Ni-Cd BATTERY LIFE EXPECTANCY IN GEOSYNCHRONOUS ORBIT

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ABSTRACT

Nickel Cadmium battery life expectancy data is required as one key element of a power system design. However, at present there are no widely accepted analytical models for predicting NiCd life expectancy for a geosynchronous orbit. This paper is an attempt to review the literature, life test data, and in orbit performance data to develop an up to date estimate of life expectancy for NiCd batteries in a geosynchronous orbit.

INTRODUCTION

GTE Satellite Corporation (GSAT) is a subsidiary of General Telephone and Electronics Corporation, one of the nation's leading communication and electronics enterprises. In December 1980, GSAT was granted authority by the Federal Communications Commission to construct and operate an advanced domestic communications satellite system providing customized digital transmission networks to a variety of users. GSAT's new satellite system is scheduled for operation in mid 1984. The space segment consists of two satellites operating in the 12/14 GHz frequency band, with two satellites to be held in reserve. The first satellite, GSTAR 1, is scheduled for launch in the second quarter of 1984.

The GSTAR baseline design uses three 30 Ampere-hour Nickel Hydrogen batteries. However, a parallel alternative is being developed in which three 27 Ampere-hour Nickel Cadmium batteries will be used if flight qualified NiH_2 batteries are not available. A study was initiated to examine the feasibility of this alternative. Initially a literature search was conducted with respect to the life expectancy of NiCd cells in a geosynchronous orbit. Life test data, prepared by the Naval Weapons Support Center (NWSC) at Crane, IN, manufacturing data and in orbit flight experience was reviewed and compiled. A curve was deduced, from the compilation of the various sources, for a prudent design criterium for batteries built in 1983 with respect to life versus depth of discharge (DOD). The data was not scrutinized to remove "bad apples" but was plotted as objectively as possible. The study assumes that deep discharge reconditioning (DDR) circuitry is available on the Spacecraft and that average battery temperatures over the year will be less than 15°C. No attempt was made to study only certain manufacturers or certain specific cell designs. The paper will be organized into a discussion of the literature search, life test data, in orbit performance data, life expectancy, and conclusions.

LITERATURE SEARCH

Figure 1 presents life expectancy for a NiCd battery operating at less than a 15°C average temperature in geosynchronous orbit. The curve is actually presented as allowable depth of discharge versus expected life time in years. The first user, GSFC, adopted this convention so I will continue using this format, whereas my personal application will be given a DOD as to what life time I can expect. This figure originally appeared in Reference 1, but recently appeared in Reference 2. The figure was originally plotted in terms of actual DOD. I have scaled it up to rated DOD assuming actual capacity to be 110% of rated. Since this curve appeared in 1976 I will use it as my 1976 baseline performance for NiCd life expectancy in a geosynchronous orbit. 60% DOD for this case would indicate a 3.4 year life.

Figure 2 presents another estimate of where life expectancy was and also where it was capable of going (Ref. 3). Sparks emphasized the importance of temperature control and DDR in extending life performance. This absicissa and ordinate will be used repeatedly for baseline comparison. As an example we will take 60% DOD and follow it through the paper. Sparks indicates that in 1973 one could expect a 5 year life and a capability of 15 years life at 60% DOD.

LIFE TEST DATA

Figure 3 presents real time life test data from the Crane Life Test program (Ref. 4). This figure only considers test packs with operating temperatures below 15°C. Three distinctions are made for the plotted data: failed cells, discontinued packs and ongoing tests. If we draw a curve between the earliest cell failures, we get a curve which correlates well with the earlier cell performance curves. A second curve drawn through the later cell failures would be indicative of what good cells can do. As you can see there are packs which have gone beyond this point before being discontinued, or are still continuing to date. The packs that were discontinued had cell failure(s) earlier in the test but continued cycling the remaining cells. Table 1 summarizes this data and shows what packs are associated with the points plotted. I think the dotted line would be a compromise curve, if one could be drawn, for this data. 60% DOD would indicate a 7.2 year life.

Figure 4 also shows Crane real time life test data for 20-25°C. The dotted line represents a compromise curve for this scattering of data. This line is not much different than the less than 15°C curve. However, it does go in the logical direction of increased temperature and decreased life expectancy. Table 2 summarizes this data. 60% DOD would indicate a 7 year life.

Figure 5 is a plot of accelerated life test data which was available, and this data is summarized in Table 3. The FLTSATCOM accelerated life test program claims 44 simulated eclipse seasons of life (Ref. 5). This data point could be indicative of great things to come. However, at this time I don't think one can skew a curve out to 22 years at 75% DOD. My estimate of a reasonable representation of the data is shown. 60% DOD would indicate an 8.4 year life for this curve.

IN ORBIT PERFORMANCE

Figure 6 indicates in orbit performance to date for available S/C. Some of the points shown are design requirements as opposed to actual flight performance. The curve shown tends to show the leading performances to date. Since most S/C operate over a range of DOD, the ranges are shown. 60% DOD would indicate a 7 year life for this curve. Table 4 summarizes this data.

Figure 7 is a composite of the curves previously shown. Real time life (RTL), accelerated life test (ACL), and in orbit performance (IOP), tend to be reasonably close. All three indicate the improvement from 1976. Since IOP and RTL do correlate well with ACL, I will use ACL as being representative of 1983 state of the art. This would again represent an 8.4 year life for 60% DOD.

Figure 8 now shows just the 1976 and 1983 curves for life expectancy. For 60% DOD we see an improvement from 5 years to 8.4 years, or 3.4 years. If we assume that improvement over the next 7 years was to continue at half this rate, we may expect a 1.7 year improvement. The curve marked desired indicates cells built today using 1983 NiCd technology could possibly last 10.2 years at 60% DOD.

CONCLUSION

A study was done to examine where NiCd technology was in terms of DOD versus life time for batteries in geosynchronous orbit. The assumption was made that cells would be operated in an average temperature environment below 15°C and subjected routinely to deep discharge reconditioning. Real time life test data, accelerated life test data, and in orbit performance data were examined as to expected life as a function of depth of discharge. The results would indicate that a prudent battery design for 1983 for a 60% DOD would be an 8.4 year life expectancy. A desired lifetime for this DOD could rationally be 10.2 years.

SYMBOLS

ACL	Accelerated life test
C	Continuing
D	Discontinued
DDR	Deep Discharge Reconditioning
DOD	Depth of Discharge
F	Failed Cell
GSAT	GTE Satellite
IOP	In Orbit Performance
NWSC	Naval Weapons Support Center
RTL	real time life test

Table 1

Crane Life Test -- Real Time

PACK #	DOD(%)	TEMP($^{\circ}$C)	COMPLETED ECLIPSE SEASONS	STATUS
222A	60	10	9	F
			14	D
223A	60	0	14	D
232A	50	0	6	C
232B	50	15	3	C
203A	40	0	27	C
205A	60	0	27	C
206A	80	0	4	F
			11	F
			22	D
227D	52	15	4	C
207A	60	0	11	F
			19	F
			20	F
			23	D

Table 2

Crane Life Test -- Real Time

PACK #	DOD(%)	TEMP(^{o}C)	COMPLETED ECLIPSE SEASONS	STATUS
221A	60	20	11	F
			14	D
228A	80	20	11	C
226A	50	20	17	D
226B	50	20	13	D
229C	60	20	6	C
229A	60	20	9	C
229B	60	20	6	C
229D	60	20	5	F
			6	C
202A	40	25	16	F
			22	D
209A	60	20	22	F
			24	C
208A	80	20	17	F
			19	F
			23	D
210A	80	20	11	F
			18	F
			20	F
			23	D
227B	60	20	6	F
			10	D
227C	60	20	11	D
201A	40	25	16	F
			22	C

Table 3

Accelerated Life Test Data
Geosynchronous

DESCRIPTION	DOD(%)	TEMP(^{o}C)	COMPLETED ECLIPSE SEASONS
NWSC 231A	80	10	9
NWSC 227E	52	15	12
NWSC 227F	52	15	12
FACC INTELSAT V (Ref. 6)	55	10	6
FACC INSAT (Ref. 6)	55	10	6
RCA (1)	66		11
RCA (2)	66		14
TRW FLTSATCOM (Ref. 5)	75	9	44

Table 4

In Orbit Performance Data

PROGRAM		DOD(%)	TEMP(^{o}C)	PERFORMANCE (YEAR) ACTUAL	EXPECTED	DESIRED
TDRSS		50	5		10	
GOES		50	15		7	
		60	15			7
IUE		57-60	15	6		
FLTSATCOM	1	65-70	<15	5		
	2	65-70	<15	4		
	3	65-68	<15	3		
	4	65-68	<15	2		
SATCOM	1	55-58		7-1/2		

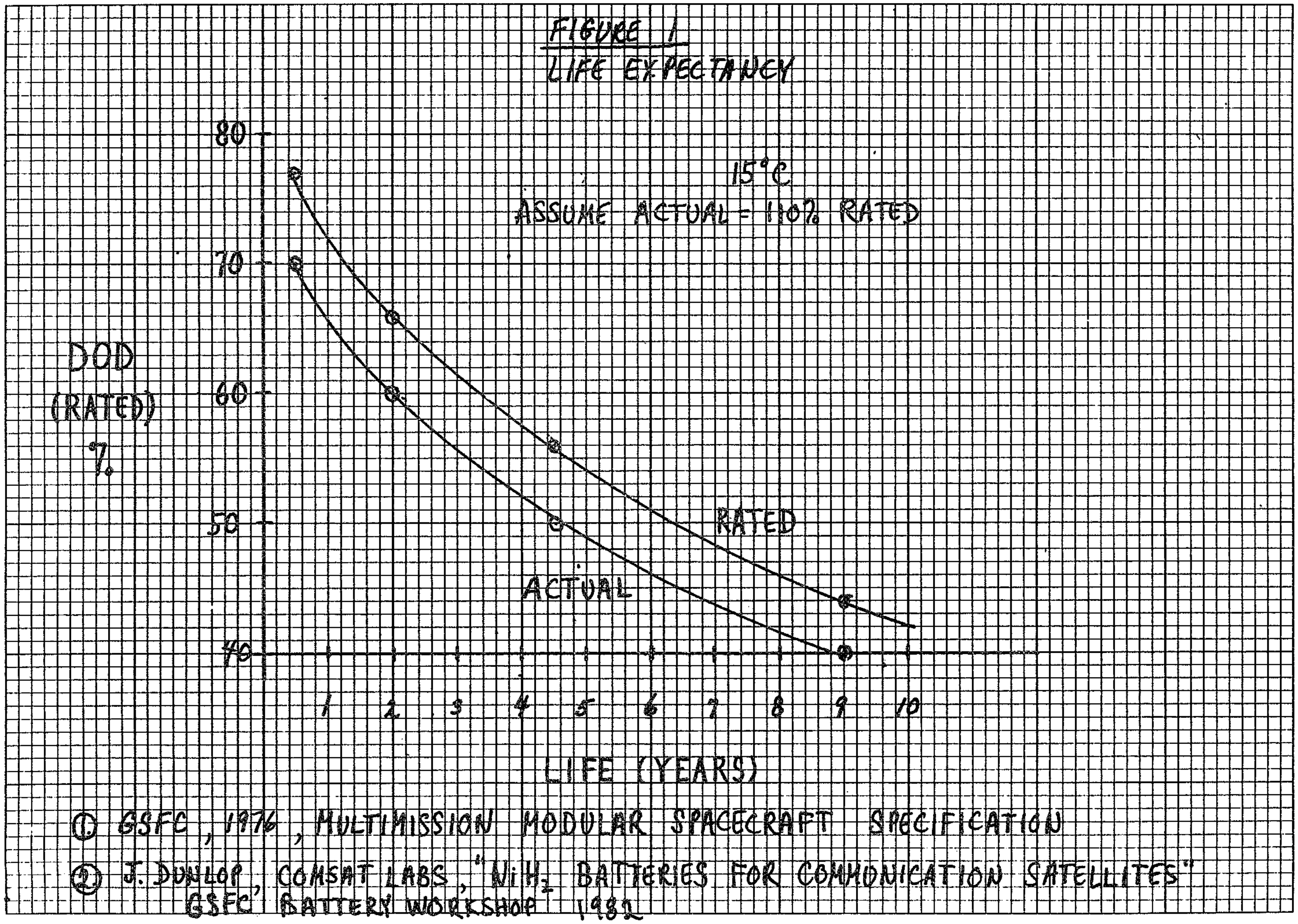


Figure 1. Life expectancy.

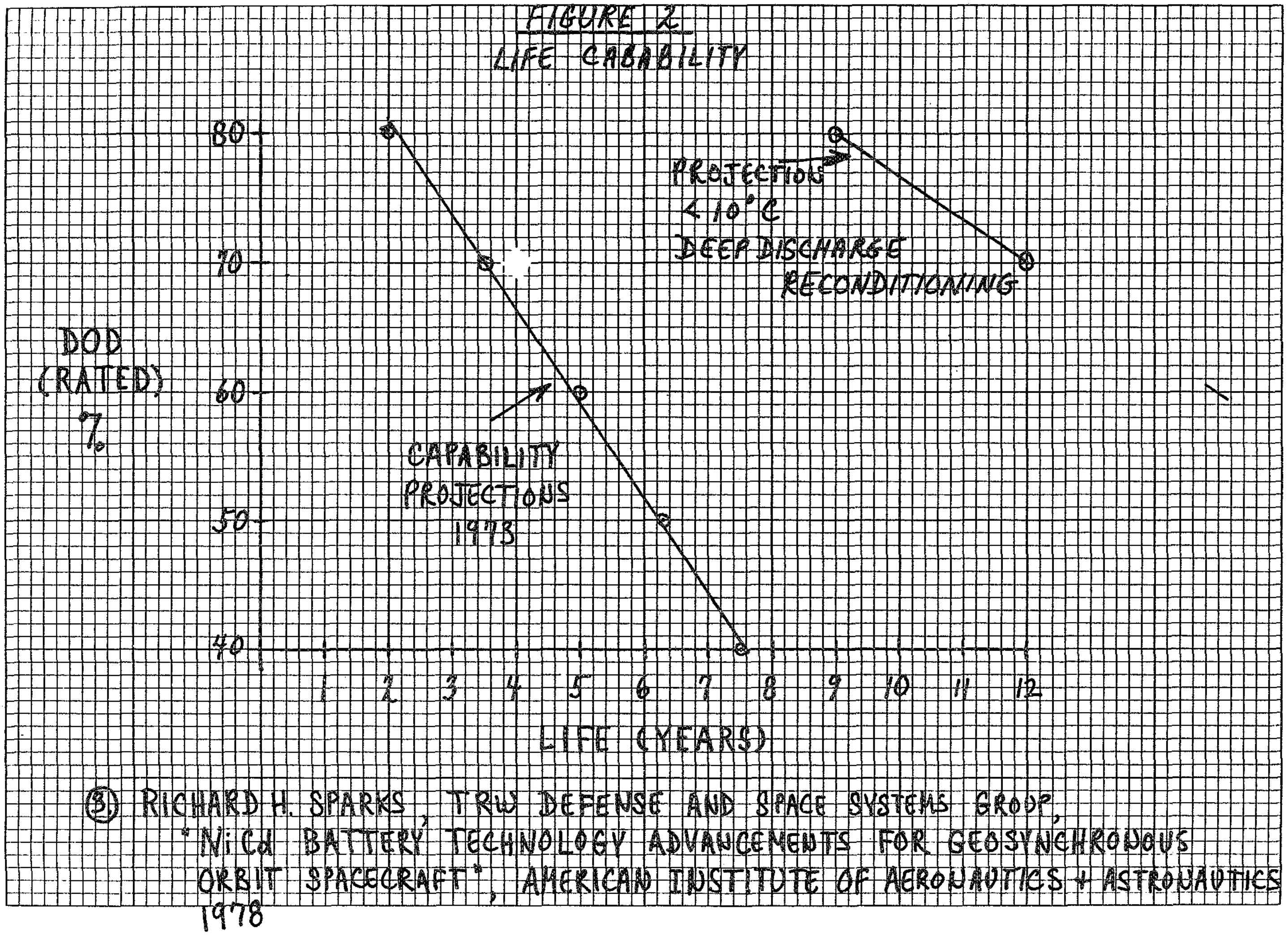


FIGURE 2
LIFE CABABILITY

③ RICHARD H. SPARKS, TRW DEFENSE AND SPACE SYSTEMS GROUP, "NiCd BATTERY TECHNOLOGY ADVANCEMENTS FOR GEOSYNCHRONOUS ORBIT SPACECRAFT", AMERICAN INSTITUTE OF AERONAUTICS + ASTRONAUTICS 1978

Figure 2. Life capability.

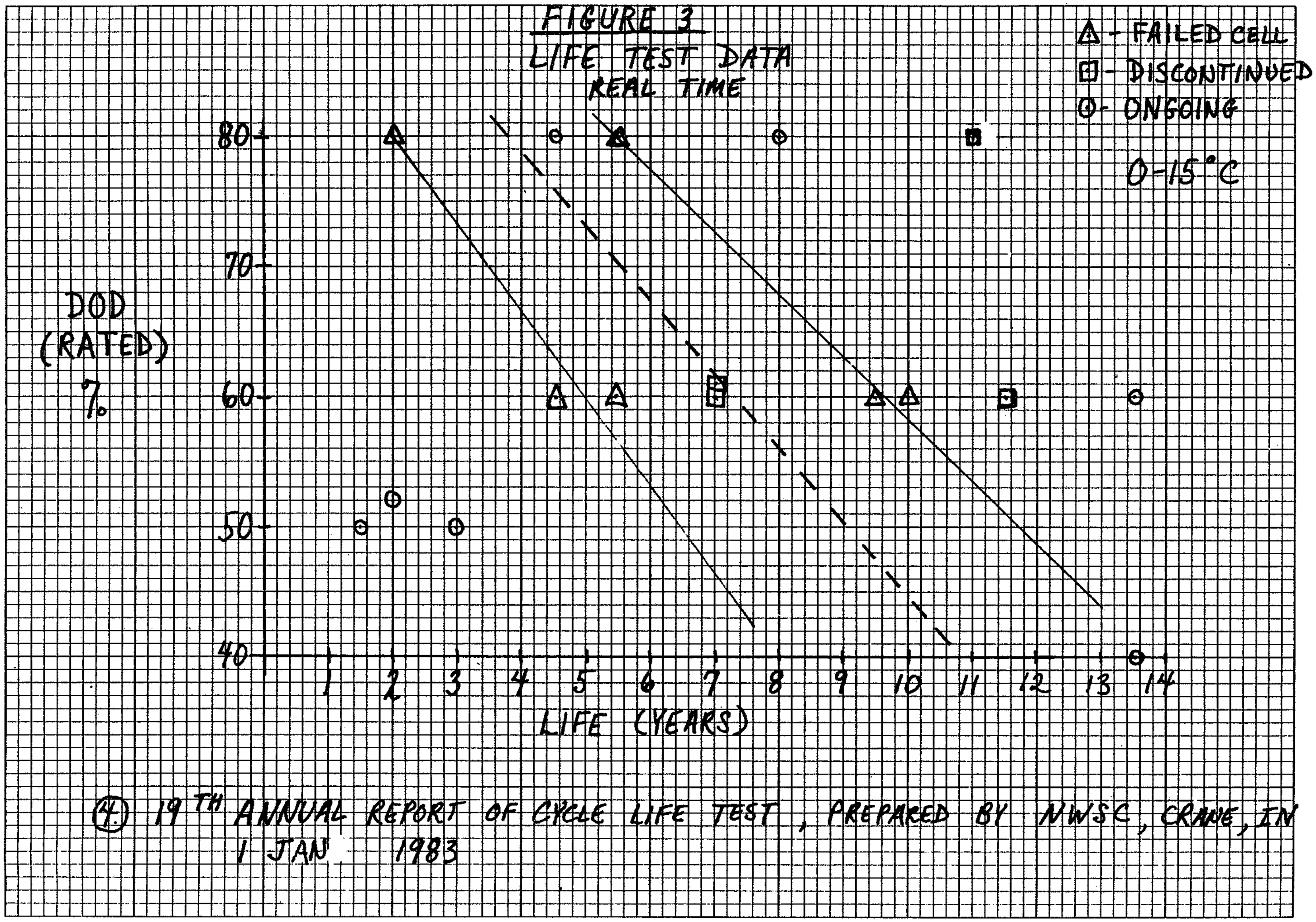
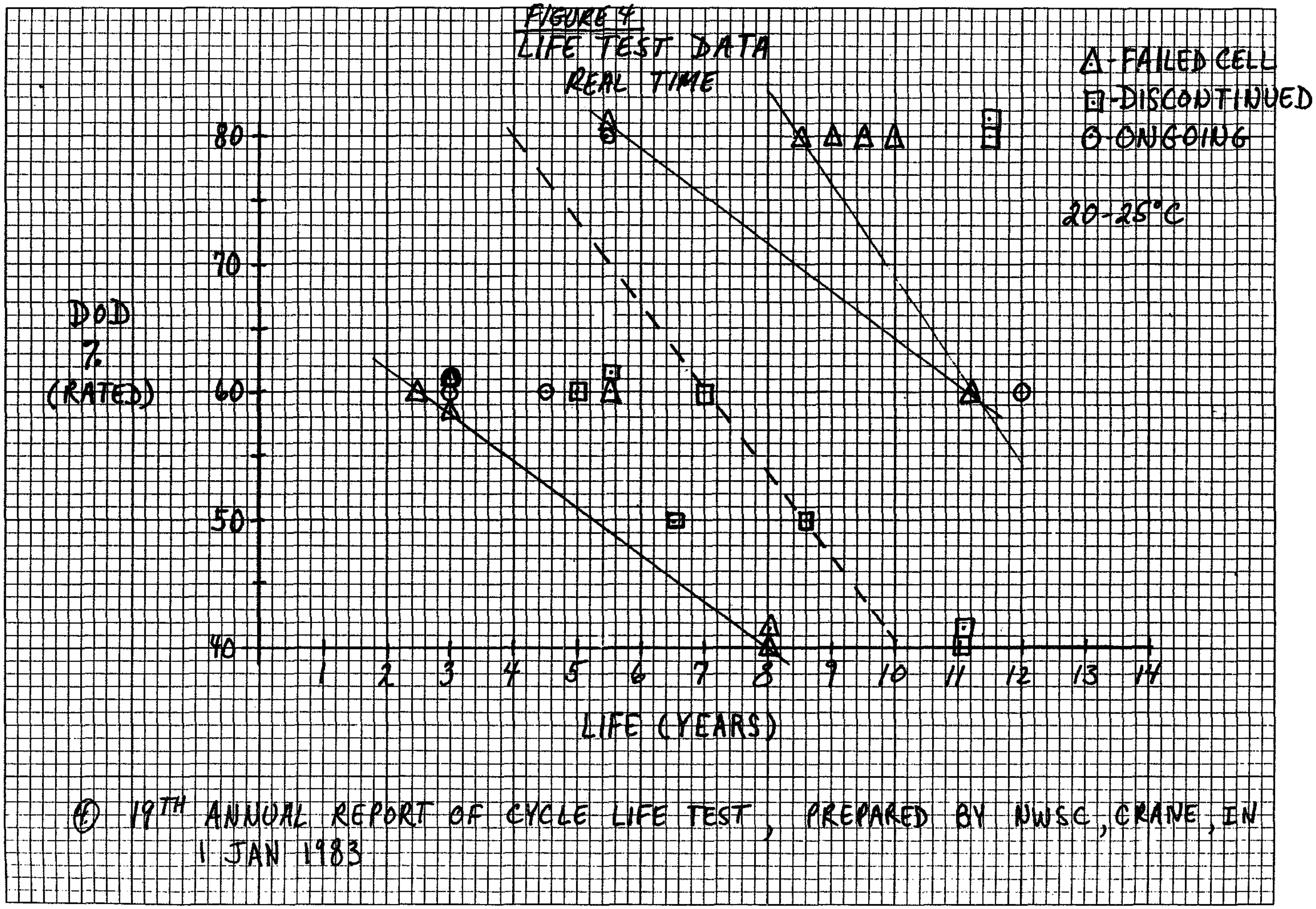


Figure 3. Life test data real time.



① 19TH ANNUAL REPORT OF CYCLE LIFE TEST, PREPARED BY NWSC, CRANE, IN
1 JAN 1983

Figure 4. Life test data real time.

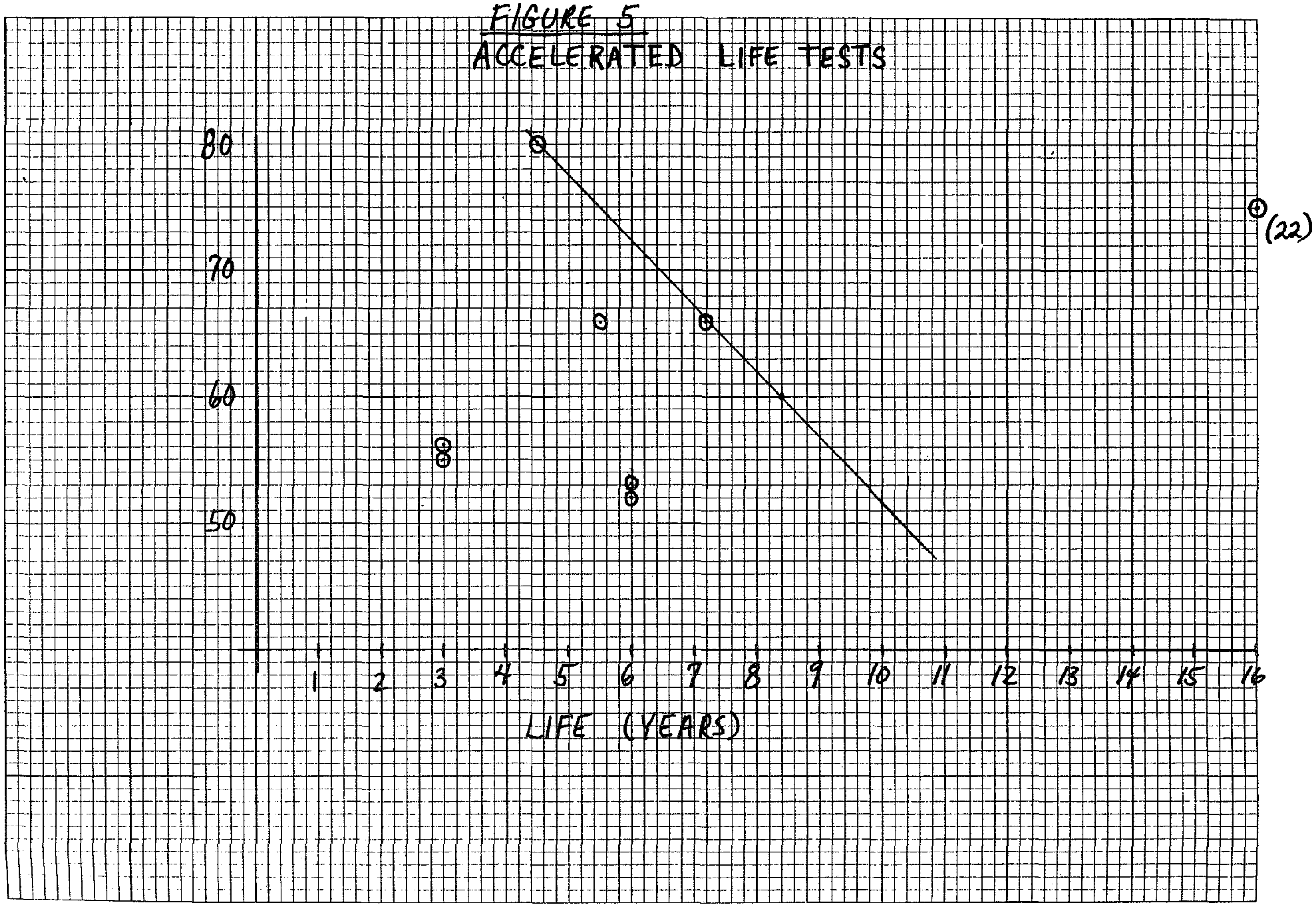


Figure 5. Accelerated life tests.

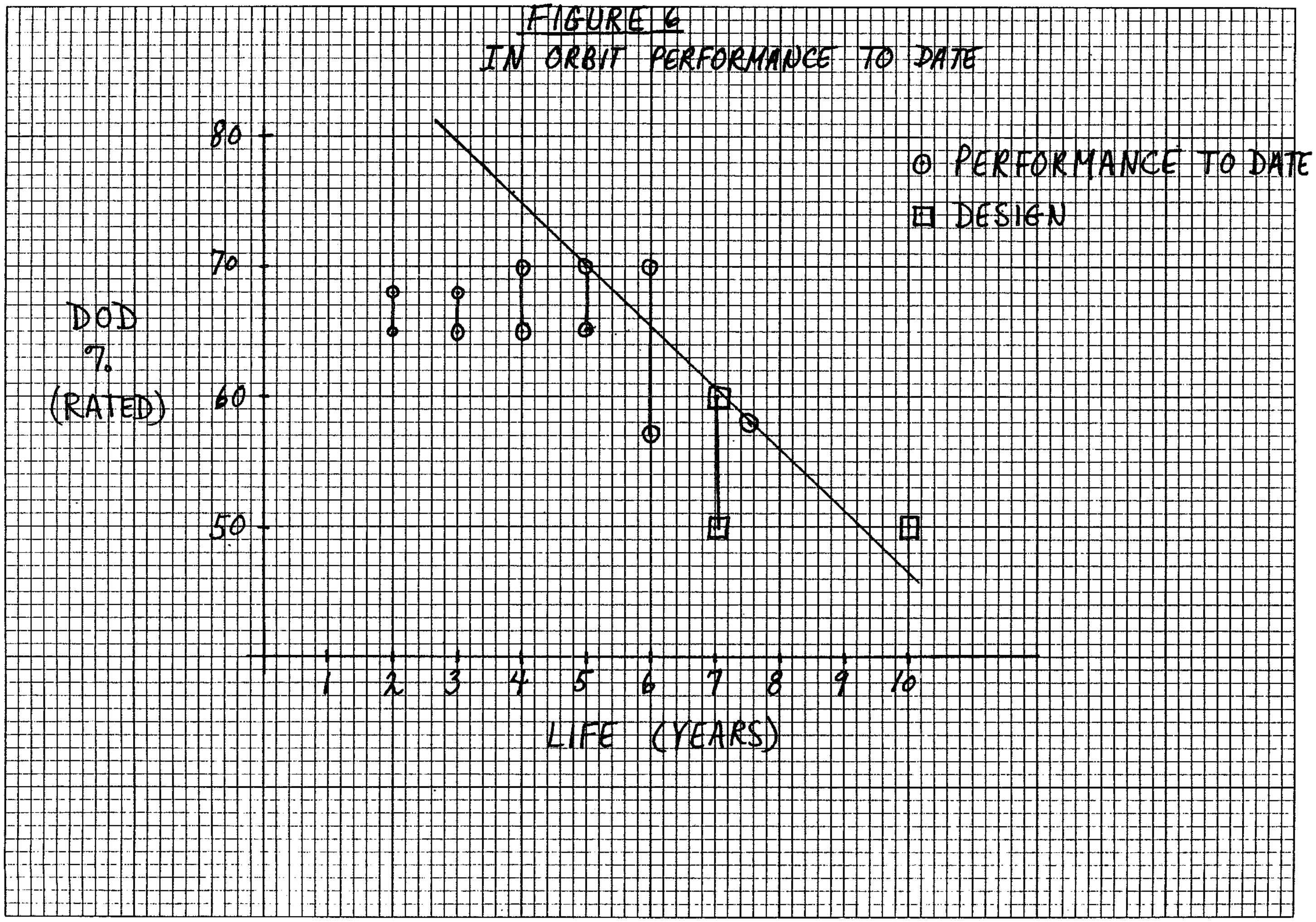


Figure 6. In orbit performance to date.

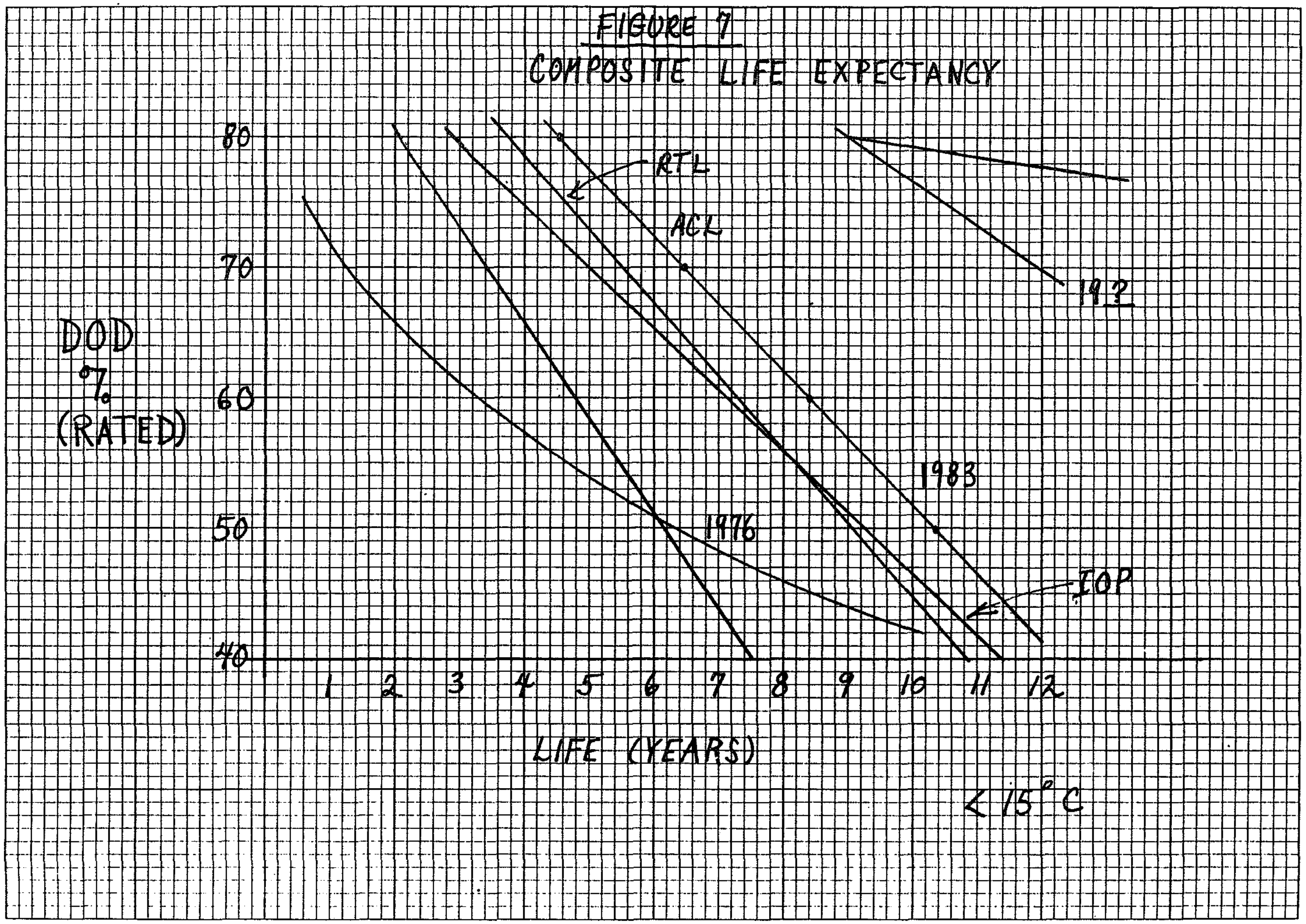


Figure 7. Composite life expectancy.

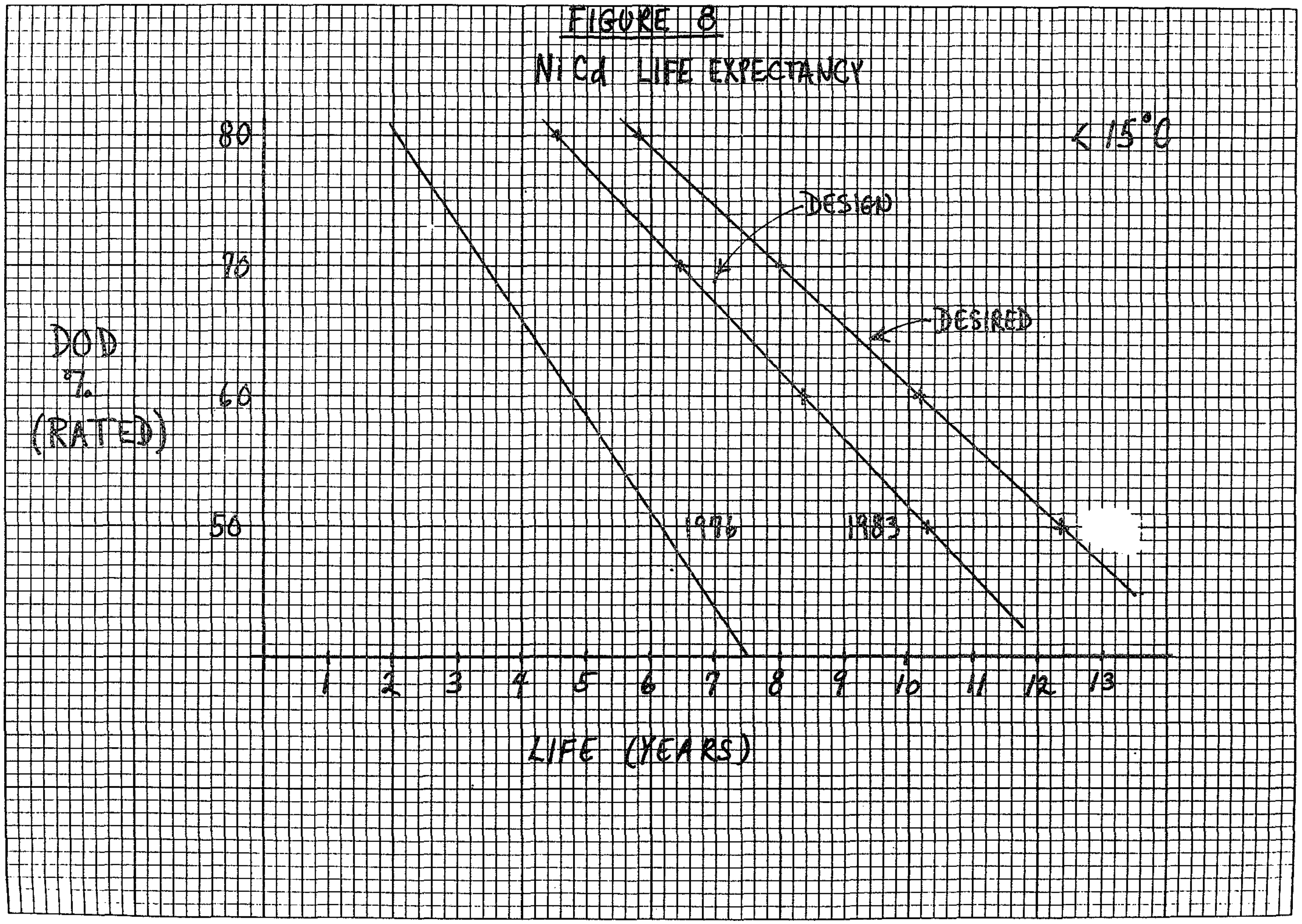


Figure 8. NiCd life expectancy.