Preservation Research and Testing Series No. 11

THE EFFECTS OF LASER ENGRAVING ON THE ESTIMATED SERVICE LIFE OF PRERECORDED COMPACT DISCS (CD-ROM)

Chandru J. Shahani, Michele H. Youket, Norman Weberg

Prepared for the Library of Congress by
William P. Murray
Consultant
St. Paul, MN

Preservation Directorate
Library of Congress
Washington, DC
2009

Objective

The objective of this research was to determine if there would be any negative impact on the Life Expectancy (LE) of prerecorded compact discs as a result of using a laser to engrave a property mark in the hub of the disc. For the purposes of this report, a prerecorded compact disc is considered to be a CD-ROM or a CD-Audio. It does not include recordable CDs (CD-R), rewritable CDs (CD-RW), or DVDs.

Introduction

The Library of Congress has been conducting research on various methods that can be used to enhance the security of the Library's collection of music recorded on digital optical discs. Such a method must be able to be applied to the disc itself, not just the case or sleeve that houses it, and therefore must not damage the disc or interfere with the playback.

Disc manufacturers customarily apply a protective coating over the metal reflective layer to seal the disc and protect the reflector from the damaging effects of oxygen, moisture, and pollutants in the atmosphere. This clear coating is often followed by screen printed artwork and/or text that identifies the content of the disc. Modification of the disc, including the application of property identification labels, labels with security devices, or writing or printing on the discs, risks introducing elements that can result in short term and / or long term harm. Disc deterioration or reduced service life could be brought about by:

- Unintentionally removing one or all of the protective coatings if an adhesive coated label were removed or repositioned.

- Upsetting the disc dynamic balance of the disc, especially at high rotational speeds, if the labels result in an asymmetric mass on the disc.

- Fracturing the metalized reflector surface from writing or printing on the disc.

Accelerated aging studies previously conducted by the Library of Congress to evaluate the use of adhesive security labels demonstrated that the use of such labels increased the rate of accumulation of errors that lead to the end of disc life. Application of the label, which covered the entire top side of the disc, was tricky, and if the label was off-center, or had uneven adhesion or trapped air bubbles, removal or adjustment of the label for a better fit was not possible as it would often take the seal-coat and the reflector up with it. Lifting edges could get snagged and also lead to delamination of the seal-coat and reflector.

Solvent based inks, such as those used in some felt tipped markers, have been shown to cause damage to the reflector from penetration of the solvent through the seal-coat. With all of the ink compositions available and all of the CD coating variables, it was not deemed practical to qualify any such markers for CD labeling. Even if once qualified, either the marker or CD manufacturer could change critical chemical or process parameters of their products. Such changes may invalidate any such qualification.

For these reasons the Library of Congress chose to explore engraving a property mark directly on the disc as an indelible means of identification for discs in the Library’s collections. The mark is applied with a laser to the polycarbonate substrate within the stacking ring of the CD. The area used for such engraving is approximately 26 mm in diameter and concentric with the disc center. The mark is well within the concentric stacking ring (located approximately 32 to 36 mm diameter) of the CD. The stacking ring is a commonly used molded feature of the disc that is raised on the read side and indented on the label side of the polycarbonate substrate. The purpose of the stacking ring is to prevent abrasion of the disc surface from disc to disc contact during manufacture and shipping in a stacked mode. The area within the stacking ring:

- Contains no functional information.
- Usually is not coated with screen-printed artwork.
- Very seldom, if ever, is covered with protective coatings such as lacquer.
- Is close to the center of rotation, thereby minimizing any possible effect of dynamic unbalance.
- Is not coated with any functioning reflector.

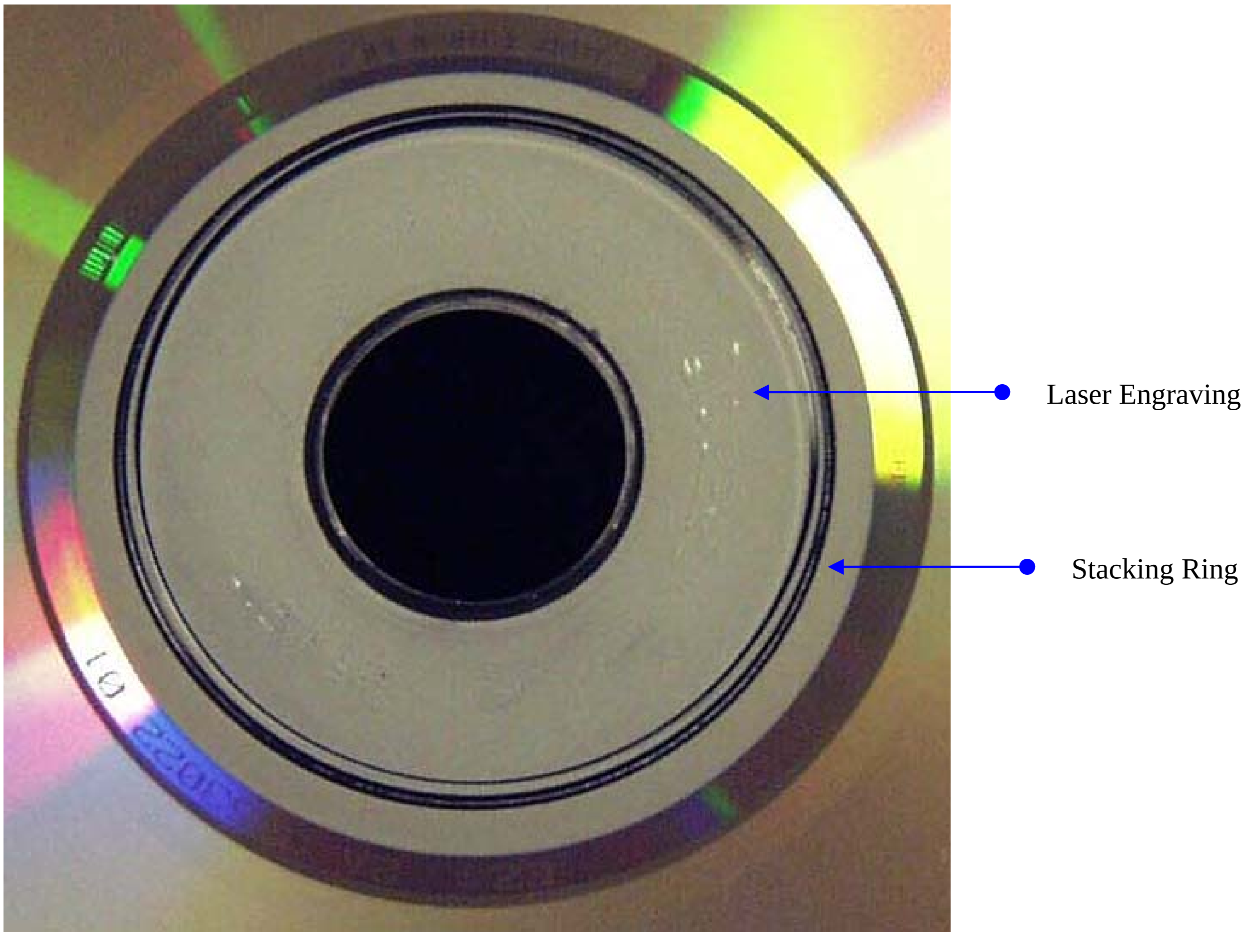
This report describes the results of accelerated aging tests conducted to compare the life expectancy of engraved discs with discs that were aged in an "as received" condition from the manufacturer.

The effects of temperature and relative humidity on the service life of CD-ROM discs have been previously modeled. The results of this modeling were reported in *Compact Disc Service Life: An Investigation of the Estimated Service Life of Prerecorded Compact Discs (CD-ROM)*, Preservation Research and Testing Series No. 10, 2009. For that study, pairs of test specimens had been selected randomly from duplicate CDs that had been submitted to the Library of Congress for copyright registration. The test population represented a variety of CD-ROM constructions.

One of each pair of discs was laser engraved with a mark, "Library of Congress ©", within the flat area of the CD between the center hole and the stacking ring. The discs in this sample set were identified by appending the suffix "C" to the specimen number. The other disc of the pair was not engraved and was identified by appending the suffix "D" to the specimen number. Thus Type C media was "Experimental" and Type D media was "Control". Photograph 1 shows the construction of a typical compact disc (CD-ROM). The arrow indicates the location of the stacking ring.

Photograph 1: Typical CD-ROM disc construction

Photograph 2 shows a close up of the center portion of this same disc. The radius of the laser engraving is approximately midway between the center hole and the stacking ring. It may be noted that the actual engraving is barely visible and therefore does not detract from the disc artwork.



Photograph 2: Close up showing stacking ring and area of laser engraving

In the *Compact Disc Service Life* report all of the discs were treated as one population. Block Error Rate was measured following known time increments of exposure to accelerated temperature and relative humidity conditions. The time to reach end-of-life (EOL) was calculated as the time required to reach a BLER max of 220 sec^{-1}. The distribution of the EOLs within a given accelerated condition was determined. The fit of the experimental data was compared to four common distributions including Weibull, Lognormal, Normal and Exponential. A lognormal failure time relationship was determined to best describe the distribution of measured or estimated life expectancies for all of the accelerating conditions.

Lognormal Distribution:

The lognormal cumulative failure equation is expressed as:

$$F_{(t)} = \frac{1}{\sqrt{2\Pi}} \int_0^t \frac{1}{\sigma l x} e^{-\frac{1}{2}\left(\frac{\log(x) - \mu l}{\sigma l}\right)^2} dX$$

Where σl = log standard deviation
μl = (log mean)
x = specimen failure time

The log mean for each temperature / relative humidity combination was regressed to fit an Eyring acceleration model.

$$t(50\%) = Ae^{-\Delta H / kT} e^{(B)RH}$$

From the resultant equation, the time for 50% failure could be calculated at any given temperature (T) and relative humidity (RH). Using 25 ˚C and 50 % RH as the user condition, the relative acceleration at each of the elevated temperature and RH conditions could be determined. By applying the acceleration factor to each of the individual disc EOLs, an estimated EOL, normalized to 25 ˚C / 50% RH, was determined for each disc. In the *Compact Disc Service Life* report, all of the discs, both Type C and Type D, were treated as one population. The combined normalized data was used obtain the final parameters for the lognormal distribution at user conditions. The life expectancy was expressed as the portion of discs surviving, with a given confidence level, when stored at a prescribed temperature and relative humidity.

Tables in Attachment 1 show the BLER values measured for each test interval as a function of stress and exposure time for each disc in the study.

For the purposes of this report, the discs were separated into two separate and distinct populations; Type C and Type D. The end-of life estimates used for this study are the same as those used to analyze the data for the *Compact Disc Service Life* report. The only difference is that the calculated EOLs for the discs in the Type C sample set and the calculated EOLs for the discs in the Type D sample set were analyzed as separate and independent populations for comparison.

Data Analysis

From the data obtained in the *Compact Disc Service Life* report, the calculated time to reach end-of-life for each disc, normalized to 25 ˚C / 50 % RH, was sorted by treatment type (Type C or Type D). Data for the Type C discs were analyzed separately from the data for the Type D Discs.

The calculated estimates for EOL for each disc are shown in Attachment 2.

The probability distribution of Years to EOL for discs receiving treatment Type C or treatment Type D were plotted separately by each of the four most commonly used probability distribution methods. These distributions included the Weibull, Lognormal, Exponential and Normal Distributions. Figure 1 shows, graphically, the fit obtained for each of the four distributions evaluated.

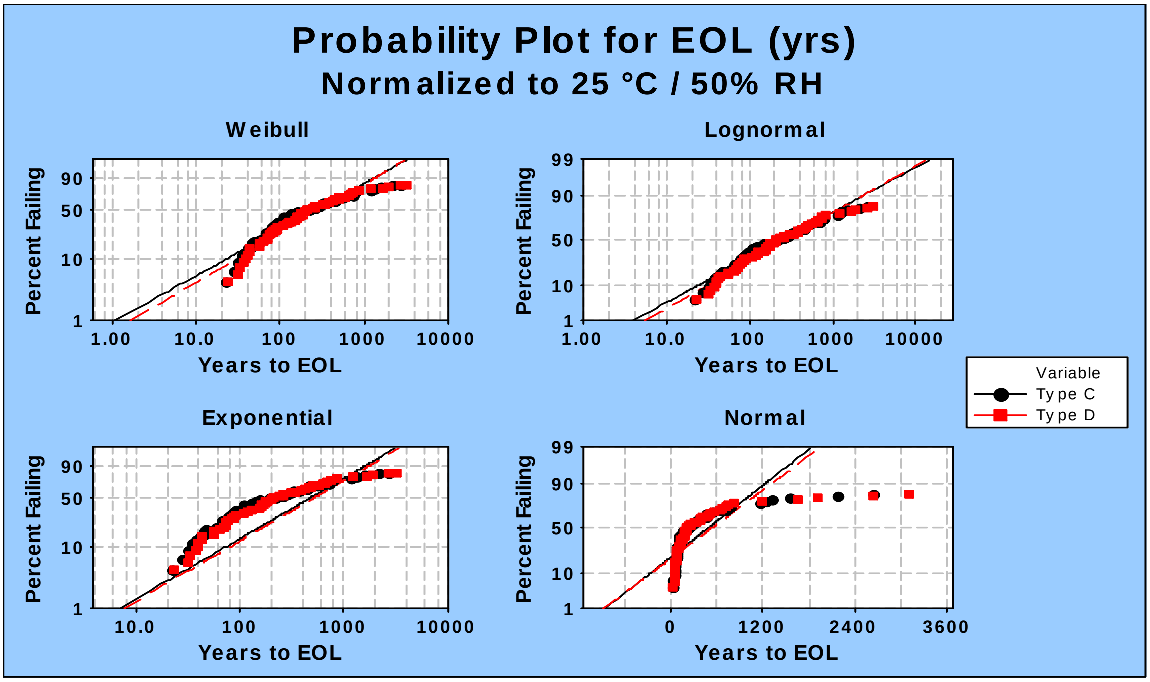


Figure 1: Comparison of Distribution Estimates for Type C and Type D EOL

The data, when examined in any of the four distribution plots, reveals that the calculated EOLs for the Type C discs are not different than the calculated EOLs for the Type D discs. As in the *Compact Disc Service Life* report there is an excellent fit of both Type C and Type D data to the lognormal distribution.

For comparison, the lognormal probability plot from the *Compact Disc Service Life* report is reproduced here, as Figure 2. Figure 2 shows the results of a lognormal distribution using both Type C and Type D data combined into one population.

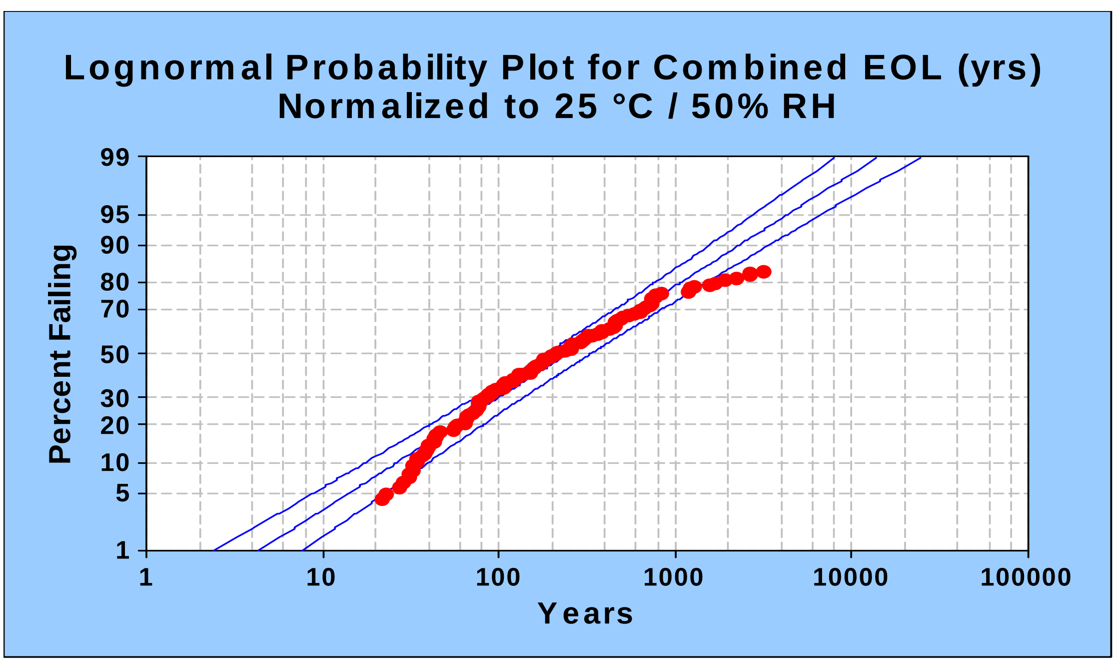


Figure 2: Lognormal Probability plot for combined Type C and Type D discs from *CD Service Life* Report

The graph in Figure 3 shows the fit of the individual discs, both Type C and Type D, to the lognormal distribution equation. This distribution shows that there is neither a practical nor a statistical difference between the two sets of discs.

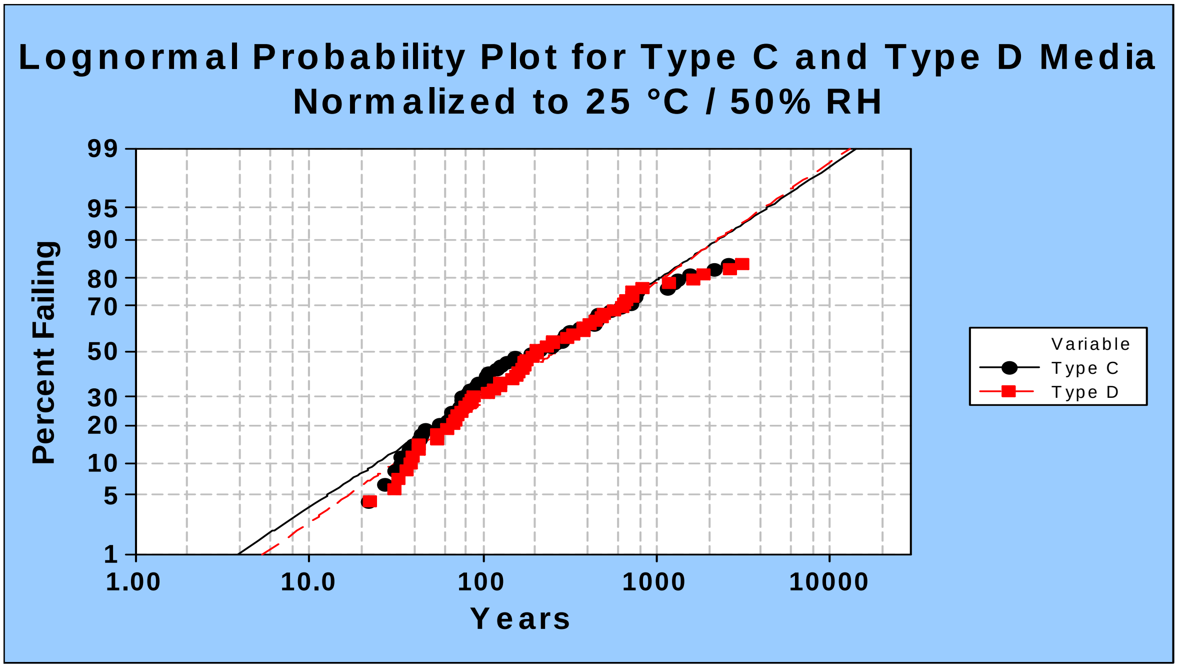


Figure 3: Probability plot comparing Type C and Type D discs to the Lognormal distribution

Figure 3 shows the probability of an individual disc, or percent of the total population, that would be expected to fail as a function of time at 25 ˚C and 50% RH. A Cumulative Failure Plot, as a function of time at 25 ˚C and 50% RH is shown in Figure 4. For the purpose of clarity and detail, a linear scale is used for both time and cumulative percent failing.

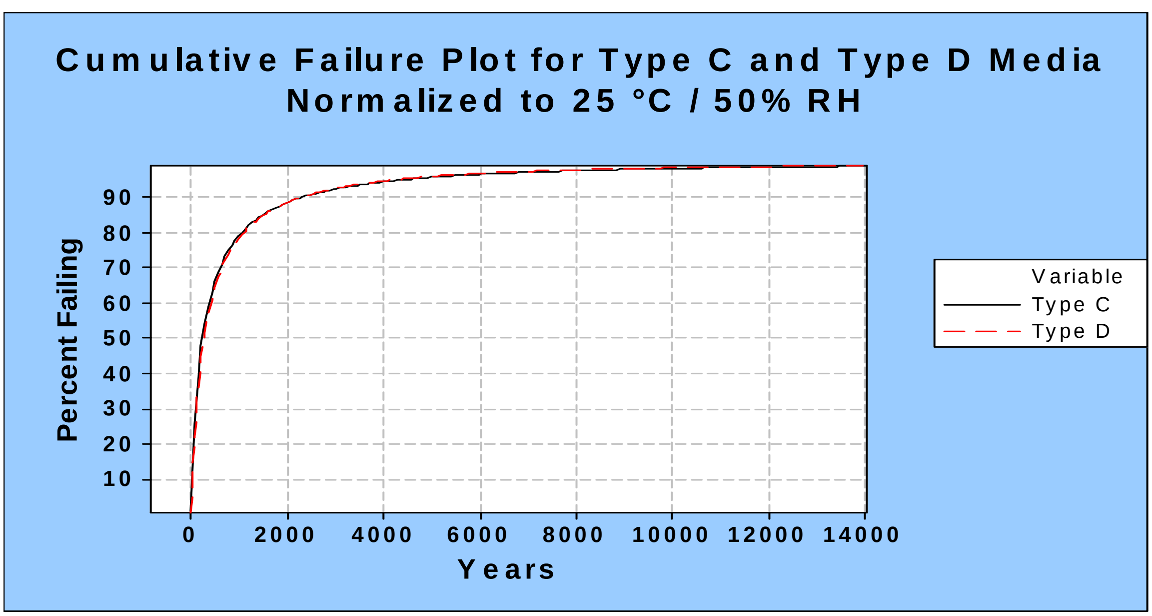


Figure 4: Cumulative Failure plot comparing Type C and Type D discs to the Lognormal distributions

Figure 5 is the same graph as Figure 4 but with a scale chosen to show the percent failing during the first 200 years. This graph shows that within the first 200 years roughly 45% of Type C and Type D discs are estimated to reach end-of-life.

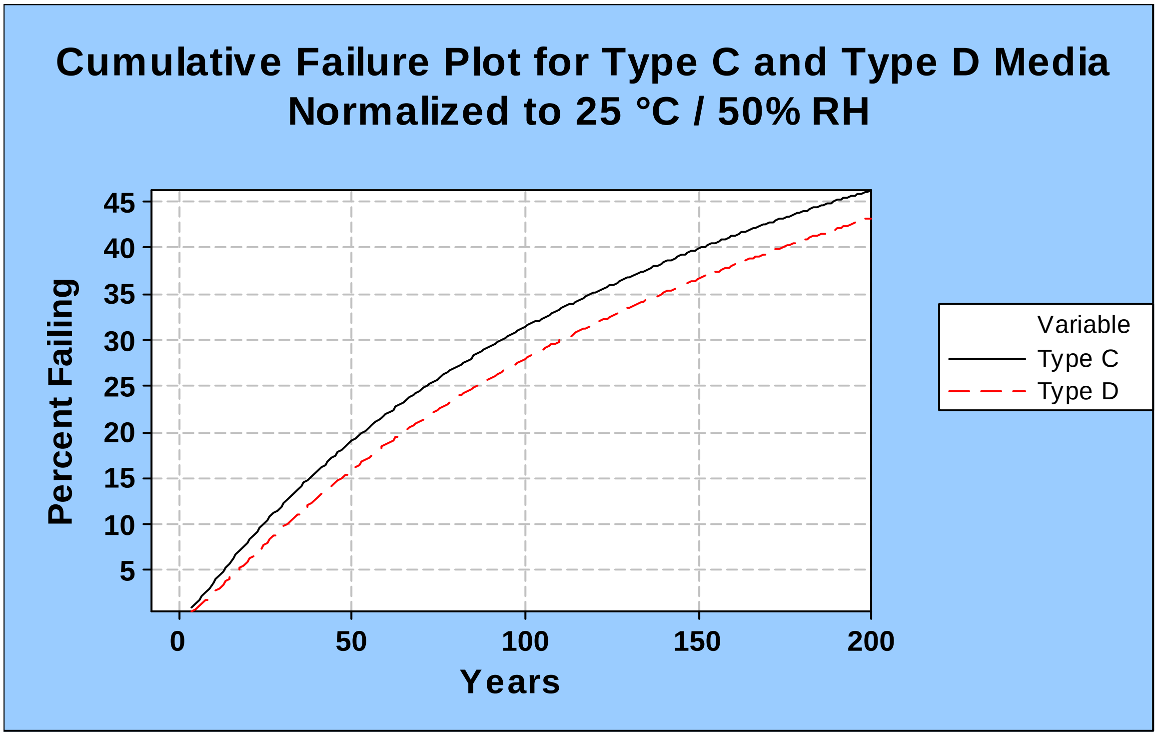


Figure 5: Cumulative Failure plot comparing Type C and Type D discs to the Lognormal distributions Expanded scale

Table 1 shows the percent of the collection population that is estimated to fail, as a function of some selected times (Years) at 25 ˚C / 50 % Relative Humidity.

Table 1: Percent of CD-ROMs Failing, by Type, as a function of selected times

Time (Years)	Percent Failing	
	Type C	Type D
1	0.10	0.04
5	1.48	0.89
10	3.72	2.51
20	8.19	6.14
25	10.27	7.93
50	19.08	15.96
75	25.92	22.55
100	31.45	28.03
150	39.97	36.70
200	46.35	43.33

The table shows that there is no appreciable difference, either statistically or practically, between the Type C and Type D failure rates.

Conclusion

The practice of using a laser to engrave a property mark for the purpose of identifying a compact disc collection item in the Library of Congress produces neither a statistical nor a practical difference in the estimated service life of CD-ROM media.

In addition, there are other advantages to using a laser engraved property mark that may be considered when selecting a marking method:

- Minimal dynamic imbalance effect as there is almost no material removed, and none added. What change does occur is close to the center of the disc rotation.
- The process introduces no inks, solvents or pigment to the disc surface.
- Engraving provides no opportunity for delamination effects caused by adding a material to the lacquered side of the disc.
- Minimal to no effect on the original disc labeling or artwork.

References

International Electrotechnical Commission. Audio recording – Compact disc digital audio system. IEC 60908:1999

International Organization for Standardization. 2002. Imaging materials – Compact discs (CD-ROM) – Method for estimating the life expectancy based on the effects of temperature and relative humidity. ISO 18921:2002.

International Organization for Standardization. 2002. Imaging materials – Recordable compact disc systems – Method for estimating the life expectancy based on the effects of temperature and relative humidity. ISO 18927:2002.

International Organization for Standardization/International Electrotechnical Commission. 1995. Information technology – Data interchange on read-only 120 mm optical discs (CD-ROM). ISO/IEC 10149:1995.

Murray, W. P. 1994. Accelerated service life predictions of compact discs. In *Accelerated and outdoor durability testing of organic materials,* ed. W D. Ketola and D. Grossman, 263-271. ASTM STP 1202. Philadelphia, PA: American Society for Testing and Materials.

Pohlman, K. C. 1992. *The compact disc handbook*. Madison, WI: A-R Editions.

Stinson, D., Ameli, F., and N. Zaino. 1995. *Lifetime of KODAK writable CD and photo CD media*. www.cd-info.com/CDIC/Technology/CD-R/Media/Kodak.html

Tobias, P. A. and D. C. Trinidade. 1986. *Applied reliability*. New York, NY: Van Nostrand Reinhold.

Wroebel, J. J. Ramp Profiles for Optical Disc Incubation. 1994. In *1994 Topical Meeting on Optical Data Storage*, ed. D. K. Campbell, M. Chen and K. Ogawa, 191-202. Proceedings of SPIE – the International Society for Optical Engineering, vol. 2338. Bellingham, WA: SPIE – the International Society for Optical Engineering.

Attachment 1

Data

Maximum Block Error Rate per Disc per Exposure Interval

Notes:

The highest value returned by the Datarius CDCS-4.2L test system for BLER is 500. Therefore, results for BLER reported by the test equipment as 500 are not considered as the actual value of this parameter. Values of 500 shown in these tables are used to indicate that the BLER has reached a level that is out of the measurable range of the tester, and therefore were not used in any calculation.

Blank cells in this table represent discs that were un-readable by the test equipment due to some sort of catastrophic failure of the disc, and have effectively reached their end-of-life.

Data for 80°C / 85% RH Test Cell					
OrdName	**BLERmax 0 hrs**	**BLERmax 500 hrs**	**BLERmax 1000 hrs**	**BLERmax 1500 hrs**	**BLERmax 2000 hrs**
EG71C	36	ND	80	350	500
EG71D	28	ND	44	250	500
EG72C	18	ND	106	348	500
EG72D	26	ND	28	38	52
EG73C	26	ND	350	500	500
EG73D	32	ND	174	242	272
EG74C	108	ND	378	500	500
EG74D	26	ND	332	500	500
EG75C	10	ND	28	46	70
EG75D	10	ND	20	32	78
EG76C	20	ND	500	500	500
EG76D	28	ND	500	500	500
EG77C	6	ND	58	92	134
EG77D	38	ND	64	74	260
EG78C	12	ND	26	28	28
EG78D	16	ND	32	36	38
EG79C	12	ND			
EG79D	22	ND			
EG80C	20	ND	56	262	500
EG80D	26	ND	32	310	500

Data for 80°C / 70% RH Test Cell					
OrdName	**BLERmax 0 hrs**	**BLERmax 500 hrs**	**BLERmax 1000 hrs**	**BLERmax 1500 hrs**	**BLERmax 2000 hrs**
EG61C	16	500	500	500	500
EG61D	16	500	500	500	500
EG62C	54	54	54	56	104
EG62D	38	40	48	98	286
EG63C	124	316	500	500	500
EG63D	106	116	120	168	230
EG64C	46	500	500	500	500
EG64D	16	500	500	500	500
EG65C	20	306	500	500	500
EG65D	20	56	272	500	500
EG66C	60	28	106	500	500
EG66D	12	28	32	58	154
EG67C	24	114	158	182	500
EG67D	32	118	168	500	500
EG68C	20	500	500	500	500
EG68D	20	500	500	500	500
EG69C	16	500			
EG69D	500				
EG70C	20	20	20	42	180
EG70D	22	24	26	72	298

Data for 80°C / 55% RH Test Cell					
OrdName	**BLERmax 0 hrs**	**BLERmax 500 hrs**	**BLERmax 1000 hrs**	**BLERmax 1500 hrs**	**BLERmax 2000 hrs**
EG46C	18	20	22	22	22
EG46D	24	26	30	44	58
EG47C	12	126	196	240	500
EG47D	20	124	186	214	338
EG48C	24	100	146	160	170
EG48D	80	120	178	198	206
EG49C	30	32	30	30	30
EG49D	30	30	32	32	32
EG50C	26	184	500	500	500
EG50D	16	148	500	500	500
EG51C	10	10	12	24	500
EG51D	16	18	26	60	86
EG52C	22	26	44	174	320
EG52D	28	32	60	228	414
EG53C	10	40	60	98	134
EG53D	10	52	58	60	64
EG54C	16	14	14	14	16
EG54D	14	14	14	16	16
EG55C	24	32	362	500	500
EG55D	20	26	302	500	500
EG56C	10	132	446	500	500
EG56D	12	94	500	500	500
EG57C	12	112	238	286	308
EG57D	12	106	252	294	316
EG58C	4	22	26	26	26
EG58D	4	10	20	20	24
EG59C	18	28	30	36	38
EG59D	22	28	42	68	74
EG60C	18	42	52	58	72
EG60D	12	14	24	130	412

Data for 70°C / 85% RH Test Cell					
OrdName	BLERmax 0 hrs	BLERmax 750 hrs	BLERmax 1500 hrs	BLERmax 2250 hrs	BLERmax 3000 hrs
EG31C	26	16	358	500	500
EG31D	18	26	344	500	500
EG32C	32	500	500	500	500
EG32D	32	500	500	500	500
EG33C	10	52	144	500	500
EG33D	10	58	112	500	500
EG34C	16	32	40	54	64
EG34D	16	26	60	86	138
EG35C	44	18	44	44	46
EG35D	18	44	20	26	66
EG36C	20	32	500	500	500
EG36D	18	20	500	500	500
EG37C	4	6	12	12	14
EG37D	6	10	8	12	14
EG38C	10	18	24	32	100
EG38D	16	18	22	24	54
EG39C	6	40	106	232	116
EG39D	8	56	74	88	102
EG40C	34	104	68	398	500
EG40D	112	26	106	108	108
EG41C	14	36	62	76	84
EG41D	30	36	68	78	84
EG42C	22	50	66	76	108
EG42D	56	58	94	94	86
EG43C	12	24	338	500	500
EG43D	12	26	270	500	500
EG44C	16	62	126	216	236
EG44D	16	64	174	220	238
EG45C	28	40	28	40	68
EG45D	30	26	42		

Data for 60°C / 85% RH Test Cell					
OrdName	BLERmax 0 hrs	BLERmax 1000 hrs	BLERmax 2000 hrs	BLERmax 3000 hrs	BLERmax 4000 hrs
EG01C	16	16	16	18	18
EG01D	14	16	16	18	18
EG02C	18	18	84	240	296
EG02D	16	28	70	274	500
EG03C	8	38	52	68	114
EG03D	10	22	46	120	500
EG04C	22	20	22	22	22
EG04D	18	16	16	16	16
EG05C	16	22	74	126	138
EG05D	42	26	92	178	200
EG06C	18	30	44	50	54
EG06D	24	34	46	50	50
EG07C	6	26	26	26	28
EG07D	14	16	26	32	32
EG08C	22	22	42	236	500
EG08D	12	12	32	266	500
EG09C	34	38	170	500	500
EG09D	34	34	86	310	500
EG10C	14	80	292	500	500
EG10D	16	60	280	500	500
EG11C	18	18	18	36	36
EG11D	18	18	18	18	18
EG12C	12	20	24	26	30
EG12D	12	18	28	32	36
EG13C	16	18	50	108	128
EG13D	58	24	48	84	94
EG14C	10	14	18	22	26
EG14D	8	16	18	18	28
EG15C	6	6	6	8	8
EG15D	12	14	14	14	14
EG16C	22	24	22	22	54
EG16D	32	34	32	40	82
EG17C	34	34	34	34	32
EG17D	16	24	24	26	28
EG18C	16	18	16	16	16
EG18D	56	52	38	62	54
EG19C	24	20	22	26	30
EG19D	26	26	36	66	100
EG20C	12	14	16	40	70
EG20D	12	12	60	44	70
EG21C	20	26	90	152	178
EG21D	18	24	72	120	142
EG22C	18	20	18	28	18
EG22D	16	18	18	18	16
EG23C	40	28	28	52	80
EG23D	10	52	54	60	84
EG24C	16	18	46	134	184

EG24D	14	14	44	80	98
EG25C	8	30	62	80	112
EG25D	8	28	46	46	64
EG26C	40	32	26	40	40
EG26D	68	68	68	70	68
EG27C	14	24	80	108	114
EG27D	12	22	84	132	146
EG28C	28	20	60	110	168
EG28D	8	14	28	54	76
EG29C	26	30	30	58	500
EG29D	62	64	62	108	500
EG30C	38	44	72	146	220
EG30D	78	80	78	80	500

Attachment 2

Normalized End-of-Life (years) Estimates for Each Disc

Notes:

Discs that exceeded BLER max too early in testing to determine a meaningful life estimate are designated as left censored. Such discs had very short lifetimes. Discs that did not show sufficient change in BLER max during the course of testing to determine a meaningful life estimate are designated as right censored. Such discs had very long lifetimes.

Disc ID	Years to EOL
1C	Right Censored
2C	38
3C	127
4C	Right Censored
5C	85
6C	318
7C	705
8C	43
9C	40
10C	21
11C	542
12C	718
13C	94
14C	761
15C	Right Censored
16C	463
17C	Right Censored
18C	Right Censored
19C	Right Censored
20C	212
21C	66
22C	Right Censored
23C	251
24C	65
25C	119
26C	Right Censored
27C	105
28C	75
29C	293
30C	57
31C	31
32C	Left Censored
33C	82
34C	453
35C	1537
36C	437
37C	2177
38C	284
39C	136
40C	46
41C	300
42C	262
43C	33
44C	90
45C	629
46C	5592
47C	76
48C	154

Disc ID	Years to EOL
1D	Right Censored
2D	36
3D	86
4D	Right Censored
5D	55
6D	418
7D	574
8D	39
9D	31
10D	22
11D	Right Censored
12D	486
13D	178
14D	732
15D	Right Censored
16D	257
17D	1138
18D	Right Censored
19D	150
20D	204
21D	85
22D	Right Censored
23D	195
24D	128
25D	236
26D	Right Censored
27D	80
28D	175
29D	168
30D	Right Censored
31D	32
32D	Left Censored
33D	108
34D	176
35D	678
36D	2646
37D	3115
38D	652
39D	252
40D	Right Censored
41D	332
42D	448
43D	42
44D	89
45D	830
46D	631
47D	76
48D	117

49C	Right Censored
50C	34
51C	1321
52C	74
53C	190
54C	Right Censored
55C	32
56C	27
57C	75
58C	1246
59C	1165
60C	451
61C	105
62C	106
63C	63
64C	44
65C	760
66C	Left Censored
67C	358
68C	2630
69C	Left Censored
70C	147

49D	Right Censored
50D	43
51D	310
52D	55
53D	501
54D	Right Censored
55D	39
56D	70
57D	72
58D	1196
59D	381
60D	63
61D	157
62D	1658
63D	160
64D	67
65D	729
66D	Left Censored
67D	205
68D	1902
69D	Left Censored
70D	125