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TECHNICAL EVALUATION REPORT OF THE SPECIALISTS' MEETING ON CHAR--ETC(U)
JUL 79 J M DRAPIER, M H HIRSCHBERG

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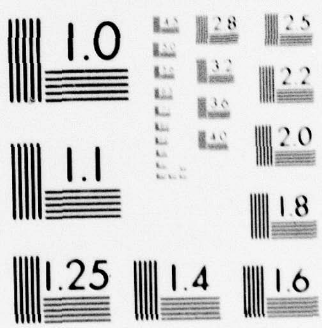

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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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LEVEL II

AGARD ADVISORY REPORT No. 130

Technical Evaluation Report of the Specialists' Meeting on Characterization of Low Cycle High Temperature Fatigue By The Strainrange Partitioning Method

by

J.M.Drapier and M.H.Hirschberg

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Advisory Report No.130

TECHNICAL EVALUATION REPORT

of the

SPECIALISTS' MEETING

on

CHARACTERIZATION OF LOW CYCLE HIGH TEMPERATURE FATIGUE BY THE STRAINRANGE PARTITIONING METHOD

by

J.M.Drapier and M.H.Hirschberg

This Advisory Report was sponsored by the Structures and Materials Panel of AGARD

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PREFACE

The AGARD Structures and Materials Panel has had a long and active interest in researching subjects that are of a critical nature and of common interest to the NATO community. In keeping with this tradition, the Panel, in the Spring of 1971 deemed it highly advisable to initiate specific activities in the area of low cycle high temperature fatigue (LCHTF).

At the Fall 1972 S&M Panel Meeting, Mr. Drapier, who was charged by AGARD with the coordination of the various activities on this subject, submitted a document entitled "Ad Hoc Group on Low Cycle High Temperature Fatigue - Status Report" (AGARD R-604), which reviewed the LCHTF work being carried out by the NATO nation laboratories interested in this problem. In the fall of 1973, Mr. Drapier presented to the S&M Panel his in-depth report entitled "Survey of Activities in the Field of Low Cycle High Temperature Fatigue". This document was published as AGARD R-618 in February 1974.

Through the continuing efforts of Mr. Drapier, supported by this Panel, AGARD has published a volume containing the papers presented at the Specialists' Meeting on Low Cycle High Temperature Fatigue (AGARD-CP-155) held in April 1974. At this meeting, experts were invited to provide replies to a number of questions raised by the organizers; each subject was introduced by a paper, the purpose of which was to survey the problem areas associated with that subject and to orient and focus the subsequent discussion.

One of the conclusions of the above noted Specialists' Meeting was the recognition of the need for reliable life prediction methods that are applicable to LCHTF gas turbine components. It was in the spring of 1975 that Mr. Hirschberg presented a pilot paper suggesting a cooperative testing program aimed at evaluating the ability of the Strainrange Partitioning Method to predict life in the creep-fatigue range. Messrs Hirschberg and Drapier were designated coordinators for this program. The laboratories surveyed in AGARD R-618 were then invited to participate. Ninteen laboratories in five countries chose to participate, each testing its own materials of interest under its own laboratory conditions so that the results obtained would provide validation for a wide range of materials and insure maximum usefulness to each of the participating laboratories. The culmination of this evaluation program was the Specialists' meeting which brought together these investigators for the purpose of sharing their laboratory testing experiences, permitting an in-depth evaluation of the Strainrange Partitioning method, and providing maximum exposure to the findings and recommendations of this distinguished body of specialists.

This Technical Evaluation Report of the Specialists' Meeting analyzes the present state of understanding of the method of Strainrange Partitioning for analysis and prediction of low-cycle high-temperature fatigue life. Recommendations for future activities which would be appropriate and valuable in this expanding area of life prediction are also included. Together with the Conference Proceedings, AGARD CP-243 published in August 1978, it represents a major contribution to this technology which is of vital concern to the NATO nations.

George C. Deutsch
Chairman, Sub-Committee on
High Temperature Materials

CONTENTS

COOPERATIVE TESTING PROGRAMME ON STRAINRANGE PARTITIONING

EVALUATION REPORT

by

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1. BACKGROUND

The AGARD Structures and Materials Panel has had a long and active interest in researching subjects that are of a critical nature and of common interest to the NATO community. In keeping with this tradition, the Panel, in the Spring of 1971 deemed it advisable to initiate specific activities in the area of low cycle high temperature fatigue (LCHTF).

This resulted in an AGARD publication (1) reviewing the LCHTF work being carried out by the laboratories in the various nations interested in this problem.

Through the continuing efforts supported by this Panel, AGARD published the proceedings of a Specialist's Meeting on LCHTF (2). One of the conclusions of this conference was the recognition of the need for more reliable life prediction methods that are applicable to LCHTF of gas turbine components. As a result, and following a suggestion made by Mr. H.HIRSCHBERG in the spring of 1975, The Structures and Materials Panel decided to support the cooperative evaluation programme we are reviewing in this report.

2. PROGRAMME OBJECTIVES

The basic objective of the cooperative programme was to evaluate the ability of the Strainrange Partitioning (SRP) method to first correlate the creep-fatigue behavior of gas turbine materials, and then to predict the creep-fatigue lives of laboratory specimens subjected to complex cycling conditions.

The programme, by its very nature, would provide a reference body of high temperature creep-fatigue data that would enable future use by researchers in the evaluation of SRP or other LCHTF predictive techniques.

It was also suggested at the beginning of this programme that each of the participants generate and record any additional creep-fatigue data that would permit them to make a direct comparison between SRP and any other life prediction method that they are currently using or are interested in themselves developing.

3. SURVEY OF THE PROGRAMME ORGANIZATION

3.1. Following invitations made to the laboratories previously surveyed (1), 16 laboratories in 5 countries (7 U.S. ; 5 U.K., 2 French, 1 German and 1 Italian) agreed to participate in the programme.

3.2. One important aspect of this agreement was that each participant test its own materials of interest under its own laboratory conditions so that the results generated would provide validation for a wide range of materials and would insure maximum usefulness to each of the participating laboratories.

3.3. The materials tested included a number of cast, wrought and P/M nickel-base superalloys, titanium and copper-base alloys as well as steels. Most of them are used or are intended for use in gas turbine components, such as blades and discs, for aircraft or land-based applications.

3.4. The programme starting in the fall of 1975 was organized and conducted by these authors, coordinating the activities among the U.S. and the European participants respectively.

3.5. The culmination of this programme was the Specialist's Meeting discussed herein which brought together the various investigators with the objective of sharing their findings to pursue an in-depth evaluation of the SRP method.

3.6. One important, and probably decisive, tool used by the coordinators to guarantee the success of this activity was the organization of interim programme review meetings. These meetings provided the opportunity to the investigators for critical in-depth interchanges of ideas, concerns, testing techniques, as well as the evaluation of test results.

Three separate interim meetings were held in the U.S. as well as in Europe, Mr. M.H. HIRSCHBERG, one of the developers of the SRP method, attended all of these meetings.

4. RESULTS OF THE PROGRAMME

In order to evaluate the results of the cooperative programme, it must be kept in mind that its main objective, recalled in Section 2, corresponds to the first, very necessary step in the evaluation of a life prediction approach:the evaluation of the ability of this method to predict the life of specimens subjected to complex loading from specimen data obtained from simple tests. One could hope to obtain reliable life predictions for engine components if is not possible to reliably predict first the lives of well controlled laboratory specimens

4.1. Data tabulation : All of the data collected from the participating laboratories were tabulated in a common format and appear in the Appendix to the Proceedings of the Specialist's Meeting (3). In addition to the creep-fatigue test conditions and data, there are also included chemical compositions, material processing and heat-treatment, and the conventional mechanical properties for each of the alloys tested.

In this form, these tabulations represent an extremely valuable body of data covering a variety of engineering alloys so that future analysis and interpretations can be made with a minimum of effort and a maximum of reliability.

4.2. Evaluation of the SRP method : Such an evaluation could be made by answering to the following questions : * Does the SRP method work in correlating, and possibly extrapolating, LCHTF data generated on laboratory specimens ?
* How does the SRP method compare to other techniques ?
* What are its specific advantages or disadvantages ?
* Are there important gaps at this point in our understanding of this approach ?

Trying to answer these questions, the following comments can be made :

-a. Through the various paper presented, and the discussions held at the Conference, the general consensus of the investigators involved in the programme appears to be positive and in agreement that the SRP method is a significant step forward in LCHTF life prediction.

Accordingly, designers of engine components express their intent to continue to work with the SRP method for the purpose of predicting the initiation phase of creep-fatigue cracking.

-b. While the application of the ductility criterion requires more extensive validation, the use of the present ductility-normalized (DN) SRP relationships appears to be a good realistic way to predict creep-fatigue life relationships in the absence of cyclic data.

-c. A single method such as SRP is not expected to apply over every set of circumstances involving variables such as material, temperature range, environment and other testing conditions which can give rise to different failure mechanisms. In this respect, it is made clear that the SRP method, in its present form, is only intended for use under crack initiation conditions.

As regards the nickel-base superalloys, or more generally materials which may have a very low fracture toughness, it becomes very important to separate crack initiation and propagation phases from each other.

-d. The numerous data generated in this programme clearly show that, for nickel-base superalloys, the DN-SRP basic life relationships, PP, PC, CP and CC, lie very close together, in some cases collapsing into one line, closer than for materials such as stainless steels and low alloy steels which were mainly investigated up to now.

-e. Despite this particular behaviour of the investigated nickel-base superalloys during LCHTF testing, the usefulness of SRP in establishing bounds of life is stated to be still valid.

On the other hand, the use of SRP appears not to require any more prior information (and in some instances much less)than other predictive methods.

From the results presented at the Conference, it was not possible to identify any advantages or improvement in life predictions in using alternative predictive methods such as the simple stress correlation or a continuous damage accumulation approach.

-f. Some problems arise when applying the SRP method to cases involving small inelastic strains and long lives. In particular, partitioning of the corresponding narrow hysteresis loops is reported as being a concern. The major problem is simply one of not being able to accurately identify the exact magnitude of the inelastic strainrange as well as the creep strain present in the hysteresis loop. However, this is a problem with some of the other approaches as well.

-g. The SRP method, in its present form, appears to require some modification in order to handle mean stress effects. Tentatively, it was proposed that, due to the very close SRP lines for the nickel-base superalloys, a mean stress effect could give rise to an apparent inversion of life relationships.

-h. Attempts are also reported to correlate the types of cycling and the modes of cracking.

Generally, PP and PC tests give rise to transgranular cracking only, whereas CP cracking was almost entirely intergranular and CC cracking was mixed. However, further investigations appear to be required in order to substantiate these correlations as well as to clarify the enviromental effects.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. From the answers to the questions posed in the previous Section, it can be concluded that the cooperative evaluation programme has succeeded in achieving its tasks.

5.2. The results of this programme allow us also to identify some topics which could be addressed to the Panel for possible future activities in the field of LCHTF :

-a. There is a general interest in the influence of mean stress on low cycle fatigue behaviour, and some critical experiments would be valuable in this area. A systematic study would certainly be required to separate the effects of strain type and mean stress, and so expand the applicability of the SRP method.

-b. Difficulties associated with the partitioning of narrow hysteresis loops involving small inelastic strains and long lives should be resolved. The proponents of the SRP method are attempting to overcome this difficulty by formulating the method in terms of total strains rather than the inelastic strains. It is however, recognized that the data base required to develop this modified formulation of SRP is presently lacking.

-c. Looking at the predictive nature of the SRP method, attemps to generate extrapolation data for superalloys, as it has already been made for low alloy steels ans stainless steels, would certainly be valuable.

-D. Further investigations would also be required in order to increase the understanding of the correlations existing between the modes of cracking and the types of cycling including the environmental effects.

5.3. Finally, from a more general view-point and returning to the programme survey given in section 3, these authors feel that this activity could serve as a reference to the Panel for the organization and fulfillment of future similar cooperative actions involving a number of partners among the various NATO nations.

6. ACKNOWLEDGEMENTS

Arriving at the completion of their tasks, the authors of this report wish to thank, for themselves and also on behalf of the Panel, all of the participants in the programme for their successful efforts in meeting the timetable established from the beginning of this 3 years activity. The success of the Specialist's Meeting, and therefore of the whole programme, is the direct result of their fruitful cooperation allowing their data and conclusions to be made available in convenient time.

7. REFERENCES

(1) DRAPIER J.M. "Survey of Activities in the Field of Low-Cycle High Temperature Fatigue" :
Critical Report AGARD - R - 618

(2) AGARD Conference Proceedings of the "Specialist's Meeting on Low Cycle High Temperature Fatigue" AGARD - CP - 155

(3) AGARD Conference Proceedings of the Specialist's Meeting on "Characterization of Low Cycle High Temperature Fatigue by the Strainrange Partitioning Method". AGARD - CP - 243.

APPENDIX A1

The contents of this appendix are some additional tabulations of Creep-Fatigue test data that were collected after the publication of AGARD-CP-243. The Chemical Compositions, Processing & Heat Treatment information, and the Mechanical Properties data appropriate to these additional data can be found in Tables I, II, and III of Appendix A1 in AGARD-CP-243.

ERRATA

AGARD Conference Proceedings No 243, page 16-14

In Table 3, the axial components of strain only must be multiplied by two to be correct. The torsional components of strain are correct as reported.

These changes affect the entries in columns 3, 4, 5, 7 and 10 only for specimens numbers A-7, A-8, A-9, A-12, A-13, A-14, A-15, N-1, N-5, N-9, N-2, N-6 and N-10.

The axial and biaxial data (R=0,2) plotted in Figs. 9, 10, 11 and 12 are also affected, as are the constants in equations 16 and 17.

Questions of clarification should be addressed to the author, Professor S.Y. Zamrik.

TABLE IV: CREEP-FATIGUE DATA (CONTINUED)

LABORATORY: NPL
MATERIAL: INCOLOY 738LC

RATE DATA & STRESSES

SPEC NO	TEST TYPE	TEMP-C TEN/COMP	RATE DATA (HALF-LIFE VALUES) FREQ HZ	STRAIN-RATE-%/SEC TEN	STRAIN-RATE-%/SEC COMP	HOLD TIME-SEC TEN	HOLD TIME-SEC COMP	STRESSES (HALF-LIFE VALUES) MPA TEN MAX	COMP MAX	RANGE MAX	RELAXATION TEN	RELAXATION COMP	CYCLIC STRAIN HARDENING %
DCH56	HRSC	750/750	5.7E-01	8.0E-01	8.0E-01	0	0	410.0	572.0	982.0	0.0	0.0	-7.50
DCH76	HRSC	750/750	5.0E-01	1.0E 00	1.0E 00	0	0	691.0	794.0	1485.0	0.0	0.0	-1.00
DCH30	CHSC	850/850	3.3E-03	8.0E-01	8.0E-01	0	300.0	773.0	408.0	1181.0	0.0	132.0	-5.00
DCH35	THSC	650/850	3.2E-03	8.0E-01	8.0E-01	300.0	0	294.0	749.0	1043.0	110.0	0.0	-15.00
DCH53	THSC	850/850	3.6E-03	8.0E-01	8.0E-01	300.0	0	279.0	734.0	1013.0	110.0	0.0	-9.50
DCH90	BCCR	750/750	6.6E-03	8.0E-01	8.0E-01	75.0	75.0	533.0	621.0	1154.0	0.0	0.0	--

STRAINS & FAILURE DATA

SPEC NO	STRAINRANGES (HALF-LIFE VALUES) % TOTAL	EL	IN	PP	PC	CP	CC	FAILURE DATA-CYCLES NO	NI	N5	NF	TF-HRS
DCH56	0.700	0.690	0.011	0.011	0.000	0.000	0.000	6200	--	8000	13100	6.40
DCH76	1.000	0.922	0.078	0.078	0.000	0.000	0.000	180	--	210	282	0.16
DCH30	1.000	0.730	0.270	0.150	0.121	0.000	0.000	--	--	--	36	3.00
DCH35	1.000	0.722	0.278	0.171	0.000	0.108	0.000	420	--	365	625	52.50
DCH53	1.000	0.730	0.270	0.170	0.000	0.100	0.000	440	--	400	610	51.00
DCH90	1.000	0.865	0.135	0.071	0.000	0.000	0.064	350	--	400	500	9.00

TABLE IV: CREEP-FATIGUE DATA (CONTINUED)

LABORATORY: ROLLS-ROYCE, LTD.
MATERIAL: WASPALOY

RATE DATA & STRESSES

SPEC NO	TEST TYPE	TEMP-C TEN/COMP	RATE DATA (HALF-LIFE VALUES) FREQ HZ	STRAIN-RATE-%/SEC TEN	STRAIN-RATE-%/SEC COMP	HOLD TIME-SEC TEN	HOLD TIME-SEC COMP	STRESSES (HALF-LIFE VALUES) MPA TEN MAX	COMP MAX	RANGE MAX	RELAXATION TEN	RELAXATION COMP	CYCLIC STRAIN HARDENING %
BASELINE SRP TESTS													
SP34	HRSC	700/700	1.3E 00	9.0E 00	9.0E 00	0	0	904.6	976.1	1880.7	0.0	0.0	--
SP35	HRSC	700/700	1.3E 00	7.1E 00	7.1E 00	0	0	847.2	878.6	1725.8	0.0	0.0	--
SP33	HRSC	700/700	1.3E 00	3.6E 00	3.6E 00	0	0	698.8	714.5	1413.3	0.0	0.0	--
SP6	HRSC	700/700	6.2E-01	1.8E 00	1.8E 00	0	0	747.6	778.7	1526.3	0.0	0.0	--
SP50	THSC	700/700	--	2.3E 00	2.0E 00	900.0	0	991.4	1162.3	2153.7	419.4	0.0	--
SP24	TCCR	700/700	--	3.7E-01	6.6E-01	720.0	0	608.2	1016.6	1624.8	0.0	0.0	--
SP21	CCCR	700/700	--	1.3E 00	8.0E-01	0	2700.0	1106.4	713.3	1819.7	0.0	0.0	--
SP17	BCCR	700/700	--	8.1E-01	7.3E-01	840.0	240.0	640.6	838.5	1479.1	0.0	0.0	--
SP43	BCCR	700/700	--	5.1E-01	4.3E-01	120.0	870.0	674.4	373.1	1047.5	0.0	0.0	--
COMPLEX TESTS													
SP2	UCCR	700/700	--	5.7E-01	6.6E-01	420.0	900.0	652.7	717.6	1370.2	0.0	0.0	--
SP19	UCCR	700/700	--	8.0E-01	9.3E-01	120.0	1800.0	901.3	699.6	1600.9	0.0	0.0	--
SP44	UCCP	700/700	--	5.5E-01	5.2E-01	90.0	60.0	596.0	631.4	1227.4	0.0	0.0	--

STRAINS & FAILURE DATA

SPEC NO	STRAINRANGES (HALF-LIFE VALUES) % TOTAL	EL	IN	PP	PC	CP	CC	FAILURE DATA-CYCLES NO	NI	N5	NF	TF-HRS
BASELINE SRP TESTS												
SP34	3.610	1.530	2.080	2.080	0.000	0.000	0.000	--	--	--	318	0.07
SP35	2.840	1.260	1.580	1.580	0.000	0.000	0.000	--	--	--	645	0.14
SP33	1.440	1.000	0.440	0.440	0.000	0.000	0.000	--	--	--	3404	0.75
SP6	1.440	1.020	0.420	0.420	0.000	0.000	0.000	--	--	--	2718	1.21
SP50	4.510	1.250	2.760	2.030	0.000	0.730	0.000	--	--	--	57	14.75
SP24	1.460	0.590	0.870	0.250	0.000	0.620	0.000	--	--	--	62	40.37
SP21	2.890	1.210	1.680	0.620	1.060	0.000	0.000	--	--	--	96	82.00
SP17	2.940	1.000	1.940	0.610	0.000	0.000	1.330	--	--	--	76	31.75
SP43	1.280	0.700	0.580	0.160	0.000	0.000	0.420	--	--	--	710	469.70
COMPLEX TESTS												
SP2	1.530	0.930	0.600	0.200	0.000	0.220	0.180	--	--	--	100	150.00
SP19	3.120	1.050	2.070	0.600	0.000	0.210	1.260	--	--	--	54	150.00
SP44	1.380	0.860	0.520	0.190	0.000	0.050	0.280	--	--	--	1840	143.70

TABLE IV: CREEP-FATIGUE DATA (CONTINUED)

LABORATORY: DFVLR
MATERIAL: TIAL6V4

RATE DATA & STRESSES

SPEC NO	TEST TYPE	TEMP-C TEN/COMP	RATE DATA (HALF-LIFE VALUES) FREQ HZ	STRAIN-RATE-%/SEC TEN	STRAIN-RATE-%/SEC COMP	HOLD TIME-SEC TEN	HOLD TIME-SEC COMP	STRESSES (HALF-LIFE VALUES) MPA TEN MAX	COMP MAX	RANGE MAX	RELAXATION TEN	RELAXATION COMP	CYCLIC STRAIN HARDENING %
199/01	HFSC	450/450	3.0E-01	6.5E-01	6.1E-01	0	0	527.9	507.0	1034.9	0.0	0.0	-3.40
199/03	HRSC	450/450	3.0E-01	6.4E-01	5.6E-01	0	0	509.6	520.0	1029.6	0.0	0.0	-2.90
199/05	HRSC	450/450	3.0E-01	5.9E-01	5.8E-01	0	0	492.6	462.8	955.4	0.0	0.0	-2.20
195/13	UCCR	450/450	1.0E-01	7.0E-01	6.8E-01	0.5	7344.0	714.3	412.7	1127.1	0.0	0.0	-0.37
194/14	UCCR	450/450	1.0E-01	6.2E-01	5.9E-01	0.5	13680.0	740.3	275.3	1015.5	0.0	0.0	-1.02
195/05	UCCR	450/450	1.0E-01	6.2E-01	7.1E-01	0.6	960.0	632.8	377.6	1010.4	0.0	0.0	-6.33
195/04	UCCR	450/450	1.0E-01	5.4E-01	5.7E-01	2.0	840.0	625.8	351.0	976.8	0.0	0.0	-7.03
194/19	UCCR	450/450	1.0E-01	5.7E-01	5.8E-01	3.0	210.0	618.2	351.7	969.9	0.0	0.0	-6.10
194/11	UCCR	450/450	1.0E-01	5.0E-01	4.9E-01	1.0	1680.0	623.1	314.1	937.3	0.0	0.0	-9.00
194/21	UCCR	450/450	1.0E-01	4.9E-01	5.0E-01	15.0	46.0	563.0	370.3	933.3	0.0	0.0	-5.60
199/13	UCCR	450/450	1.0E-01	5.2E-01	4.8E-01	324.0	0.5	334.4	731.8	1066.3	0.0	0.0	-3.55
199/12	UCCR	450/450	1.0E-01	4.7E-01	4.5E-01	360.0	0.5	290.0	780.3	1070.3	0.0	0.0	4.00
199/10	BCCR	450/450	1.0E-01	5.7E-01	5.5E-01	21.0	30.0	528.2	486.8	1015.0	0.0	0.0	-5.58
190/13	BCCR	450/450	1.0E-01	5.5E-01	5.9E-01	10.8	24.0	537.2	490.7	1027.9	0.0	0.0	-6.31
199/11	BCCR	450/450	1.0E-01	4.8E-01	4.9E-01	15.0	30.0	516.8	415.1	932.0	0.0	0.0	-4.00
199/19	BCCR	450/450	1.0E-01	4.5E-01	4.6E-01	4.2	8.4	505.2	409.3	914.5	0.0	0.0	-7.60
199/18	BCCR	450/450	1.0E-01	4.5E-01	4.3E-01	6.0	8.0	480.3	442.4	922.8	0.0	0.0	-1.50

STRAINS & FAILURE DATA

SPEC NO	STRAINRANGES (HALF-LIFE VALUES) % TOTAL	EL	IN	PP	PC	CP	CC	FAILURE DATA-CYCLES NO	NI	N5	NF	TF-HRS
199/01	0.992	0.918	0.074	0.074	0.000	0.000	0.000	3470	--	3800	5018	4.65
199/03	0.964	0.884	0.080	0.080	0.000	0.000	0.000	4718	--	5110	7315	6.77
199/05	0.923	0.873	0.051	0.051	0.000	0.000	0.000	6600	--	7320	7717	7.13
195/13	1.465	1.051	0.414	0.175	0.123	0.000	0.116	210	--	255	284	448.95
194/14	1.230	0.989	0.241	0.073	0.091	0.000	0.078	270	--	292	384	1127.90
195/05	1.232	0.972	0.260	0.130	0.034	0.000	0.096	380	--	445	546	363.45
195/04	1.097	0.937	0.160	0.083	0.026	0.000	0.052	520	--	595	710	432.03
194/19	1.061	0.867	0.194	0.111	0.029	0.000	0.054	750	--	870	1044	214.33
194/11	0.953	0.842	0.111	0.036	0.016	0.000	0.059	925	--	971	1087	387.45
194/21	0.959	0.858	0.101	0.029	0.008	0.000	0.065	1800	--	1970	2117	117.66
199/13	1.074	0.890	0.184	0.082	0.000	0.036	0.067	2300	--	2650	3378	240.82
199/12	0.935	0.816	0.119	0.052	0.000	0.033	0.034	4212	--	4277	4549	474.66
199/10	1.128	0.908	0.221	0.118	0.000	0.000	0.103	1000	--	1210	1332	44.17
190/13	1.099	0.766	0.333	0.180	0.000	0.000	0.153	1215	--	1299	1437	228.60
199/11	0.903	0.793	0.110	0.051	0.000	0.008	0.051	2140	--	2424	2603	192.00
199/19	0.799	0.725	0.074	0.038	0.000	0.000	0.036	3900	--	4350	4751	124.68
199/18	0.814	0.755	0.059	0.023	0.000	0.000	0.036	4800	--	5070	5293	105.50

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7. Presented at

8. Author(s)/Editor(s)	9. Date
J.M.Drapier* M.H.Hirschberg†	July 1979

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15. Abstract

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This Advisory Report was sponsored by the Structures and Materials Panel of AGARD.

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