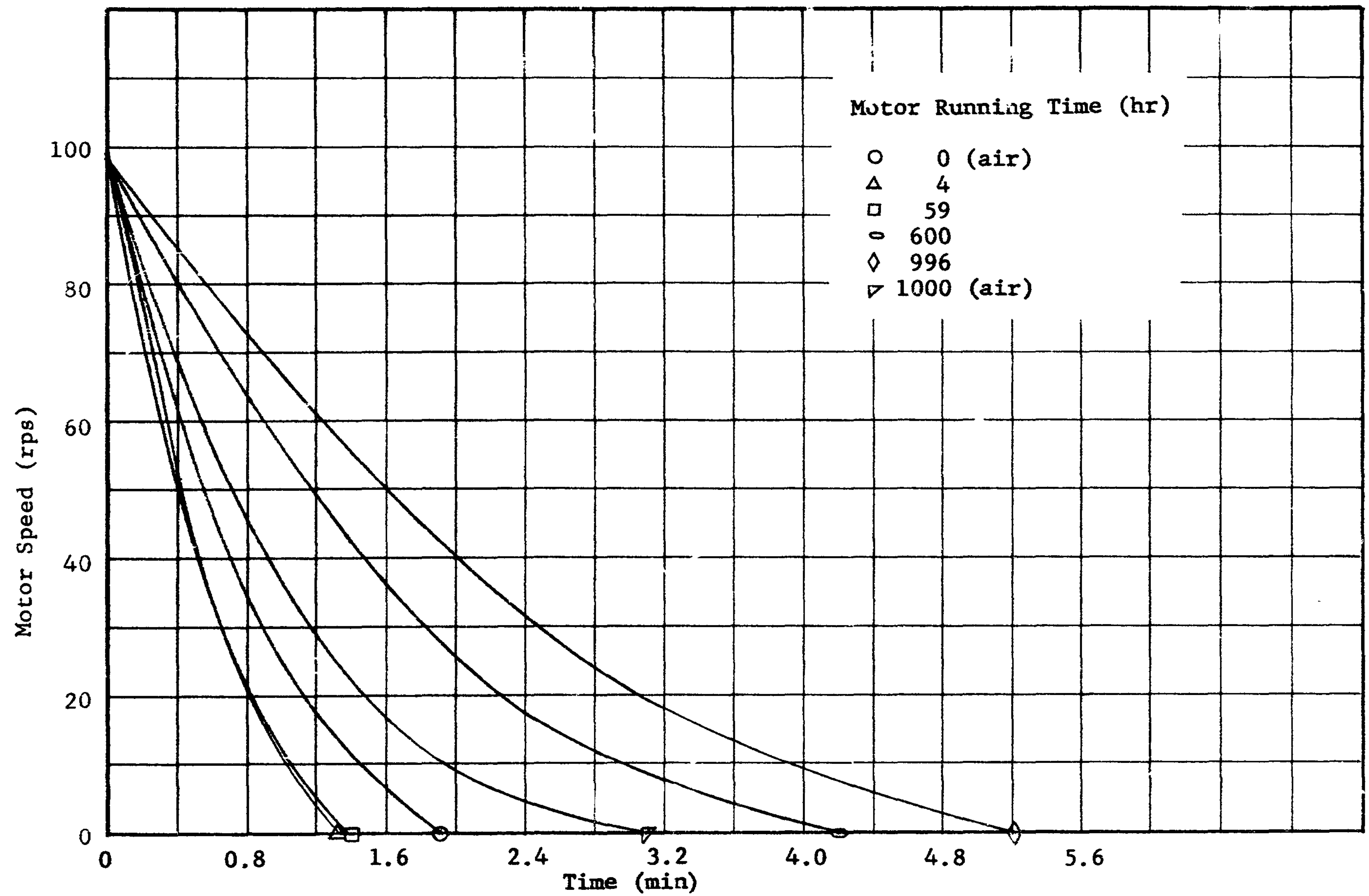

Figure 11.35 Speed During Coastdown of Motor 6 for Minapure: Vacuum Control (Low Power to Phase 1)

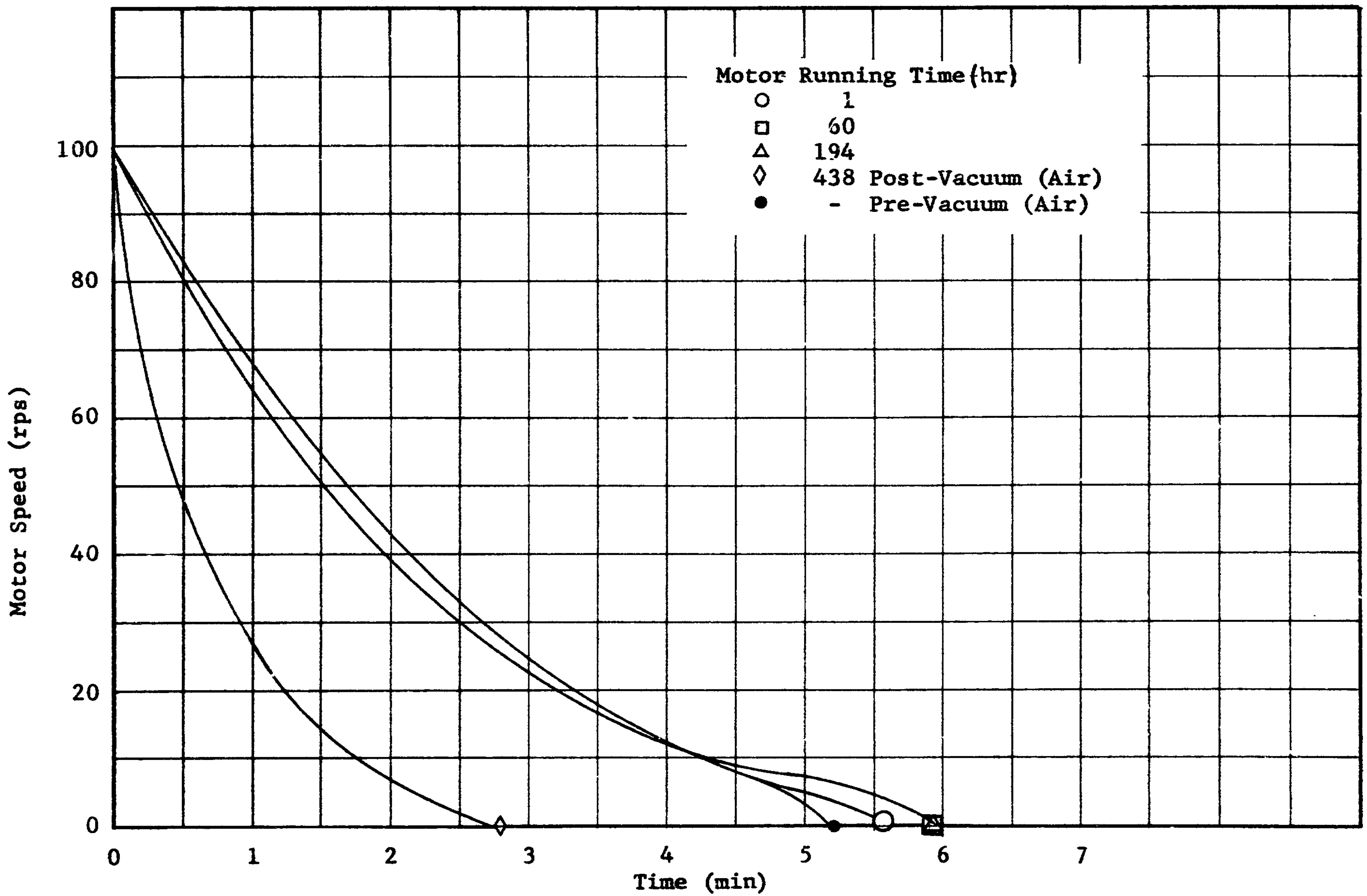

Figure 11.36 Speed During Coastdown of Motor 6 for MLF-5: Vacuum Control (Low Power to Phase 1)

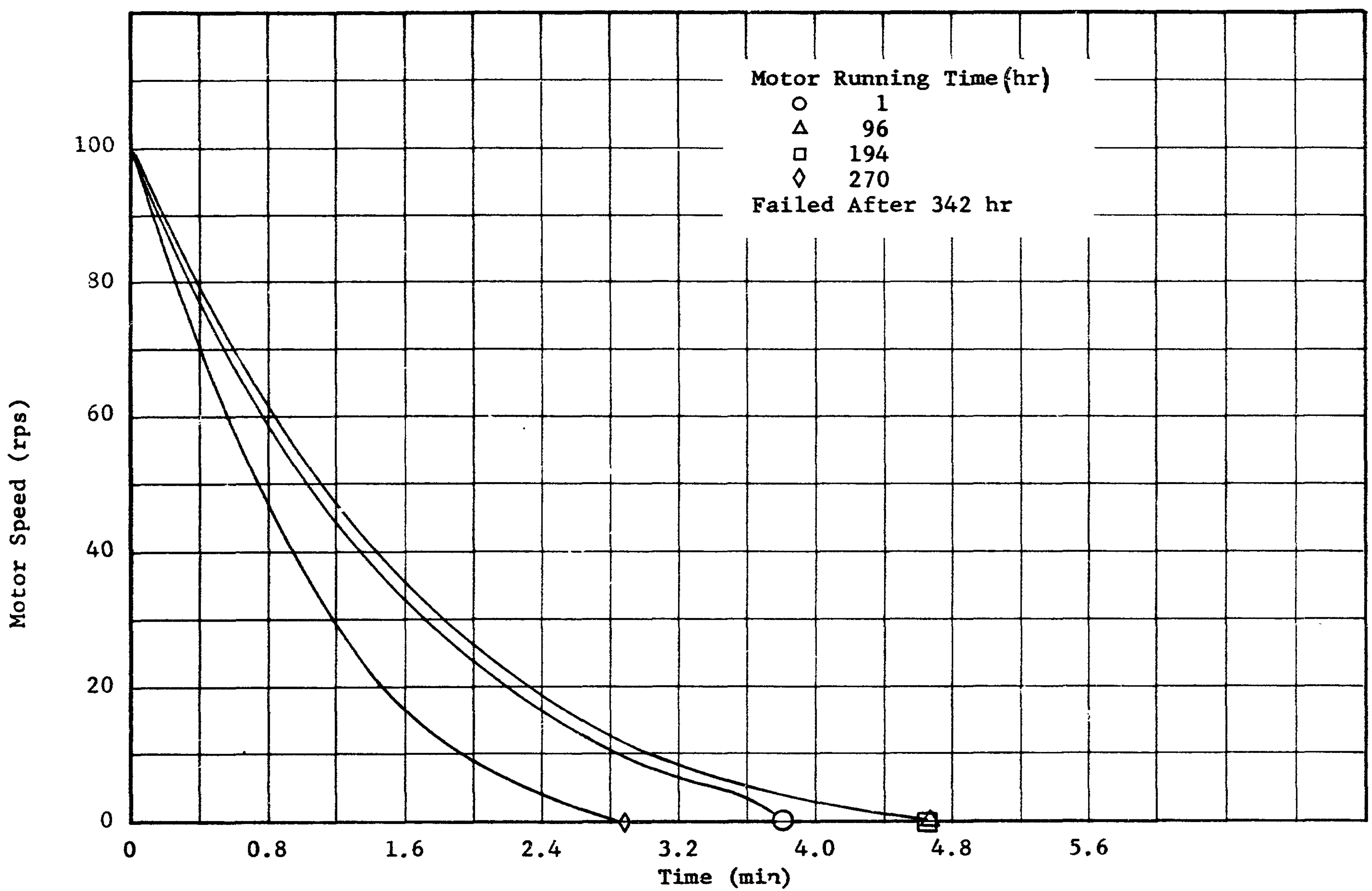

Figure 11.37 Speed During Coastdown of Motor 5 for MLF-5: Vacuum Control (Low Power to Phase 1)

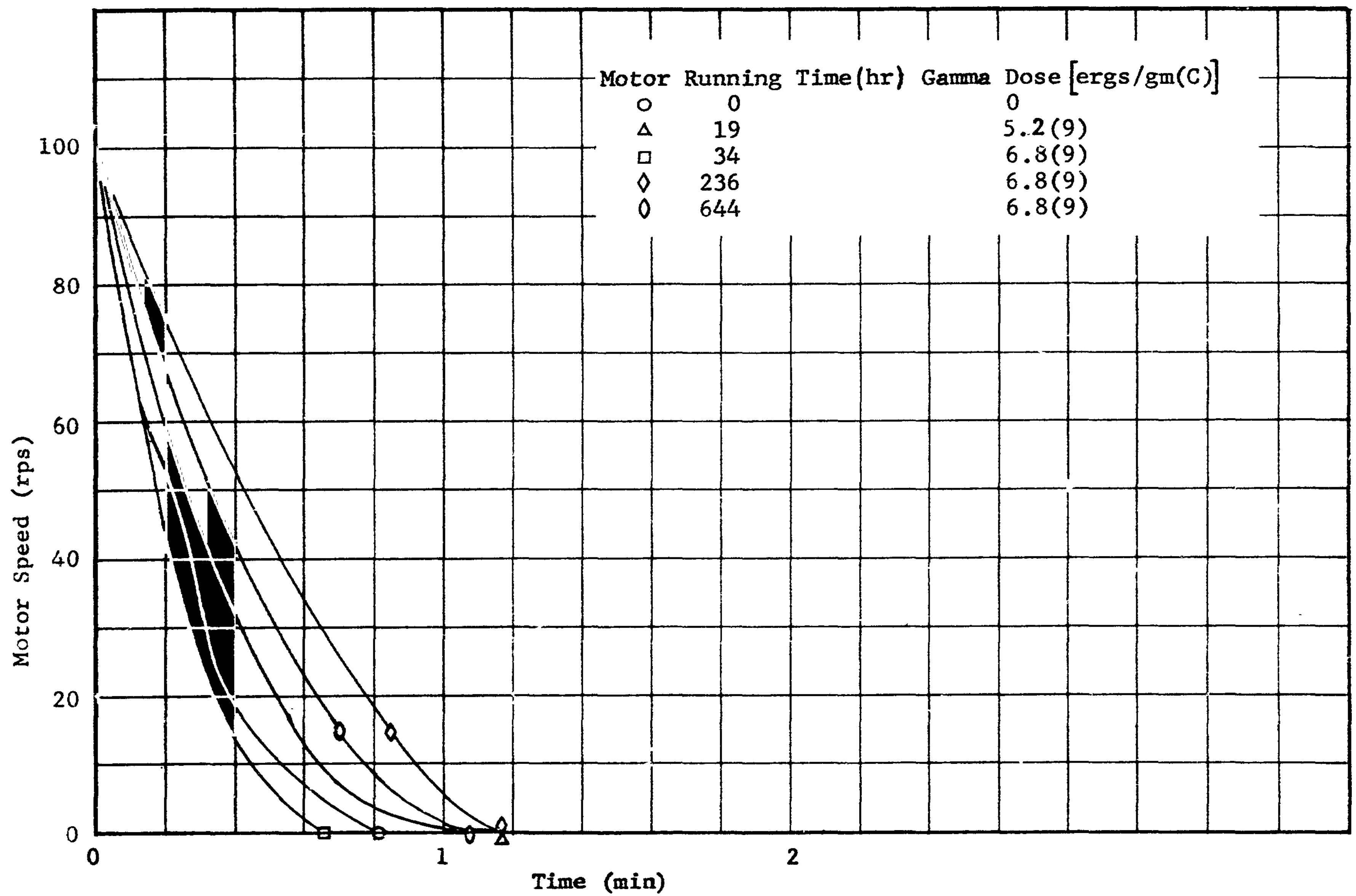

Figure 11.38 Speed During Coastdown of Motor 4 for OS-124: Vacuum Irradiation (Low Power to Phase 1)

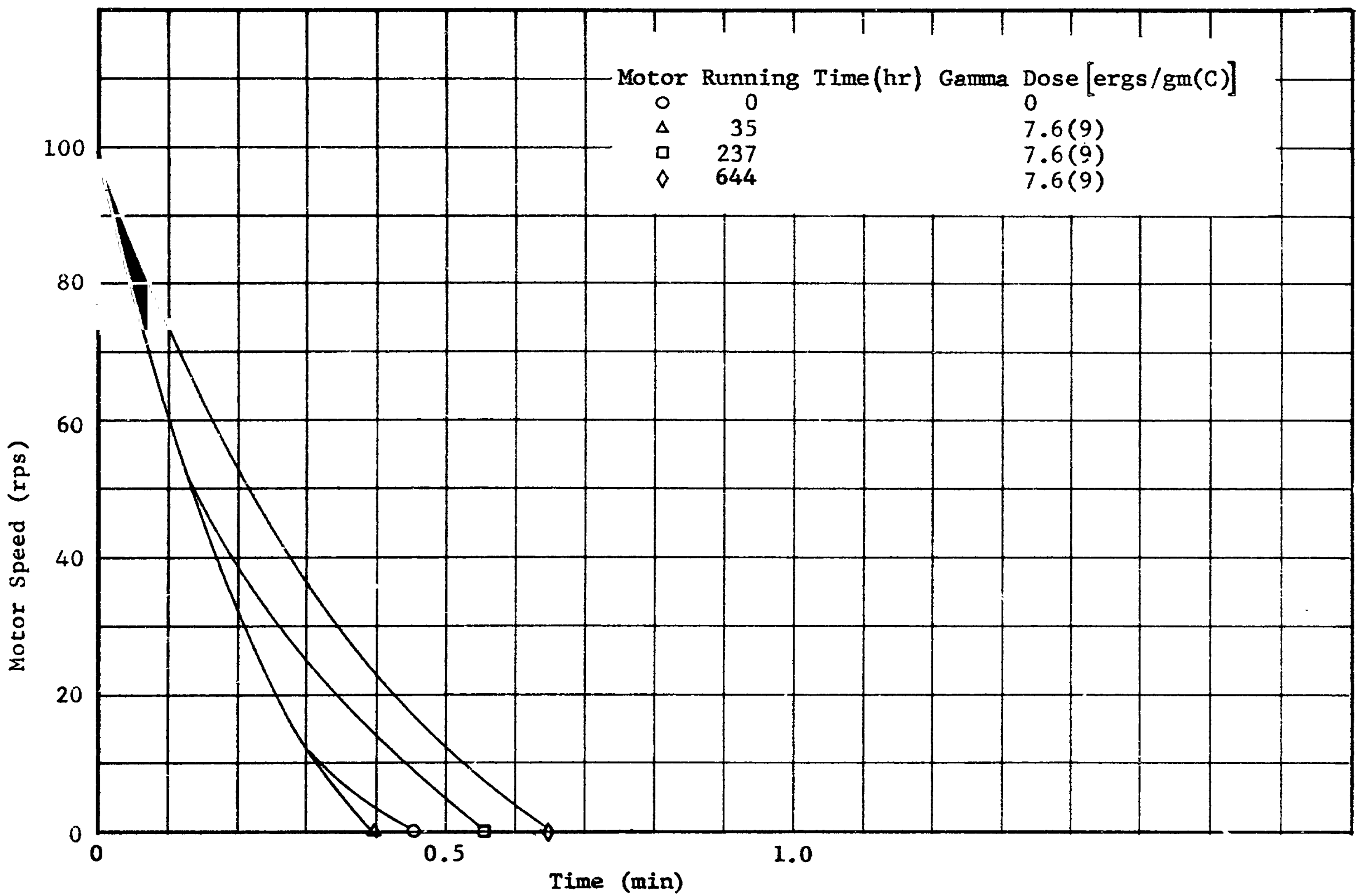

Figure 11.39 Speed During Coastdown of Motor 3 for OS-124: Vacuum Irradiation (Low Power to Phase 1)

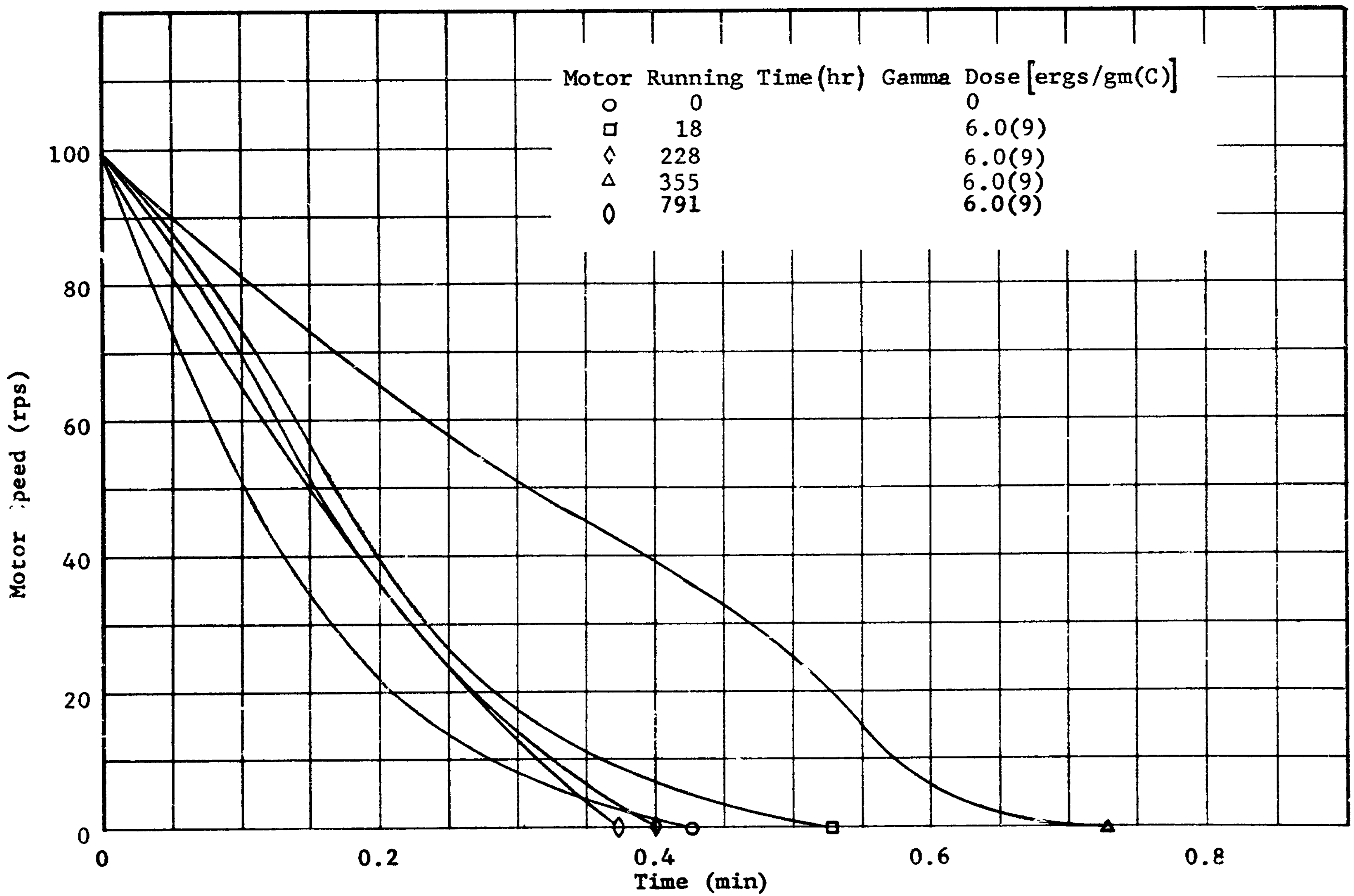

Figure 11.40 Speed During Coastdown of Motor 4 for OS-124: Air Irradiation (Low Power to Phase 1)

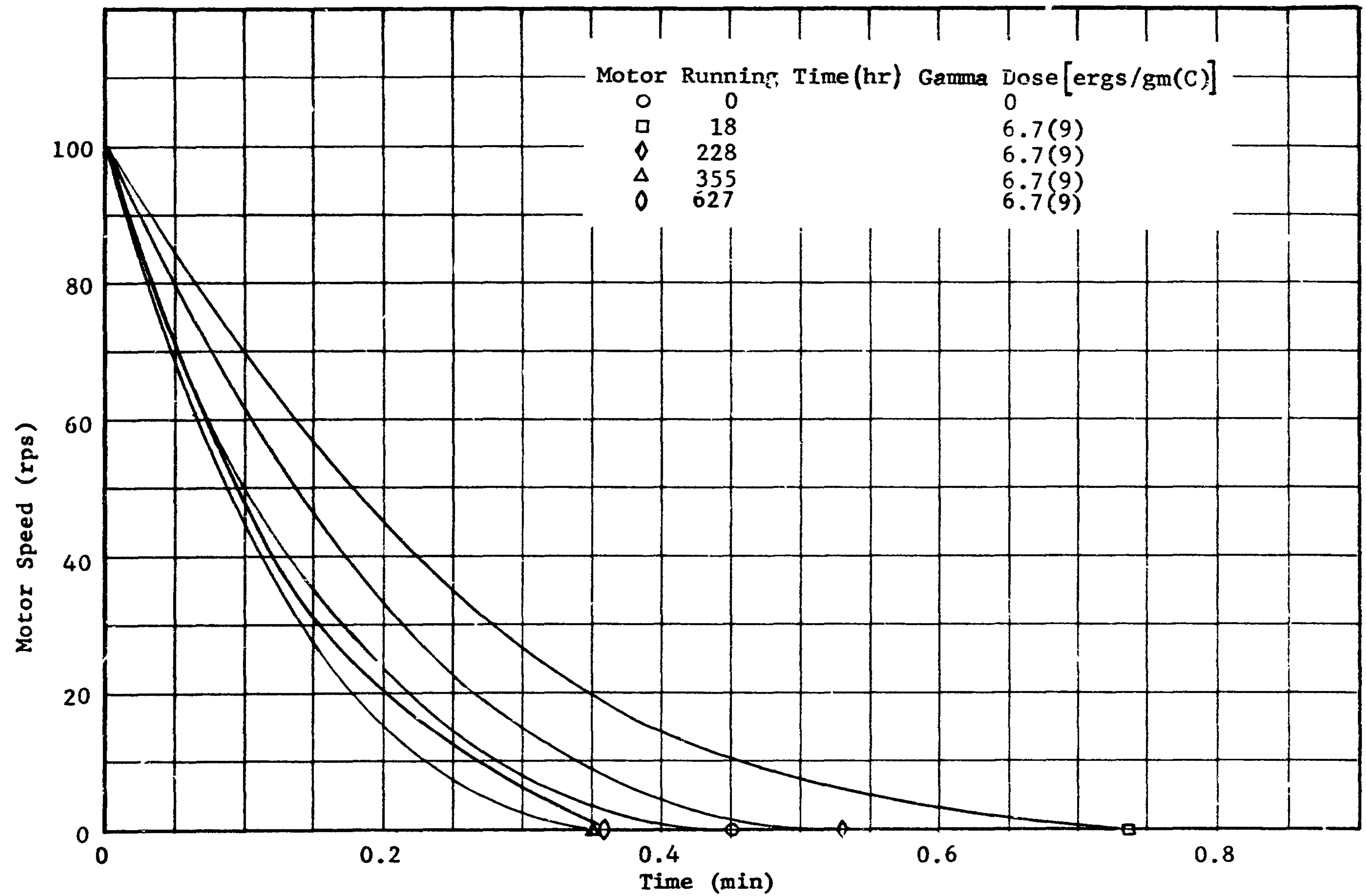

Figure 11.41 Speed During Coastdown of Motor 3 for OS-124: Air Irradiation (Low Power to Phase 1)

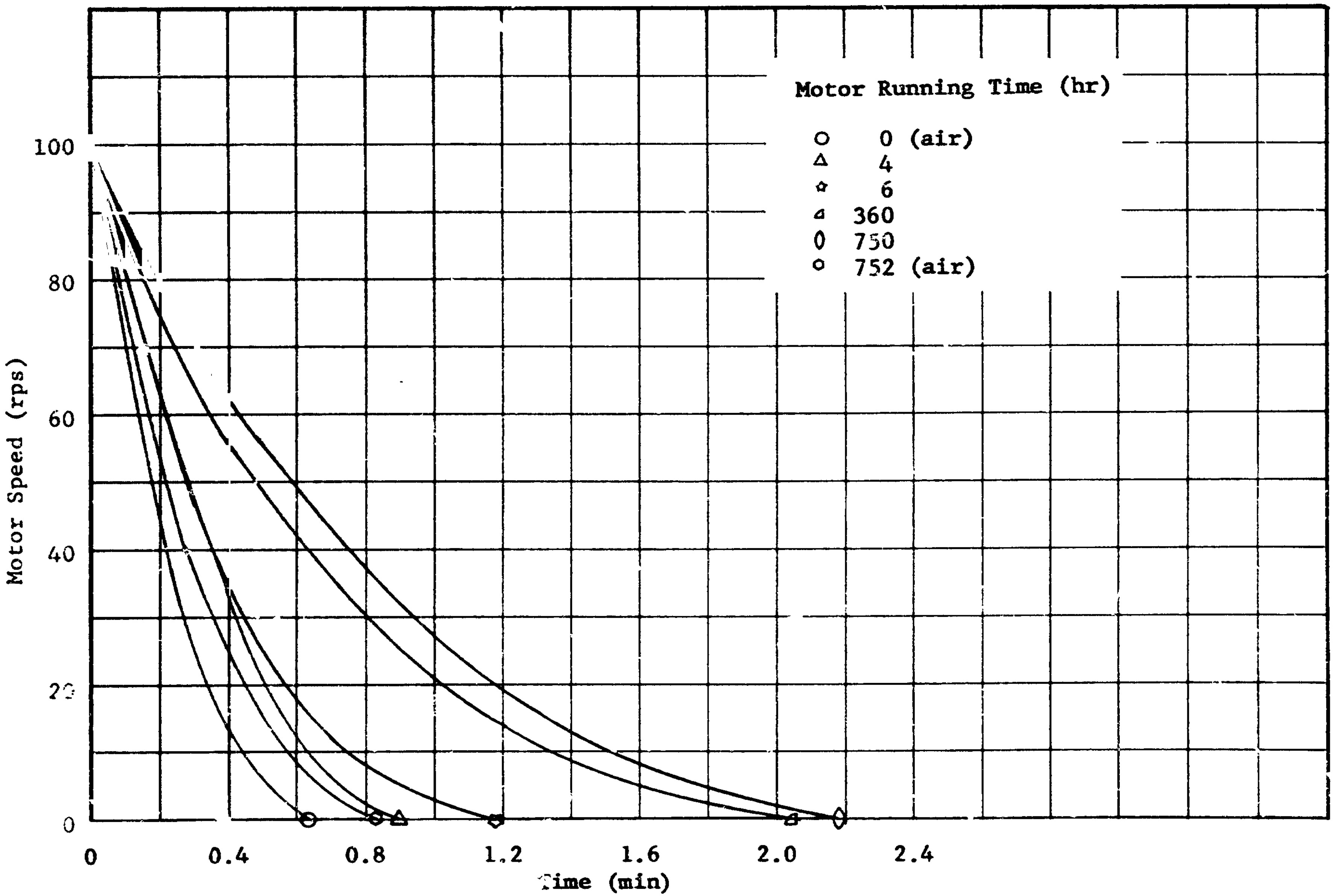

Figure 11.42 Speed During Coastdown of Motor 3 for OS-124: Vacuum Control (Low Power to Phase 1)

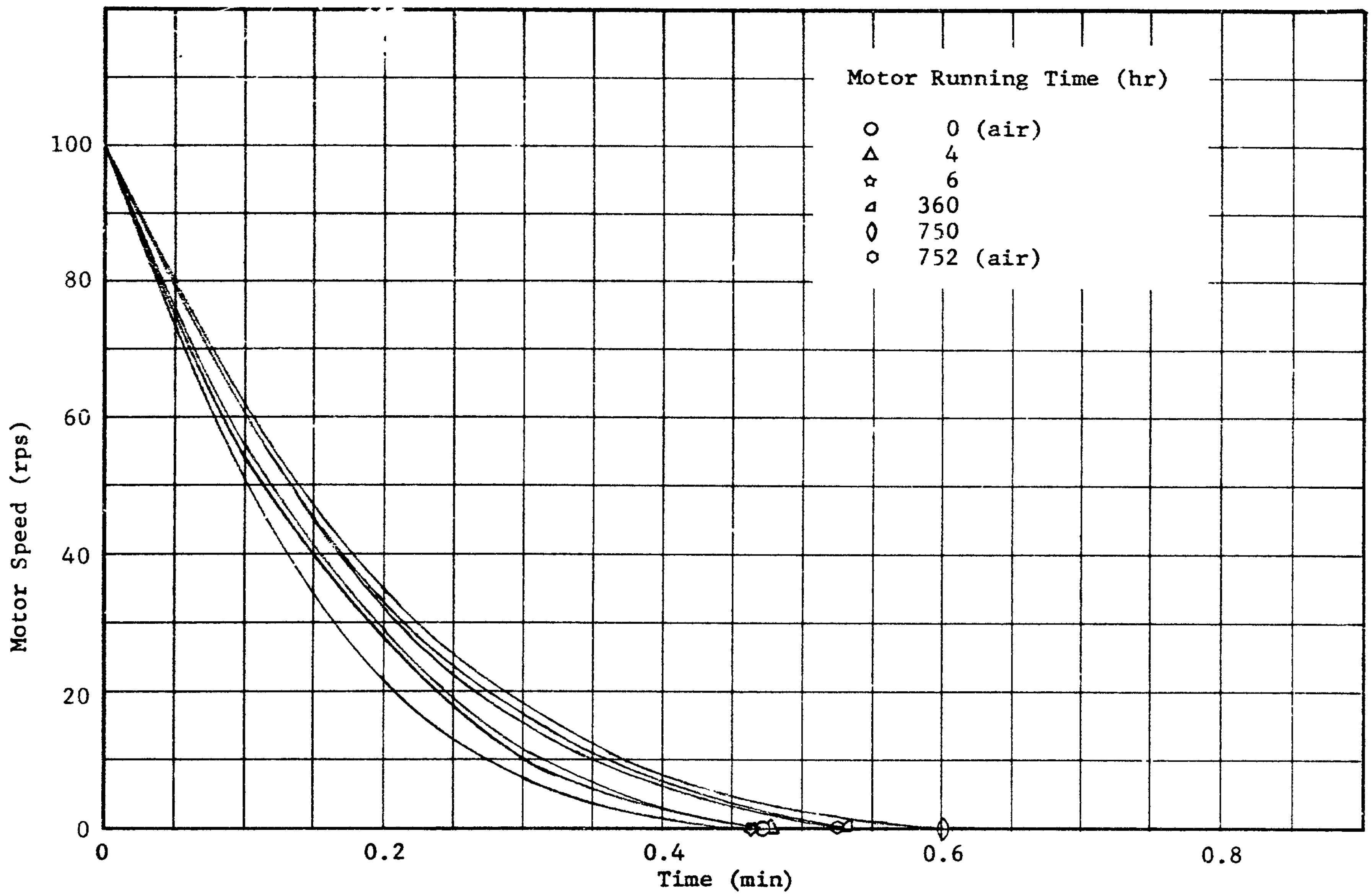

Figure 11.43 Speed During Coastdown of Motor 4 for OS-124: Vacuum Control (Low Power to Phase 1)

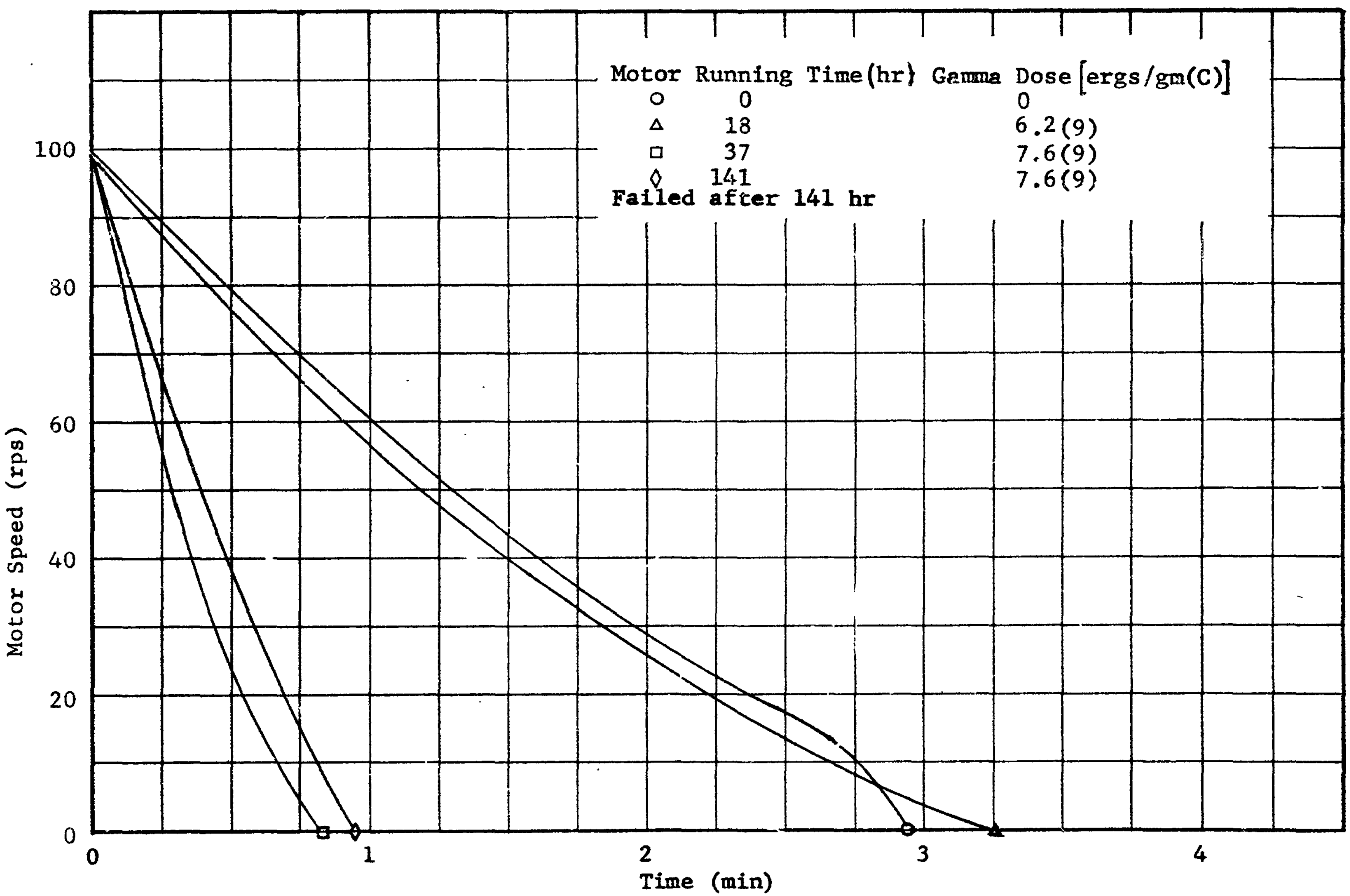

Figure 11.44 Speed During Coastdown of Motor 1 for Polymer SP-F: Vacuum Irradiation (Low Power to Phase 1)

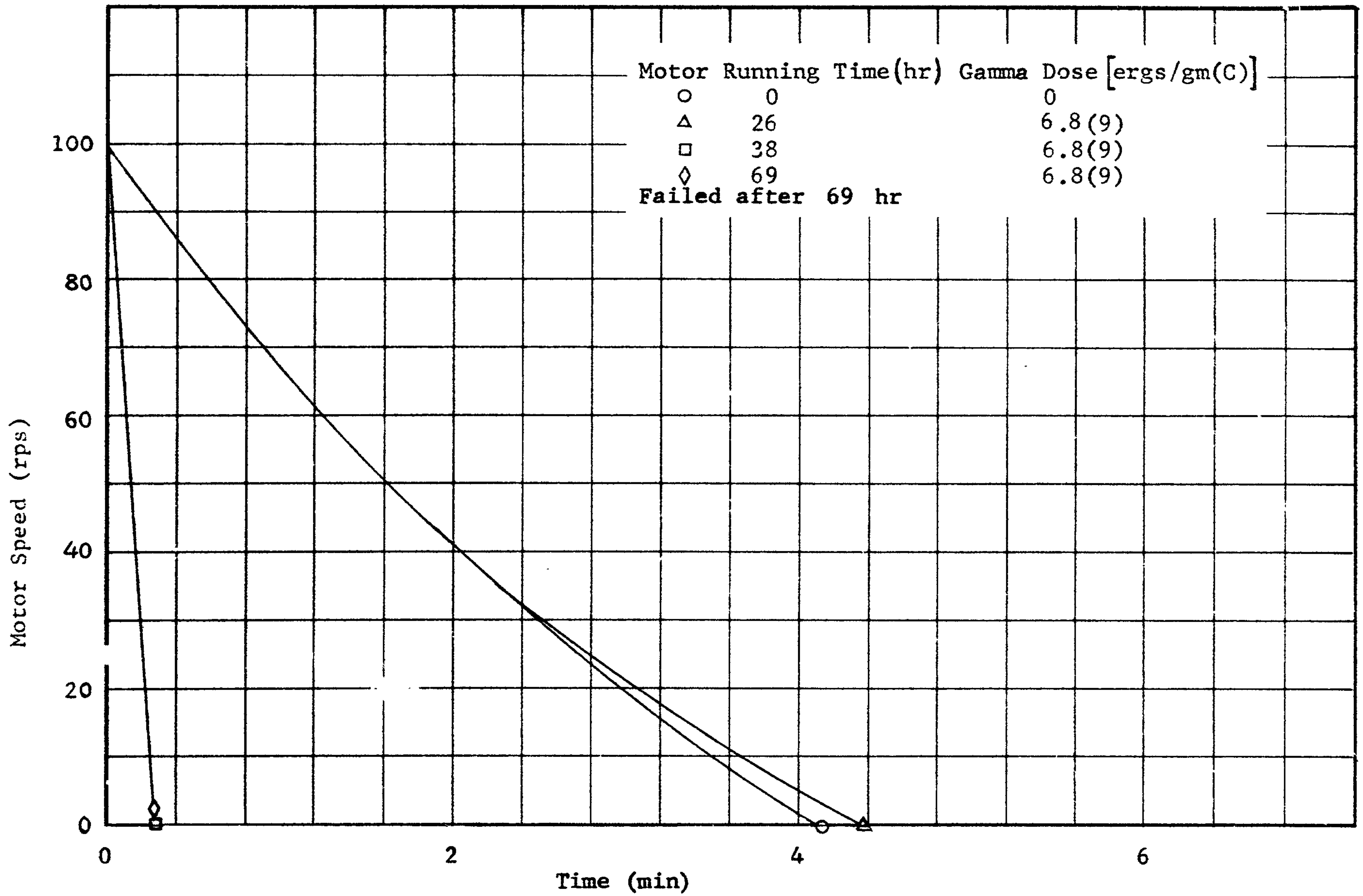

Figure 11.45 Speed During Coastdown of Motor 2 for Polymer SP-F: Vacuum Irradiation (Low Power to Phase 1)

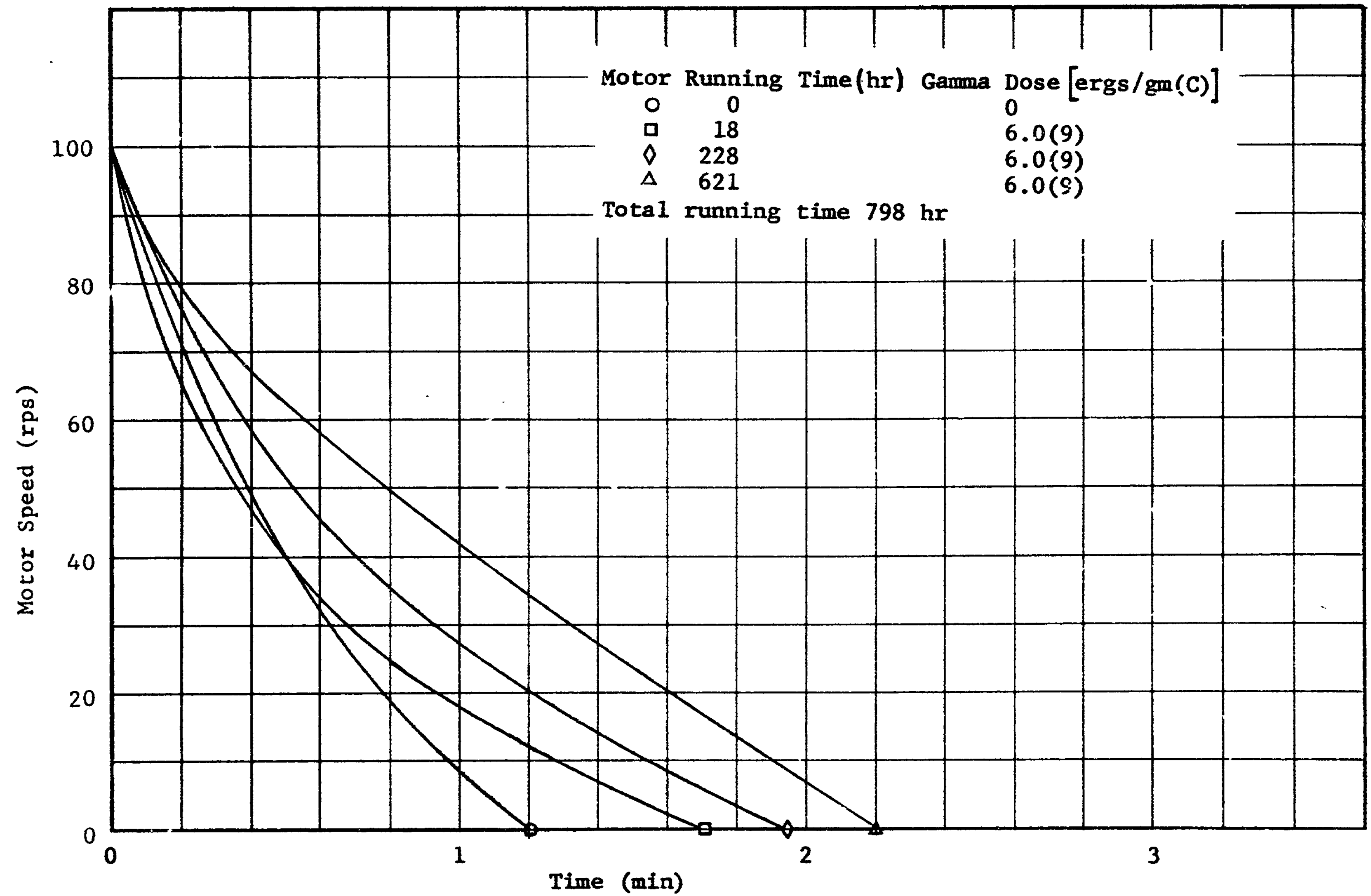

Figure 11.46 Speed During Coastdown of Motor 2 for Polymer SP-F: Air Irradiation (Low Power to Phase 1)

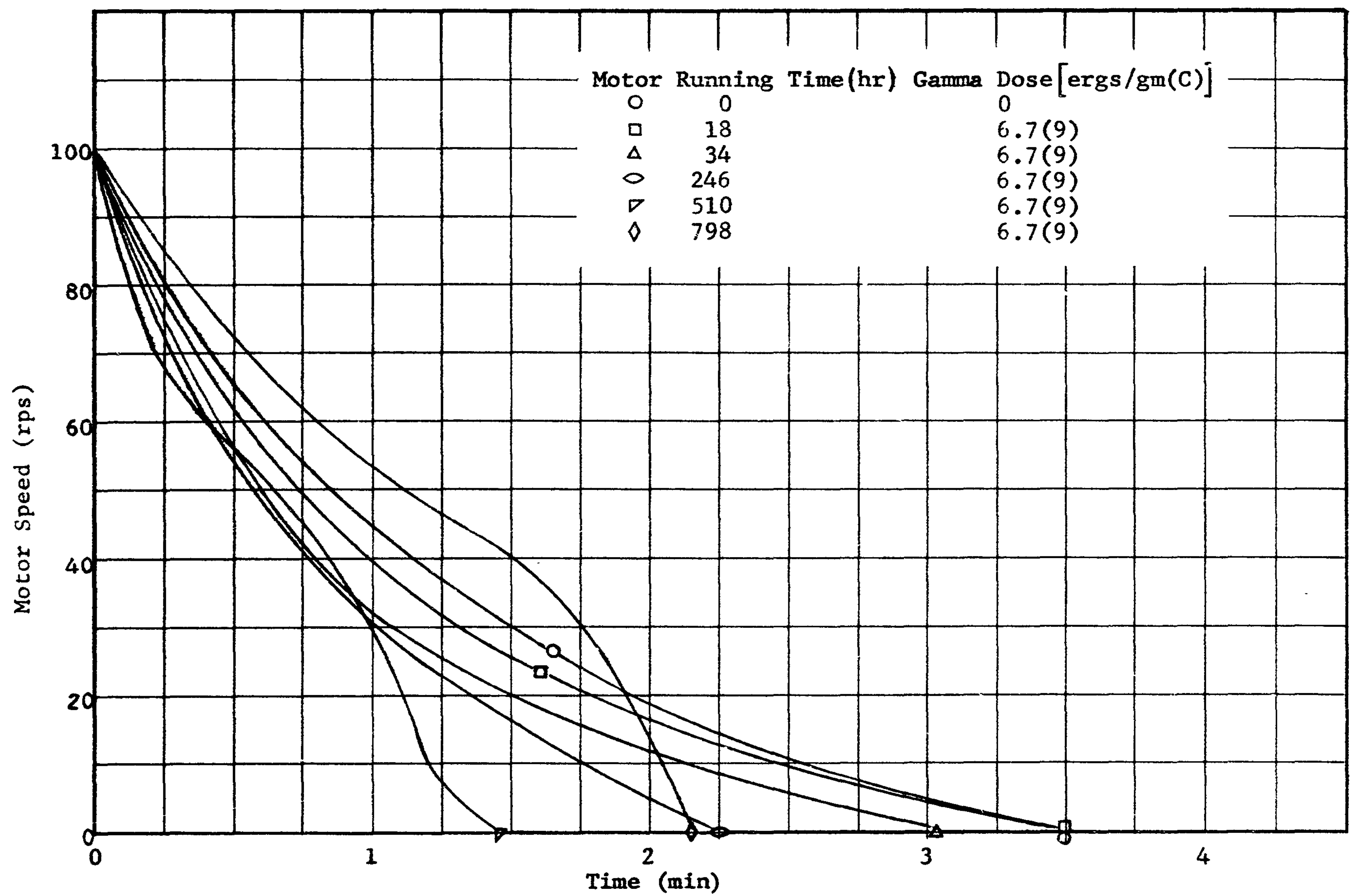

Figure 11.47 **Speed During Coastdown of Motor 1 for Polymer SP-F: Air Irradiation (Low Power to Phase 1)**

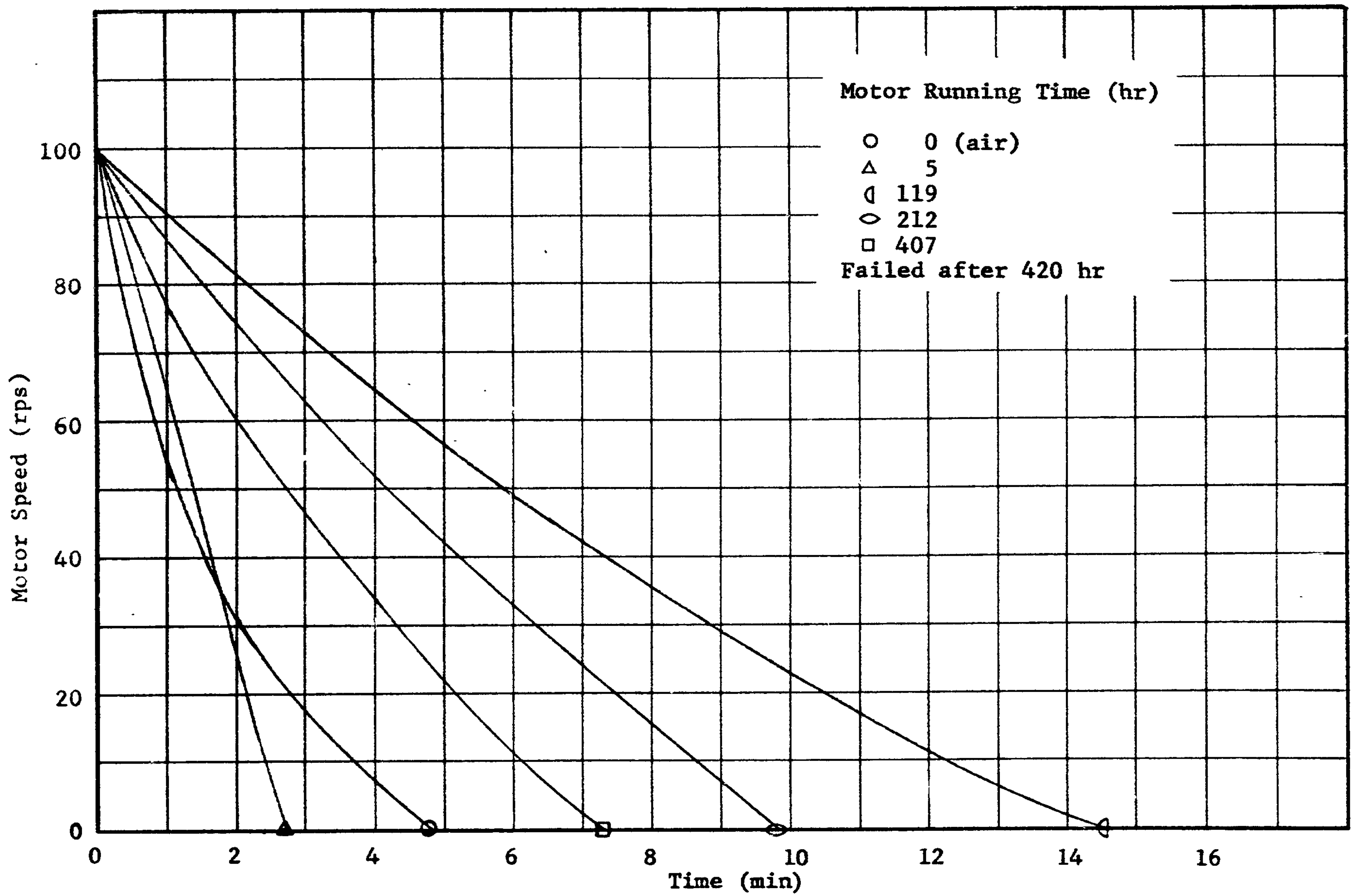

Figure 11.48 Speed During Coastdown of Motor 2 for Polymer SP-F: Vacuum Control (Low Power to Phase 1)

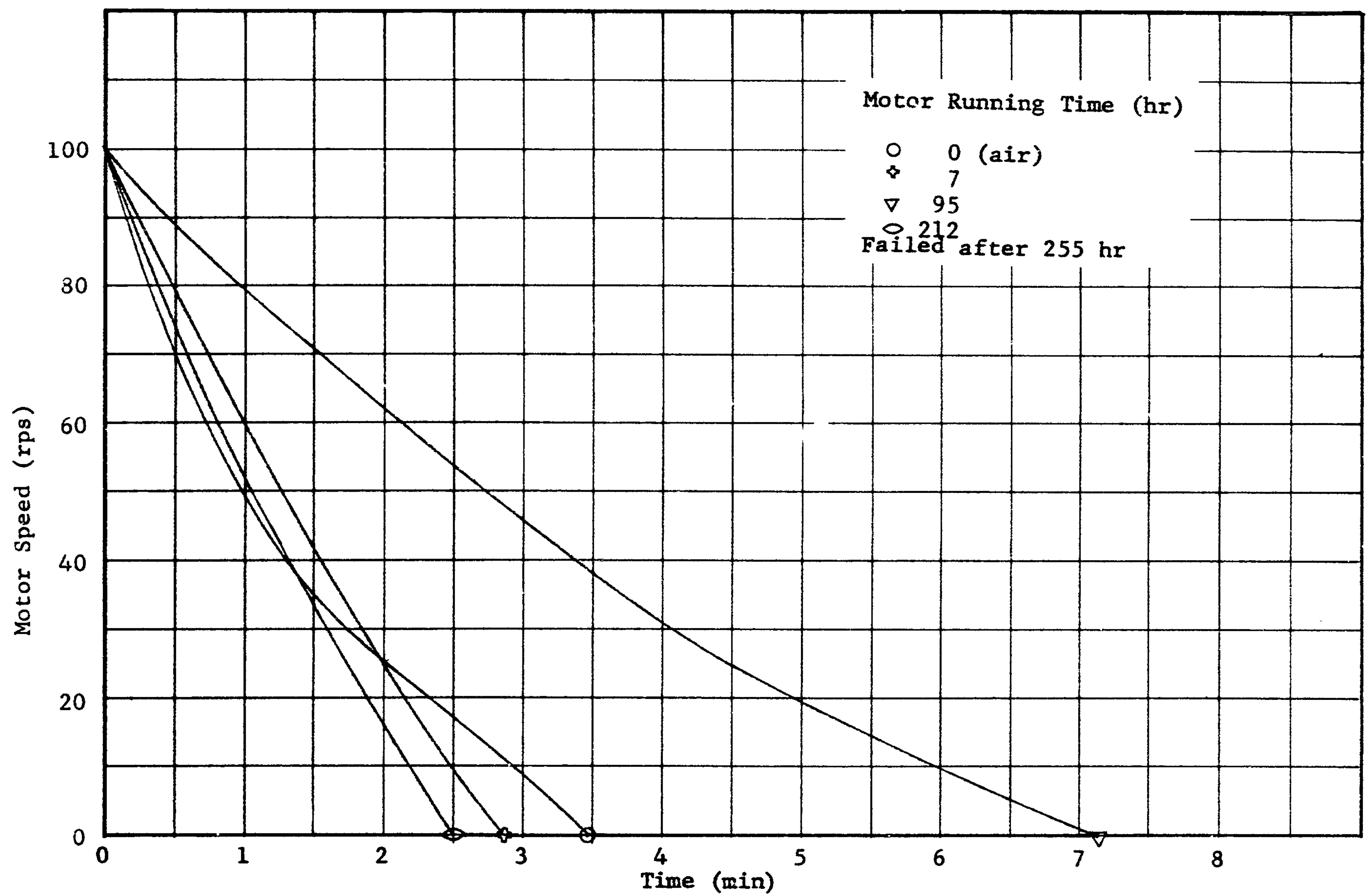

Figure 11.49 Speed During Coastdown of Motor 1 for Polymer SP-F: Vacuum Control (Low Power to Phase 1)

APPENDIX A

DESCRIPTION OF MATERIALS IRRADIATED AND TESTED

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Table A-1

Materials Used in Structural Adhesive Tests

Section	Trade Name and Source	Material Description and Preparation of Stock Items
5.1	Aerobond 422J Adhesives Engr. Co. San Carlos, California	Chemical Class: epoxy-phenolic Skins of 2024T86 clad aluminum, 0.064 by 4 by 9 in., were cleaned with methyl ethyl ketone, vapor-degreased in trichloroethylene, heated in dichromate-sulfuric acid etch bath for 10 min. at 150°F, then rinsed in distilled water. A strip of dry-film adhesive was applied to one of the faying surfaces and the two skins placed together with a 1/2-in. overlap. The samples were cured by heating from room temperature to 350°F in 30 min and maintained at 350°F for 1 hr under a bond pressure of 100 psi. The bonded adhesive is olive-green after cure. Prepared at GD Ft Worth Div
5.2	Aerobond 430 Adhesive Engr. Co. San Carlos, California	Chemical Class: epoxy-phenolic Cure data: 45 min, 340°F, 25 psi Samples prepared by NASA.

Table A-1 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
5.3	APCO 1252 Applied Plastics Co. Inc. El Segundo, California	Chemical Class: polyurethane Cure data: 14 days, room temperature, 10 psi Samples prepared by NASA.
5.4	Epon 934 Shell Chemical Co. Pittsburg, California	Chemical Class: epoxy (Two Parts: A and B) A - filled epoxy, B - amine curing agent Panels: 2024-T3 clad sheets of aluminum, 0.064 in. width and length to fit Shell Chemical Company bonding jig. Panels furnished by GD Ft Worth Div. Bonding by Shell Chemical, cutting and milling of specimens by GD Ft Worth Div. Surface Preparation: After vapor degreasing in trichloroethylene, the panels were dipped in a chromic acid solution at 150°F for 10 min, followed by rinsing the metal thoroughly with distilled water and oven dried at 150°F. Bonding of the Epon 934 panels was done as follows: (1) A thin film of mixed adhesive in the ratio of 100 parts by weight Part A to 33 parts by weight Part B was applied to both faying surfaces in the lap joint area (half-inch). The lapping panels were placed in a fixture. They were clamped at a pressure of approximately 35 pounds per square inch. The panels were then placed in a preheated oven and cured for one hour at 180°F bond line temperature.

Table A-1 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
5.4	Epon 934 (cont'd)	(2) After the panels were cured and cooled to room temperature, adhesive was applied to the doubler area. All faying surfaces were coated to give a total of 5 mils of adhesive in the bond line. The assembled panels were then placed in a preheated press and cured for one hour at 180°F under 10 psi pressure. The panels were removed from the press while hot.
5.5	Epon 951 (Film) Shell Chemical Co. Pittsburg, California	Chemical Class: epoxy-nylon film adhesive Preparation: The Epon Adhesive 951 panels were handled in a similar fashion to Epon 934, except that a 7-mil dry-film adhesive was used and the curing temperature was 350°F for one hour.
5.6	FM-1000 Bloomingdale Dept., American Cyanamid Company Havre de Grace, Maryland	Chemical Class: epoxy-nylon Panels: 2024-T3 clad aluminum sheets, 0.064-in. thick, furnished by GD Ft Worth Div. Surface Preparation: (1) Acetone-wipe all metal to remove grease and lettering.

Table A-1 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
5.6	FM-1000 (cont'd)	(2) Immerse metal for 10-12 min at 170°F-190°F in solution: Sprex AN-9 (4 to 6 oz) Water (To make one gallon) (3) Remove metal from Sprex solution and immediately rinse in hot water, 140°F to 160°F for 2 to 3 minutes. (4) Repeat step 3 using another rinse tank at 140°F to 160°F. Metal is then rinsed in tap water at 140°F and checked for water break, finally dried in oven (120°F max.). (5) The metal was then immersed in the following solution for 15 min at 150°F $\pm$ 10°F: Chromic Acid (142 gm) Sulfuric Acid (652 gm) Water (To make one gallon) (6) Rinse thoroughly in cold water, check for water break, and dry in oven (120°F max.) Bonding Panels: (1) Assembled per GD Ft Worth Div drawings (2) All panels press bonded with the following cycle: 60 minutes heat-up rate to 350°F 60 minutes hold at 350°F with 25 psi. (3) Panels were cooled under pressure to room temperature.

Table A-1 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
5.7	HT-424 (film) Bloomingdale Rubber Co. Aberdeen, Maryland	Chemical Class: epoxy-phenolic (supported film) Aluminum filled on glass cloth. Cure data: 40 min, 340°F, 25 psi Samples prepared by NASA.
5.8	Narmco A Narmco Materials Div. Whittaker Corp. Costa Mesa, California	Chemical Class: modified epoxy Cure data: 3 days, room temperature, 10 psi Samples prepared by NASA.

Table A-2

Materials Used in Structural Laminate Tests

Section	Trade Name and Source	Material Description and Preparation of Stock Items
6.1	Conolon 506 (Narmco 506-181) Narmco Materials Division Whittaker Corporation Costa Mesa, California	Chemical Class: Phenolic resin Fiberglass cloth 181 Cure data: Lamination under the following conditions: (1) the laminate was placed in a vacuum bag in an air-circulating oven at 150°F; (2) the temperature was raised to 200°F in 20 min; and (3) the laminate was held: one-half hr at 29 in. Hg at 200°F one-half hr at 250°F one-half hr at 300°F two hr at 350°F The physical properties of the "B" stage laminating material were: Resin content (36%); Volatile content (6.5%); Flow (17%). Panels were 12- by 12- by 1/8-in. laminates with plies of fiberglass cloth. The fill and warp direction was alternated with each ply. Panels prepared by Narmco Materials Division. Specimens prepared by GD Ft Worth Div from the panels. Brownish red color laminate and finished laminate is hard and rigid. Name of finished product was changed during test period from Conolon to Narmco by the manufacturer.

Table A-2 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
6.2	CTL 91-LD American Reinforced Plastics Co., Los Angeles, California	Chemical Class: Phenolic resin Fiberglass cloth 181 Special Order: This is a phenolic laminate of 38-in.-width fiberglass 181 cloth, treated with Volan A (Batch No. S7-1) that meets the physical requirements of specification MIL-R-9299. It was supplied in 12- by 24- by 1/8-in. sheets. The liquid-resin stock was formulated by Ironside Resins, Inc., Columbus, Ohio; the fiberglass prepreg was prepared by the Coast Mfg. Co.; and the completed stock item was purchased from the American Reinforced Plastics Co., Los Angeles, California. Preparation and Cure: (From Eldon Fiberglass Operation Outline) CTL-91LD-181-Volan-38 in. prepreg per MSS 306, 12 plies, 18 by 36 in. Set up mold in press; prepare mold; cut material as shown above in B/M; load (12) plies (stacked) in press and close; cure 1/2 hr at 300°F and 1/2 hr at 325°F with 20 tons on Dake press (applies 150 psi on part); post cure 1 hr at 200°F 1 hr at 300°F, and 2 hr at 350°F. Color is dark reddish-brown, and finished laminate is hard and rigid.

Table A-2 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
6.3	Dow Corning 2104 (DC-2104) Dow Corning (resin) Midland, Michigan	Chemical Class: Silicone resin Fiberglass cloth 181 Special Order: Fiberglass cloth 181, 38-in.-width, finish 112 Neutral ph., silicone resin content 43.4% (lot C-4554-1), Dow Corning catalyst XY-15. Finished size is 12- by 14- by 1/8-in. for laminate sheets; white in color; laminate is rigid and hard. Preparation and Cure: Load 12 plies stacked in press; press-curing condition: 350°F for 30 min at 10 psi; oven-curing condition: 195°F for 16 hr, then 2 hr at each of the following temperatures, 260°F, 300°F, 350°F, and 390°F. Resin from Dow Corning Corporation Prepreg from Geige Goods Laminator or molder was Eldon Fiberglass Mfg. Co., Compton, California. Stock item purchased from American Reinforced Plastics Co., Los Angeles, California.

Table A-2 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
6.4	Epon 828/A Shell Chemical Co., Houston, Texas	Chemical Class: Epoxy resin Fiberglass cloth 181 The test material was prepared by the Shell Chemical Co., Plastics and Resins Division, Houston, Texas, per the following specifications: 1. Reinforcement: 181 glass fabric, glass fabric finish 2. Finish: Volan A 3. Resin: Epon 828 with wet lay-up 4. Resin Content: 30% by weight 5. Catalyst: Shell A (diethylaminopropylamine) 6. Press Cure: 30 min at 240°F at 25 psi Finished laminate is greenish-yellow, translucent hard, rigid and smooth surfaced.

Table A-2 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
6.5	Mobaloy 81-AH7 Cordo Division Ferro Corporation Mobile, Alabama	Chemical Class: Phenolic resin Fiberglass cloth 181 The test panels were prepared by the manufacturer per the following general specifications: Size: ten 12- by 12-in. 12-ply fiberglass cloth 181 reinforcement laminate about 1/8-in. thick Resin: In uncured mixture, volatiles 5.6%, resin 39.7%; the panel resin content was approximately 23.1% in cured sheet. Cure data: 60 min, 325°F, 67 psi with no post-cure requirement.
6.6	Paraplex P-43 Rohm & Haas Philadelphia, Penn.	Chemical Class: Polyester resin (Paraplex P-43 is a solution of an unsaturated polyester (70%) dissolved in styrene monomer (30%), that contains an inhibitor to provide adequate storage stability. Cure data: 1 hr at 212°F

Table A-2 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
6.6	Paraplex P-43 (cont'd)	Reinforcement: 11-ply fiberglass cloth 181 Prepared by NASA Laminate is greenish-white in color.
6.7	Selectron 5003 Pittsburgh Plate Glass Co. Houston, Texas	Chemical Class: Polyester Fiberglass cloth 181 Resin: Selectron RS-5003 Reinforcement: 10 to 12 plies of 181 glass cloth with Volan A finish - used 11 layers Panel Thickness: 0.100 to 0.125 in. Size of Panel: 12 by 12 in. minimum Cured: 1 hr at 143°C, pressed firmly to 0.110 shim Resin Content: approximately 34% Prepared by NASA

Table A-3

Materials Used in Seal Tests

Section	Trade Name and Source	Materials Description and Preparation of Stock Items
7.1	Buna N (PRP 737-70 FLX) Precision Rubber Products Corp., Dayton, Ohio	Chemical Class: Acrylonitile butadiene copolymer Compound formulation is proprietary. It is an NBR elastomer with 3 parts per hundred FLX antioxidant as an antirad. Color: black Tested compression buttons and size 215 0-rings of nominal dimensions of 1-1/16- by 1-5/16- by 1/8-in. as prepared by manufacturer.
7.2	Neoprene (PRP-2277) Precision Rubber Products Corp., Dayton, Ohio	Chemical Class: Chloroprene rubber Compound formulation is proprietary. Color: black Tested compression buttons and size 215 0-rings as prepared by manufacturer.
7.3	Polymer SP-1 E. I. duPont de Nemours Wilmington, Delaware	Chemical Class: Polyimide resin The SP-1 resin, with no filler, was molded in blocks under high pressure, then sawed into slabs approximately 1/4- by 1-1/2- by 10-in.

Table A-3 (cont'd)

Section	Trade Name and Source	Materials Description and Preparation of Stock Items
7.3	Polymer SP-1 (cont'd)	Color: dark chocolate brown Tested dumbbell-type tensile specimens machined from slabs.
7.4	Viton A (V495-7) The Parker Appliance Co. Rubber Products Division Cleveland, Ohio	Chemical Class: A linear copolymer of vinylidene fluoride and hexa-fluoro propylene Compound formulation is proprietary. Color: black Tested Parker 2-224 O-rings as prepared by manufacturer.
7.5	Viton B (PRP-19007)	Chemical Class: A linear copolymer of vinylidene fluoride and hexa-fluoro propylene. Compound formulation is proprietary. Color: black Tested compression buttons and size 215 O-rings as prepared by manufacturer.

Table A-4

Materials Used in Sealant Tests

Section	Trade Name and Source	Material Description and Preparation of Stock Items
8.1	Dow Corning 92-018 Aerospace Applications Laboratories, Engineering Products Division, Dow Corning Corporation, Midland, Michigan	Chemical Class: One part silicone rubber adhesive/ sealant that air cures in 24 hr. Specimen Preparation: All specimens prepared by Dow Corning. The dumbbell specimens for the tensile tests were cut with a Die C according to ASTM D-412. Lap-shear specimens having a one-half-inch overlap were prepared according to ASTM D-1002-53T. The aluminum surfaces were thoroughly cleaned with chlorothene and MIBK, primed with Silastic RTV 1200 Primer, and adhesive applied according to manufacturer's recommendations. QQ-A-362 aluminum alloy plate, Alcad 2024, was used in the lap shear specimens. Dow Corning prepared the lap-shear specimens, using .040- by 3-in. aluminum strips rather than the .064- by 4-in. strips designated in ASTM D-1002-53T. Color: black
8.2	Dow Corning 94-002 Aerospace Applications Laboratories, Engineering Products Division, Dow Corning Corporation, Midland, Michigan	Chemical Class: One part, room-temperature-curing fluorosilicone sealant. Specimen Preparation: (Same as Dow Corning 92-018) Color: red

Table A-5

Materials Used in Electrical Insulation Tests

Section	Trade Name and Source	Material Description and Preparation of Stock Items
9.1	Duroid 5600 Rogers Corporation Rogers, Connecticut	Chemical Class: Tetrafluoroethylene reinforced with fiberglass fibers This pressure board is hard and rigid being similar to Masonite in appearance. Color: brown Sheets supplied by NASA.
9.2	Estane 5740X1 B. F. Goodrich Chemical Co. Akron, Ohio	Chemical Class: Polyurethane of the ester type that is a tough, pliable rubber Cure data: 15 min at 143°C and 5 min in (preheated) mole at 290°C Color: yellow Stock sheets supplied by NASA.
9.3	Epon 828/Z	Chemical Class: Epoxy (epichlorohydrin/bisphenol, A-type) without any filler with type Z catalyst. The curing agent Z is a modified polyamine.

Table A-5 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
9.3	Epon 828/Z (cont'd)	Color: reddish-brown Prepared at GD Ft Worth Div
9.4	H-Film (Kapton) E. I. duPont de Nemours Wilmington, Delaware	Chemical Class: Polyimide resin Color: clear yellow Supplied by manufacturer as film. These tests are on the 1/2-in. stock from a roll. Note that the name is being changed by duPont to Kapton for the polyimide films.
9.5	Kel F-81 Chemical Division 3M Company St. Paul, Minnesota	Chemical Class: Fluorocarbon plastic (chlorotri-fluoroethylene) Supplier: Tube Turn Plastics, Inc. Garland, Texas Standard stock items furnished by manufacturer.

Table A-5 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
9.6	Kynar 400 Pennsalt Chemicals Corp. Los Angeles, California	Chemical Class: A crystalline, high-molecular-weight polymer of vinylidene fluoride Color: light yellowish cream Stock sheets furnished by manufacturer.
9.7	Lamicoid 6038E Mico Division 3M Company Schenectady, N.Y.	Chemical Class: Melamine resin Fiberglass cloth General preparation and cure data not available, but used standard stock item. Color: greyish-tan Purchased from Graco Supply, Fort Worth, Texas Finished laminate supplied by manufacturer.
9.8	Lexan Materials Department Chemical and Metallurgical Division, General Electric Company, Pittsfield, Mass.	Chemical Class: Polycarbonate plastic Color: clear, transparent sheets Two sheets (24- by 48-in.) in 100-mil thickness furnished by manufacturer. Standard stock item.

Table A-5 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
9.9	Marlex 6001 Chemical Department Plastics Division Phillips Petroleum Co. Bartlesville, Oklahoma	Chemical Class: High-density polyethylene Application: Thermoforming applications Special Characteristics: This resin combines excellent rigidity and toughness with a high melt strength for very little sheet sag during forming. The sheet was fabricated by conventional extrusion using a temperature-controlled three-roll polished stack. Color: milky white ASTM classification: Type III, Class A, Grade 3 Supplied by manufacturer from stock at plant.
9.10	Marlex 6002 Chemical Department Plastics Division Phillips Petroleum Co. Bartlesville, Oklahoma	Chemical Class: High-density polyethylene General-purpose resin for blow molding, sheet and film extrusion, and thermoforming. This is an extrusion-grade resin with excellent rigidity and toughness.

Table A-5 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
9.10	Marlex 6002 (cont'd)	Fabricated same as Marlex 6001. Color: milky white ASTM classification: Type III, Class A, Grade 3
9.11	Mylar 100C Film Department E. I. duPont de Nemours Wilmington, Delaware	Chemical Class: Polyester film Type C is a capacitor-grade film used in the capacitor industry. Color: clear film (in thin sections) Samples cut from 1-in.-width roll, type 100C (1-mil) film supplied by manufacturer from stock.
9.12	Plaskon CTFE X2204 Plastics Division Allied Chemical Corp. Edgewater, New Jersey	Chemical Class: Stabilized CTFE (chlorotrifluoroethylene) for molding and extrusions This is a stabilized version of the Plaskon CTFE 2200 of the ASTM D-1430, Grade 2 type. Color: pinkish and translucent-stabilizer is the material that gives the pinkish cast. Experimental quantity supplied by manufacturer.

Table A-1 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
9.13	Silastic RTV 501 Dow Corning Corp. Midland, Michigan	Chemical Class: Silicone elastomer that is a fluid that vulcanized to silicone rubber with catalyst. Cure data: 24 hr, room temperature with Silastic RTV 501 catalyst A (dibutyl tin dilaurate) Cured Sheet Color: white Sheets for testing furnished by manufacturer.
9.14	Silastic 950 Dow Corning Corp. Midland, Michigan	Chemical Class: Silicone rubber for high strength for gaskets, seals, shock mounts, etc. Temperature range: -130 to 480°F Color: grey Vulcanized sheets supplied by manufacturer.

Table A-5 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
9.15	Silastic 1410 Dow Corning Corp. Midland, Michigan	Chemical Class: Silicone rubber that is heat shrinkable. Usually furnished as a tubing. Color: grey Vulcanized rubber sheets prepared by manufacturer to fabrication of tensile specimens. Test material had been preshrunk before specimens were prepared.
9.16	Sylgard 182 (DC 93-002) Dow Corning Corp. Midland, Michigan	Chemical Class: Silicone potting and encapsulating resin for electrical applications. It cures at moderate temperatures, and without exotherm. When mixed with the correct amount of curing agent, the resin will cure in 4 hr at 65°C (149°F); cure can be accelerated by using higher temperatures. The rate of cure is constant regardless of sectional thickness, or the degree of confinement. When set up, Sylgard 182 resin needs no further after-bake. Color: nearly transparent Cured sheets of the Sylgard were prepared by the manufacturer for the dielectric and compression test specimens.

Table A-5 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
9.17	Tedlar Film Department E. I. duPont de Nemours Wilmington, Delaware	Chemical Class: Polyvinyl fluoride film (PVE) Color: transparent Film obtained from manufacturer in 1-in.-width roll, 2 mils thick. Film code identification is 200 S G 40 TR.
9.18	Teflon FEP Film Department E. I. duPont de Nemours Wilmington, Delaware	Chemical Class: Fluorocarbon film (fluorinated copolymer of ethylene and propylene) Color: transparent DuPont furnished the Teflon FEP films as follows: 2-mil (200A), sheets (8-1/2- by 11-in.) 10-mil (1000A), sheets (8-1/2- by 11-in.) 40-mil (4000A), sheet (15- by 36-in.) These films were cut into strips for testing.

Table A-5 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
9.19	Teflon TFE E. I. duPont de Nemours Wilmington, Delaware John L. Doré P.O. Box 7772 Houston, Texas Dixon Corporation Bristol, Rhode Island	Chemical Class: Fluorocarbon (tetrafluoroethylene) Material for 125-mil tensile dumbbell-type specimens: This material is Teflon TFE, Grade A, Type T-7 electrical grade, molded by performing sintering technique and ram extruded. Since Teflon is difficult to bond to without treatment, the John L. Doré Company prepared the ends by special treatment sufficient to receive the aluminum doublers used with the tensile specimens. The material was received from Doré as individual slabs ready for preparation of each test specimen with ends already treated. Material for Film tests: The 2.5-mil, 5-mil, and 40-mil films are Dixon CMV Controlled Teflon skived tape supplied by Dixon Corporation. The 10-mil and 20-mil are Teflon TFE Grade A, type T-7 supplied by Doré. Color: white Test specimens and film strips for testing were prepared at GD Ft Worth Div.

Table A-6

Materials Used in Thermal Insulation Tests

Section	Trade Name and Source	Material Description and Preparation of Stock Items
10.1	CPR-200-2* Chemical Plastics Research International Corporation Torrance, California (A Division of Upjohn Corp.)	Chemical Class: Polyurethane rigid foam of the combination of polyether and polyester resins Carbon dioxide blown Density: 2 lb per cu ft Color: white Rigid blocks were supplied by manufacturer.
10.2	CPR-1021-2 Chemical Plastics Research International Corporation Torrance, California (A Division of Upjohn Corp.)	Chemical Class: Polyurethane rigid foam of polyfunctional polyether base resin Carbon dioxide blown Density: 2 lb per cu ft Color: white Rigid blocks were supplied by manufacturer.

*Referred to as CPR-20 in FZK 188-2 (Ref. 4).

Table A-6 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
10.3	EFS 175 Plastics and Resins Div. Shell Chemical Co. Houston, Texas	Chemical Class: Epoxy spray foam (rigid, 88% closed cell, halocarbon blown) Epon Foam Spray 175 (EFS 175) is a liquid, two-component system composed of: (1) Epon foam spray resin and (2) Epon foam spray curing agent. The foam is applied with spray equipment by means of repeated passes of the spray gun. Foam may be built up to any required thickness in increments of approximately one inch. Within seconds after deposition, the resin and curing agent react. The resultant heat (exotherm) volatilizes a chlorofluorocarbon and expands the layer approximately thirty-fold in thickness. Resin is 100 and curing agent 5 to 6 parts by weight. Density: about 2 lb per cu ft Color: white Rigid blocks were supplied by manufacturer.

Table A-6 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
10.4	Stafoam H-1502 American Latex Products Co. Hawthorne, California (A Division of the Dayton Rubber Co.)	Chemical Class: Urethane rigid foam (halocarbon-blown polyether type) This foam is a modification of the AA 402 tested previously with a finer, closed-cell structure and was recommended to be tested in place of the AA 402. It cures at ambient temperature. Density: about 2 lb per cu ft Color: cream Rigid blocks were supplied by manufacturer.

Table A-7

Materials Used in Lubricant Tests*

Section	Trade Name and Source	Material Description and Preparation of Stock Items
11.1	Almasol SFD-238 Almasol Corporation Fort Worth, Texas	Chemical Class: Dry-film lubricant. MoS_2 and PbO plus organic binder (binder composition is proprietary) Material applied to bearings by Almasol Corporation.
11.2	DC-705 Dow Corning Corporation Midland, Michigan	Chemical Class: Phenyl silicone Viscosity: 175 cs at 70°F Vapor Pressure: 3×10^{-10} torr at 70°F Material supplied by Dow Corning Corporation and applied to bearings by Miniature Precision Bearing Co. (MPB).
11.3	Duroid Rogers Corp. Rogers, Conn.	Chemical Class: Teflon impregnated with MoS_2 Teflon was impregnated with MoS_2 and reinforced with fiberglass. Coefficient of friction: 0.03 at room temperature and pressure. Retainer was machined and furnished by Miniature Precision Bearing Company.

*All bearings are SR-3 type furnished by Miniature Precision Bearing Company, Keene, New Hampshire

Table (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
11.4	Electrofilm 66-C Electrofilm Incorporated North Hollywood, Calif.	Chemical Class: Assumed to be MoS_2 plus additive, and with an epoxy-resin binder. Material supplied by manufacturer to MPB who applied lubricant to bearings.
11.5	ETR-H Shell Oil Co. New York, N. Y.	Chemical Class: Chlorophenylmethyl polysiloxane with indanthrene thickener. Apparent viscosity: 565 poise (at 65°F, shear rate at 20 sec^{-1}) ASTM penetration at 77°F: Unworked: 314 Worked 60 strokes: 282 Material supplied by manufacturer to MPB who applied lubricant to bearings.
11.6	FS-1265 Dow Corning Corporation Midland, Michigan	Chemical Class: Fluorosilicone Viscosity: 1,000 cs @ 77°F 74 cs @ 212°F Low vapor pressure Material supplied by Dow Corning Corporation and applied to bearings by Miniature Precision Bearing Co.

Table A-7 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
11.7	GE F-50 Versilube General Electric Co. Silicone Products Dept. Waterford, N. Y.	Chemical Class: Chlorophenylmethyl polysiloxane Viscosity: 90 cs @ 32°F 40 cs @ 100°F 13 cs @ 210°F Material supplied by manufacturer.
11.8	Kynar (filled) Pennsalt Chemical Corp. Philadelphia, Pa.	Chemical Class: Vinylidene fluoride For use as lubricant, material filled with MoS_2. Material supplied by manufacturer.
11.9	Minapure Miniature Precision Bearing Company Keene, New Hampshire	Formulation: Company proprietary Material supplied and applied to bearings by manufacturer.
11.10	MLF-5 Midwest Research Inst. Kansas City, Mo.	Chemical Class: MoS_2 plus sodium silicate binder (Dry Film) Constituency: Parts by Wt. MoS_2 10 Graphite 1 Gold powder 5 Sodium silicate 7 Distilled water 60

Table A-? (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
11.10	MLF-5 (cont'd)	<u>Coefficient of friction</u> <u>at 760 mm Hg</u>: 0.29-0.30 @ 80°F 0.14-0.18 @ 250°F 0.18-0.32 @ 400°F <u>at 10^{-6} torr</u>: 0.20-0.25 @ 80°F 0.09-0.11 @ 250°F 0.09-0.10 @ 400°F Material a[illegible]ied to bearings by Midwest Research Inst.
11.11	OS-124 Monsanto Chemical Co. St. Louis, Mo.	Chemical Class: Five-ring polyphenyl ether Nomenclature of compound: mixed isomers (predominately metal of bis (phenoxy-phenoxy) benzene Viscosity: 1000 cs @ 80°F 13.1 cs @ 210°F Material furnished by manufacturer.

Table A-7 (cont'd)

Section	Trade Name and Source	Material Description and Preparation of Stock Items
11.12	Polymer SP-F E. I. DuPont Co. Wilmington, Delware	Chemical Class: Polyimide "F" class filled especially for these tests. Composition: Wt % — MoS_2 10; Copper 20; Polyimide Polymer 70 Material DuPont-supplied and bearing retainers machined by DuPont.

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APPENDIX B

REPRESENTATIVE SPECIMEN TEMPERATURES, VACUUM-CHAMBER PRESSURES, AND REACTOR POWER LEVELS DURING STATIC, LOW-FORCE DYNAMIC, AND BEARING-LUBRICANT TESTS

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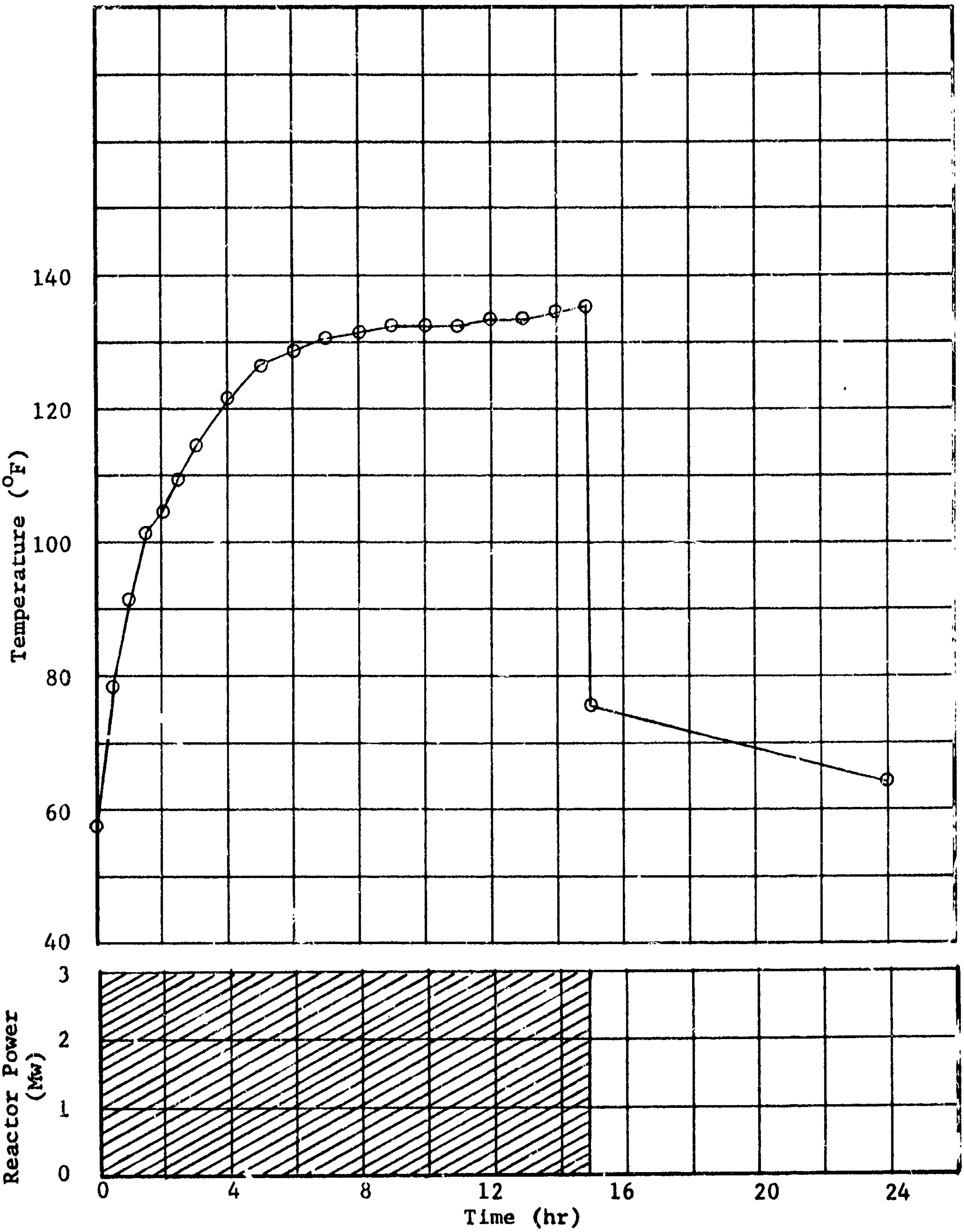

Figure B-1 Temperature History of Mylar 100C Specimen During Low-Force Irradiation Test: Run 5a, East Position

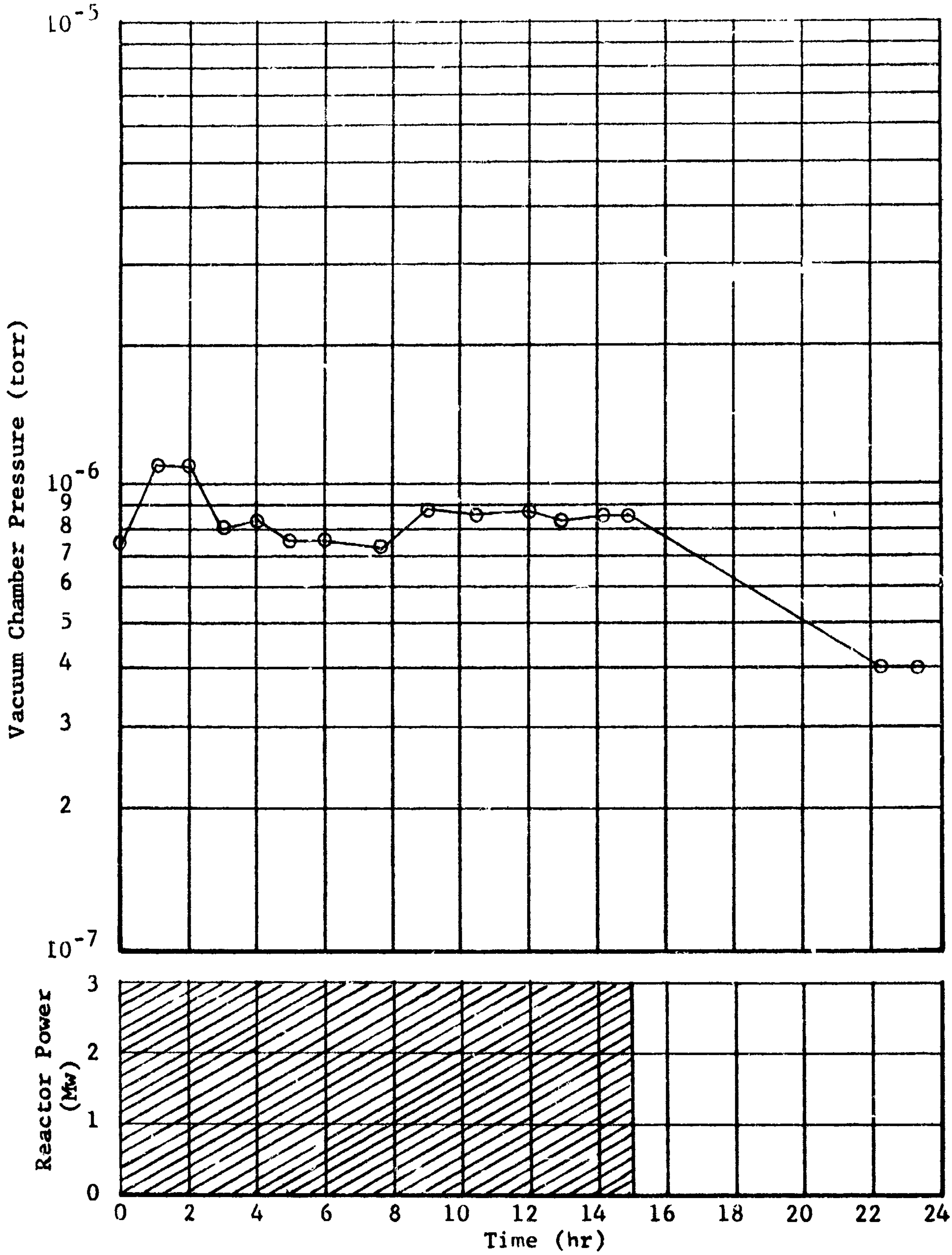

Figure B-2 Vacuum-Chamber Pressure and Reactor Power During Low-Force Irradiation Test: Run 5a, East Position

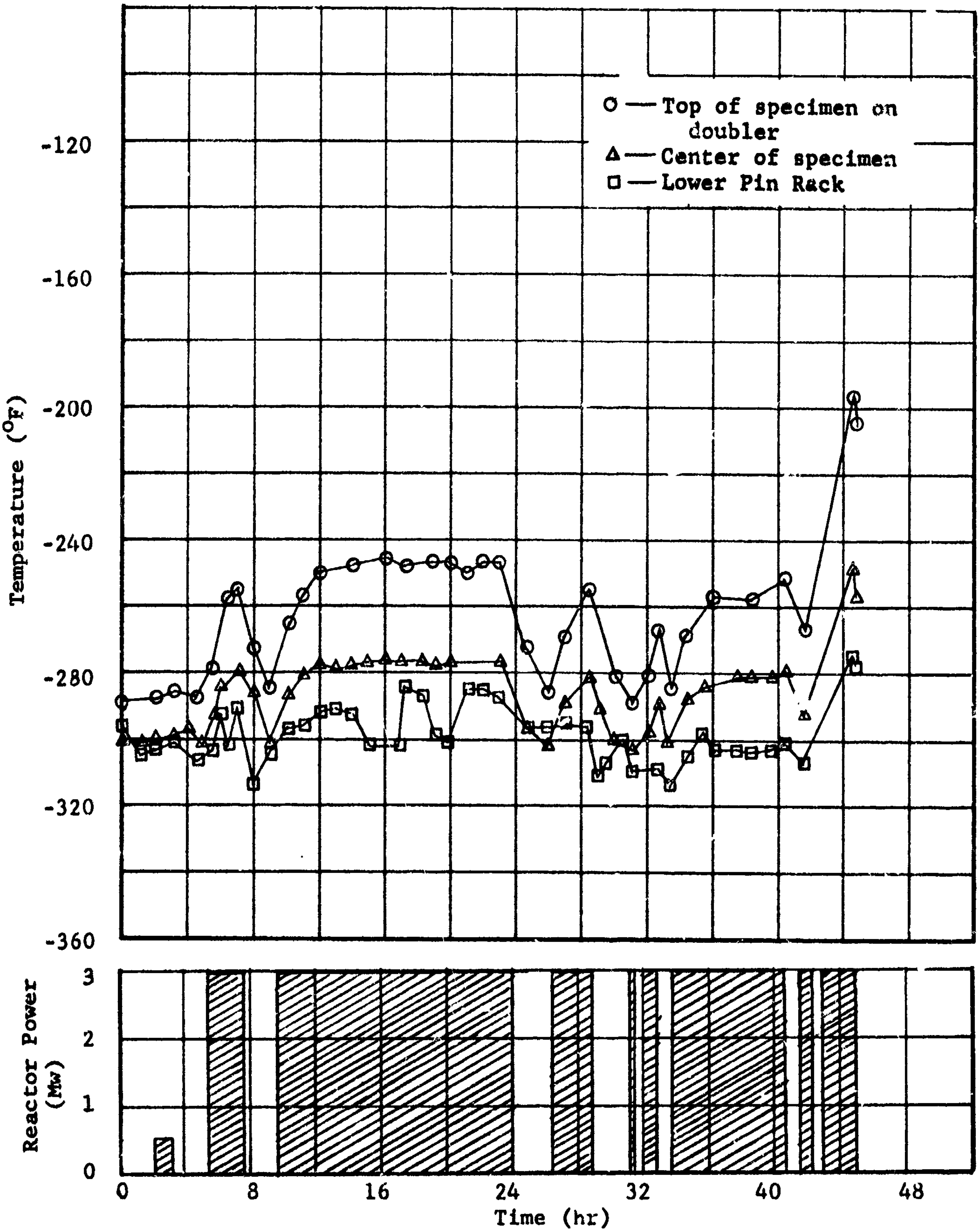

Figure B-3 Temperature History of Duroid 5600 Specimen During Cryomechanical Irradiation Test: Run 4?, West Position

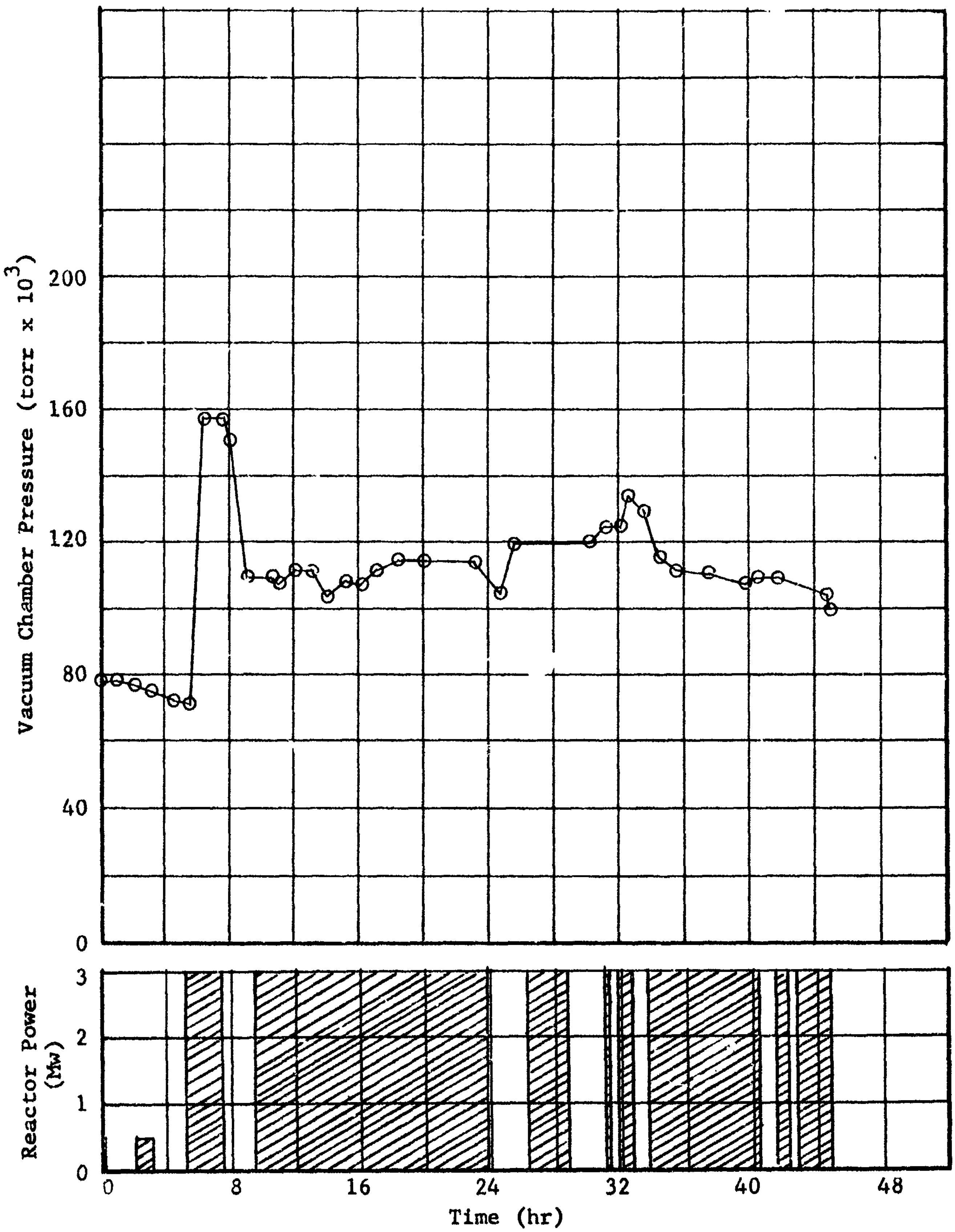

Figure B-4 Vacuum-Chamber Pressure and Reactor Power During Cryomechanical Irradiation Test: Run 4c, West Position

APPENDIX C

GTR RADIATION EFFECTS TEST FACILITY

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APPENDIX C

GTR RADIATION EFFECTS TEST FACILITY

The radiation source used in these tests was the Ground Test Reactor (GTR) - a heterogeneous, highly enriched, thermal reactor utilizing light water as neutron moderator and reflector, as radiation shielding, and as coolant (Ref. 13). Maximum power generation is 3 Mw.

The irradiation pool is shown in Figures C-1 and C-2. The reactor (Fig. C-1) is located in an aluminum water-filled tank, and the components to be irradiated are located in the adjacent test cell open to the atmosphere (Fig. C-2). A reactor closet, consisting of an offset in the north tank wall, extends into the irradiation test cell to provide three locations for equipment and specimen irradiations. The corresponding irradiation positions - east, west, and north - are clearly visible in Figure C-2. In Figure C-1, the reactor is in a retracted position on the horizontal positioning mechanism. This mechanism enables the reactor to be positioned at any distance from 2 to 90 in. from the north face of the closet and will traverse the reactor the full 88-in. distance in 1 min, providing an effective source termination time of 10 sec.

The reactor closet is constructed of 1-in. aluminum plate and is partially covered by 1/4-in.-thick boral to attenuate thermal neutrons. The boral extends 36 in. east and west along the north tank wall from the closet and 36 in. up and down from the horizontal centerline of the reactor. The centerline is 57 in. above the cell floor.

Adjacent to the north wall of the irradiation test cell is the equipment handling area. Equipment permanently installed in this area includes a gas-monitoring system, a Davis explosion meter, and environmental conditioning equipment for the Radiation Effects Testing System.

An integral part of the GTR Radiation Effects Testing Facility is the shuttle system, which is used to move items to be irradiated into position next to the reactor closet. This system consists of cable-driven dollies mounted on three sets of parallel tracks. The tracks extend from the irradiation positions adjacent to the reactor closet, up an incline to the north wall of the irradiation cell, and to a loading area on the ramp just north of the handling area. The system can be operated from either the control room or the dolly motor-drive shed on the north ramp. Full-coverage televiewing of the entire shuttle system is provided by means of a closed-circuit television system in the control room.

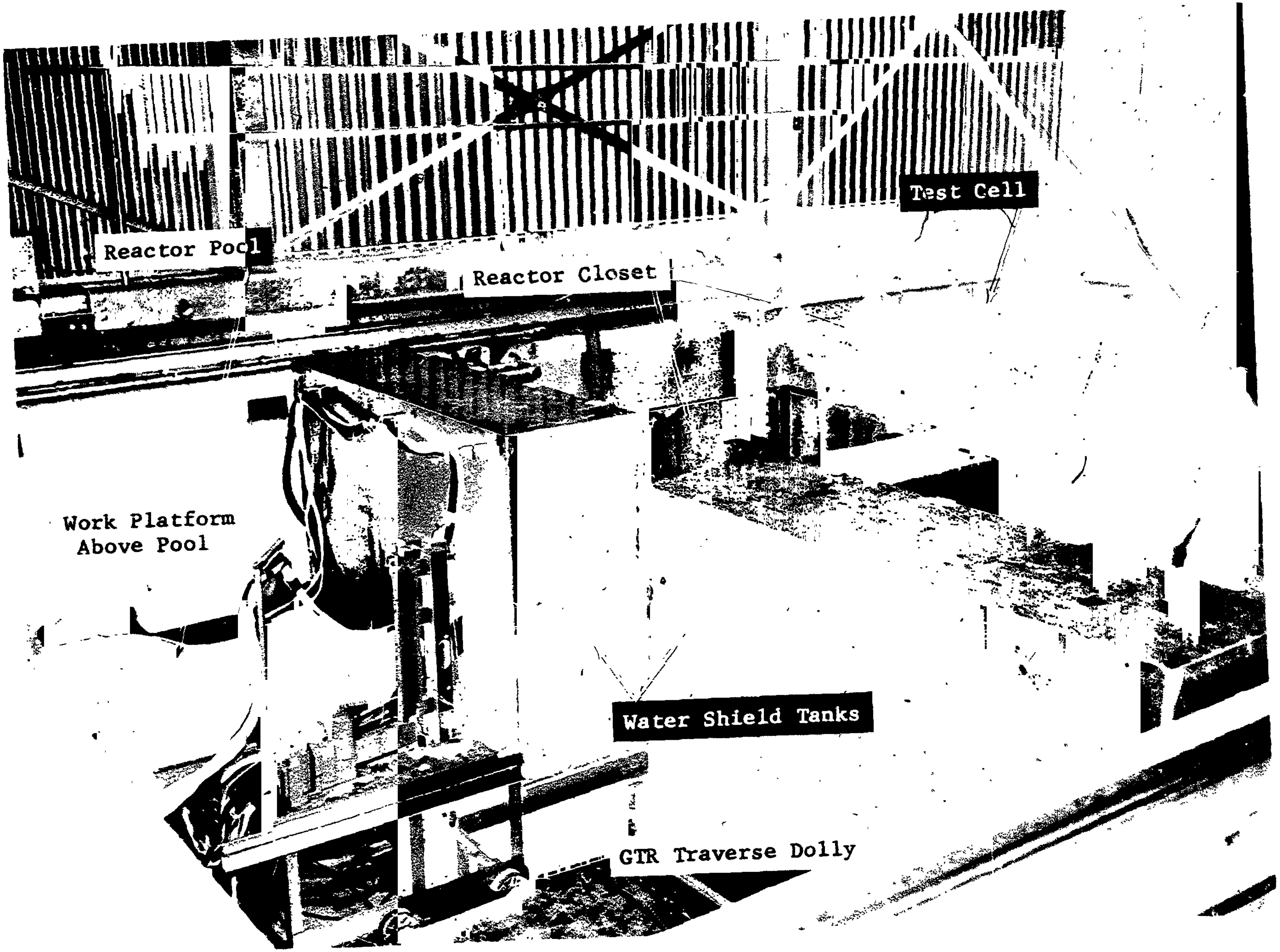

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Figure C-1 Upper View of GTR Tank

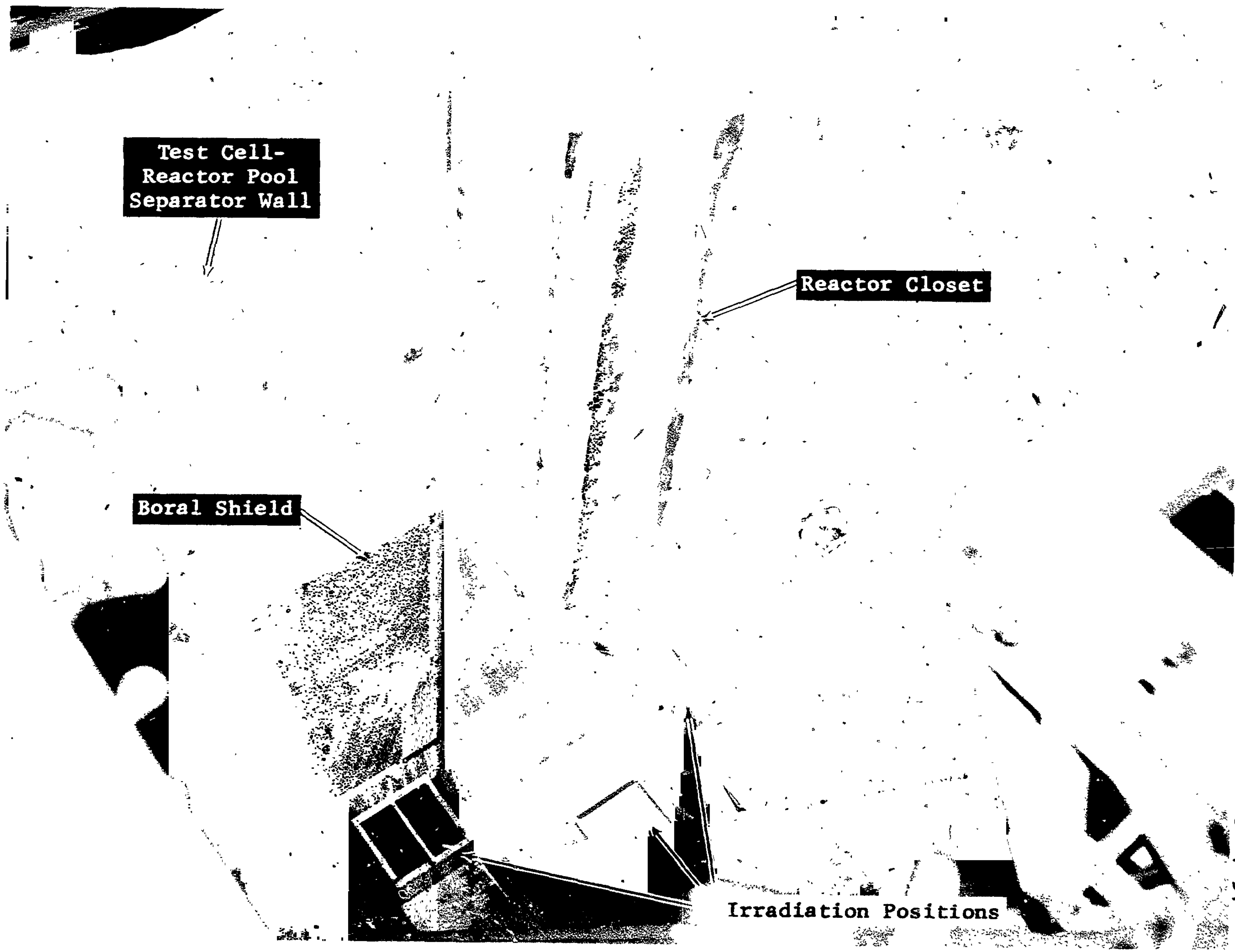

Figure C-2 GTR Irradiation Test Cell

APPENDIX D

DOSIMETRY TECHNIQUES

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APPENDIX D

DOSIMETRY TECHNIQUES

Extensive nuclear measurements, made prior to and during this series of irradiations, were used to characterize radiation fields within test systems located at the three GTR irradiation positions. Information thus obtained was used to stipulate equipment geometries required to obtain the various gamma dose levels that were called for in the test specifications.

Nuclear-measurement packets were positioned in strategic locations in each test assembly to monitor the neutron fluxes and gamma doses. Each measurement packet contained a bare and cadmium-shielded pellet (or foil) and a sulfur pellet for determining, respectively, the thermal-neutron flux ($E < 0.48$ ev) and the fast-neutron flux ($E > 2.9$ Mev). Each packet also contained a nitrous oxide (N_2O) or a pair of tetrachloroethylene (TCE) gamma dosimeters, or, in some cases, all three. Gamma and neutron detectors were processed in a routine manner in the NARF Nuclear Measurement Facility. Neutron-flux data were reduced by standard foil techniques, which have been programmed for use on the IBM 7090 computer.

Nitrous oxide (N_2O) and tetrachloroethylene (TCE) dosimeters were used to obtain gamma-dose measurements during the test exposures. The N_2O dosimeter measures gamma dose in mixed or pure gamma-radiation fields in the range 10^7 to 5×10^{11} ergs/gm(C). Its operation is based on the radiation-induced decomposition of nitrous oxide gas, for which the overall reaction is:

$$6N_2O \rightarrow 5N_2 + O_2 + 2NO_2$$

The TCE dosimeters are chemical dosimeters which consist of 0.8 ml of tetrachloroethylene over-layered with 0.2 ml of water. The tetrachloroethylene contains 3 gm/liter of Ionol stabilizer; the water contains 16 gm/liter of chlorophenol red pH indicator dye. The chemical reaction which takes place within the dosimeter subjected to radiation results in the formation of hydrochloric acid, the amount of which is directly related to the total gamma dose absorbed. Readout of the dosimeter is accomplished by means of microchemical titration with dilute sodium hydroxide. The nominal range of the TCE dosimeter is 8.9×10^4 to 8.9×10^9 ergs/gm(C).

As a result of recent research into the response characteristics of the N_2O dosimeter, a sizable increase in the decomposition of the nitrous oxide gas at LN_2 temperature (-196°C) has been observed in the range of dose between 4×10^8 and 1×10^{11} ergs/gm(C). This results in a commensurate increase of about 70% in the dose measured at LN_2 temperature over that measured at room temperature (+30°C). Where applicable, the gamma-dose measurements shown in the tables in the test results sections reflect a temperature correction.

Although there is little experimental verification, there is reasonable indication that the decomposition of N_2O is greater at LH_2 temperature (-252°C) than at LN_2 temperature (Ref. 12). In order to present the most logical picture, therefore, measurements of the gamma dose in LH_2 also reflect a temperature correction. The correction factor assumes a linear relationship between the moles of $N_2 + O_2$ produced in the dosimeter at LN_2 temperature (-196°C) and that produced at LH_2 temperature (-252°C). Since the relationship is linear between +30°C and -196°C, the assumption of linearity between -196°C and -252°C is considered to be correct. Additional research into the response characteristics of the nitrous oxide dosimeter when exposed to gamma radiation at LH_2 temperature is currently in progress.

The radiation exposures presented in the test results sections of this report were based on mapping data and actual measurements made during the irradiations. In order that the most reliable gamma doses might be presented, an analytical approach for data evaluation was used, based upon nuclear measurements made prior to and during this series of experiments. The method is simple and utilizes the following radiation measurements of known reliability: (1) The fast-neutron fluence (E > 2.9 Mev) nvt_1 measured during this series of experiments at the location of interest; (2) nvt_2 and $gamma_2$ measured previously at the same location.

Then, with the relationship,

$$\frac{nvt_2}{gamma_2} = \frac{nvt_1}{gamma_1} ,$$

the gamma dose at the location of interest ($gamma_1$) can be calculated:

$$gamma_1 = \frac{gamma_2(nvt_1)}{nvt_2} .$$

APPENDIX E

STATISTICAL ANALYSIS OF DATA OBTAINED FROM TESTS ON LAP-SHEAR SPECIMENS OF TWO ADHESIVE MATERIALS

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APPENDIX E

STATISTICAL ANALYSIS OF DATA OBTAINED
FROM TESTS ON LAP-SHEAR SPECIMENS
OF TWO ADHESIVE MATERIALS

The allocation of the experimental material for FM-1000 and Epon 934 adhesives tested during this period was predicated on the number of lap-shear specimens that could be cut from a single panel and the number of specimens that could be tested in the dewars for the various conditions specified. The design matrix and the number of specimen units tested under each condition were as follows:

Test Environment	Material	Radiation Levels		
		R_o (control)	R_{low}	R_{high}
Air	FM-1000	5	5	5
	Epon 934	5	5	5
LN_2	FM-1000	4	4	4
	Epon 934	4	4	4
LH_2	FM-1000	4	4	4
	Epon 934	4	4	4

Data from past experiments with bonded lap-shear panels show that the specimens cut from the same panel are less variable than specimens cut from different panels. In some cases, the difference between supposedly similar panels was quite large. Therefore, because of the possibility of large panel differences and the fact that all specimens could not be cut from a single panel, an allocation of the specimen units was made to obtain estimates of radiation and temperature effects within panels.

The FM-1000 panels were sized so that only three specimens per panel were available. For purposes of discussion they are designated as:

Panel A	-	specimens	a	a	a
Panel B	-	specimens	b	b	b
∘					
∘					
Panel M	-	specimens	m	m	m

Allocation of these units to the design matrix was as follows:

Test Environment	Radiation Level		
	R_o	R_{low}	R_{high}
Air	(abc) de	(abc) fg	(abc) jk
LN_2	(hi) de	(hi) fg	(hi) jk
LH_2	(lm) de	(lm) fg	(lm) jk

An analysis of radiation effects is based on specimens cut from panels A, B, and C (air tests); H and I (LN_2 tests); and L and M

(LH_2 tests). The specimen designations are the lower-case letters shown in parentheses in the above table. Analysis for temperature effects is based on specimens cut from panels D and E (unirradiated - control), F and G (low dose), and J and K (high dose). Corresponding specimen designations are those in the lower-case letters in the above table that are not in parentheses.

Analysis of variance was used to determine the significance or non-significance of the radiation and/or temperature effects. A combined analysis was not performed because the radiation levels designated as R_{low} and R_{high} were not the same under all temperature conditions.

Epon 934 material was allocated in a similar way as the FM-1000 material. Analysis of variance was also applied to these data.

FM-1000

There were significant radiation effects. Estimated standard deviations and confidence levels for FM-1000 are shown in the following table:

Test Environment	Confidence Level	Standard Deviation	
		Percentage	Arithmetic
Air	$0.90 < CL < 0.95$	5.5	340
LN_2	$CL > 0.99$	10.5	405
LH_2	$0.90 < CL < 0.95$	18.0	401

There were significant temperature effects, for all cases, with a confidence level greater than 0.99.

Epon 934

There were no significant radiation effects (confidence level less than 0.90). Estimated standard deviations for Epon 934 are shown in the following table:

Test Environment	Standard Deviation	
	Percentage	Arithmetic
Air	6.8	190
LN_2	6.4	128
LH_2	4.6	85

There were significant temperature effects, for all cases, with a confidence level greater than 0.99.

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