Results of CD-R Media Study

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ABSTRACT

CD R media is increasingly being looked upon as an excellent archival media with an estimated storage life on the order of 100 years. Since the government will be making large investments in CD-R media, it is imperative that the characteristics of media, recorders, test devices and compatibility with CD-ROM readers be under-shod, This article summarizes the results of a CD-R media evaluation conducted by SIGCAT (tile federal Special Interest Group for CD-ROM Applications and Technology) and follow-on evaluations performed by the Data Distribution Laboratory al JPL. For this evaluat ion, 250 media samples from various manufacturers were recorded on several recorders at different record ram. Every byte of every disc recorded in the study was retrievable on some, but not ail CD-ROM readers. We arc confident that any commercially available media recorded on 2X recorders will provide a reliable archival media. We have, however, identified incompatibilities between single-speed (1X) recorders and phthalocyanine based media and between high speed recorders (i.e.. 4X and 6X recorders) and cyaninc-based med i a. We recommend that the industry address the recorder and media incompatibilities and that a specification be developed for a robust CD-R reader for use. in archival applications.

Keywords: **CD-Recordable, CD-R, Optical Disc, C D-ROM, BLER, Test Device**

1.0 EVALUATION PROCEDURE

SIGCAT sent letters to all CD-R media vendors requesting their participation in a media study. Each vendor was asked to donate 30 pieces of 63 and 74 minute media, preferably from different batches. The Data Distribution Lab recorded three pieces of media on each recorder setup: Sony CDW-900E at 1X (single speed) and 2X (double speed), Kodak PCD-Writer ?(K) (Philips recorder) at 2X and JVC at 1X. Informal tests were also conducted with a new Sony CDW-900E, a Yamaha 4X and Kodak PCD 600 6X recorder but are not included in the statistics presented in this paper.

The discs were then evaluated at each of three test sites (National Institute of Standards and Technology (NIST), National Technical Information Service (NTIS), and the Naval Air Warfare Center (NAWC). Each test site has either a CD-CATS Model SA2 or SA3 compact disc analyzer (a specialized PC computer and audio CD player). The CD-CATS dc.vice reports a large number of parameters which describe the physical characteristics of the disc, pit geometry and the quality of the recorded signal. The device also provides the location on the disc where certain minimum anti maximum value.s were encountered (block error rate, reflectivity, etc.). All test results were provided to JPL for analysis.

2.0 TEST DEVICE EVALUATION

Before attempting to interpret the results of the tests it is important to have some confidence that the results are accurate and repeatable. One of the reasons for the evalua [ion was the conflicting results of different test devices when evaluating CD-ROM media.

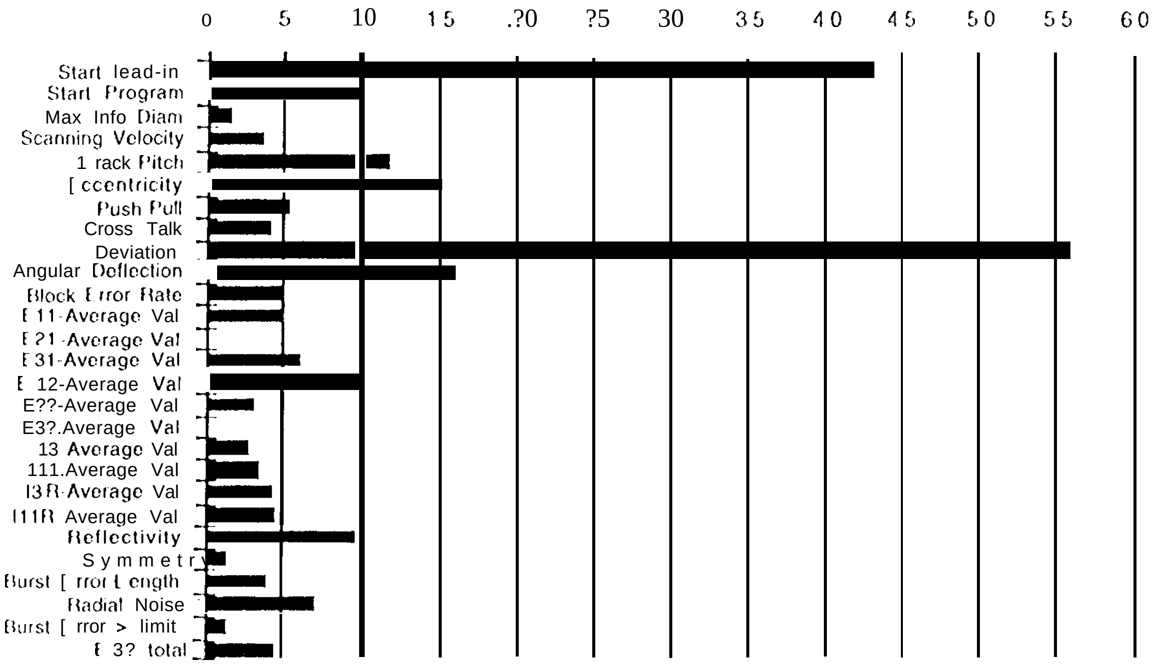
A summary of the percentage differences in values reported by the two test devices is provided in '1'able 1. The greatest differences are for start k-ad-in area and deviation which show large differences in values measured by the two devices. Values for track pitch, eccentricity, angular deflection, and reflectivity vary in the range of 10 to 20%. Values for maximum information diameter, scanning velocity, push pull, cross-talk, block error rate, the specific error types, signal strength, symmetry, burst errors an(i permanent error counts vary by about 5%. The values for the locations on the disc where minimum and maximum measurements were encountered tended to vary substantially (up to 30 percent).

These results lead us to believe that the CD-CATS wiii provide a gross indication of CD quality if used in a controlled manner (e.g. calibrated to some standard) and will differentiate very good or very bad discs.

3.0 OBS ERVATIONS FROM TEST RESULTS

Our testing indicates that CD-R media is robust. We did not encounter any permanent data loss on any of the test media despite some discs being recorded far out of specification The average block error rate for the vast majority of discs is lower than that found 011 pressed CD-ROMs. Figure 2 summarizes the average block err or rate for 180 discs, Several relationships are expressed in this figure, including the vendor, recorder and media duration. The scale on the left indicates the recorder. The scale. on the right gives the average block error values. It is clear that there. is a major incompatibility between recorder 1 and certain media types. Discussions with the vendors indicated a prior knowl edge of this incompatibility which could not be remedied with a hardware or software upgrade. A further statistical analysis of all the parameters provided by the test dt.vices does not present any unanticipated correlations

Figure 1. Percentage difference of tested values



Based on these test results we determined that a quality specification could be developed for archival media procurements, but that such a specification must include the recorder model and version id that would be used to record the media. The specification we dc'vc.lope.ci required a block error rate less than I (), no E32's and no Burst Errors Greater than Limit when tested on a CD-CATS tester. This specification was used in a large procurement and several vendors were disqualified based on CD-CATS tests of their media. '1'0 oor dismay, vendor re-testing of some of the discs on other CD-CATS devices produced block error measurements an order of magnitude smaller than those obtained on our tester. Recalibrating our lest device produced changes in some but not all of the test results (see '1'able 1). We still do not understand the reasons for these extrordinary differences. Perhaps they stem from the calibration procedures used for the vendor tests.

4.0 CD-ROM _ READER TESTING

Another goal of the CD-R evaluation was to investigate the compatibility of CD-R media with CD-ROM readers. Because of the differences in specifications of the Red Book and 01 ange Book, it is possible that readers designed to Red Book specifications will not perform optimally with Orange Book media. In particular, limits for reflectivity (which will effect signal strength) and push-pull (which may effect tracking) arc. extended

It was intended to conduct a thorough study of all the sample media with a variety Of CD-ROM readers and to perform longevity evaluations on the media. Unfortunately, we have not had the resources to carry out these tests. A large number of media from the evaluation have been supplied to the National Institute of Science and Technology for hazaradous environment and longevity testing, but no results have been released.

A limited evaluation of "defective" discs and commercial CD-ROM readers was conducted to determine if E32 errors reported by the test devices would produce real read errors. The layered error correction capability available for CD-ROM discs would be expected to correct some amount of the E32s found on discs. The data files on the discs were named with their approximate megabyte location so it was straightforward to associate the location of occurences of bad spots from the CD-CATS tests with file names on the discs. These "suspect" files were then copied with different CD-ROM readers using standard system utilities and the resulting files compared to the original. Most readers were able to successfully read the file contents. Some readers encountered unrecoverable read errors. it is our opinion from this test that some some CD-ROM reader vendors may not be incorperating layered error correction in their driver software. NOTE: Disc 5 was retested on another test device anti showed no E32 errors, which may account for why Reader 6 was able to read it successfully, but was not able to read any other discs with E32 errors.

Figure 2. Summary of Average Block Errors for all discs tested

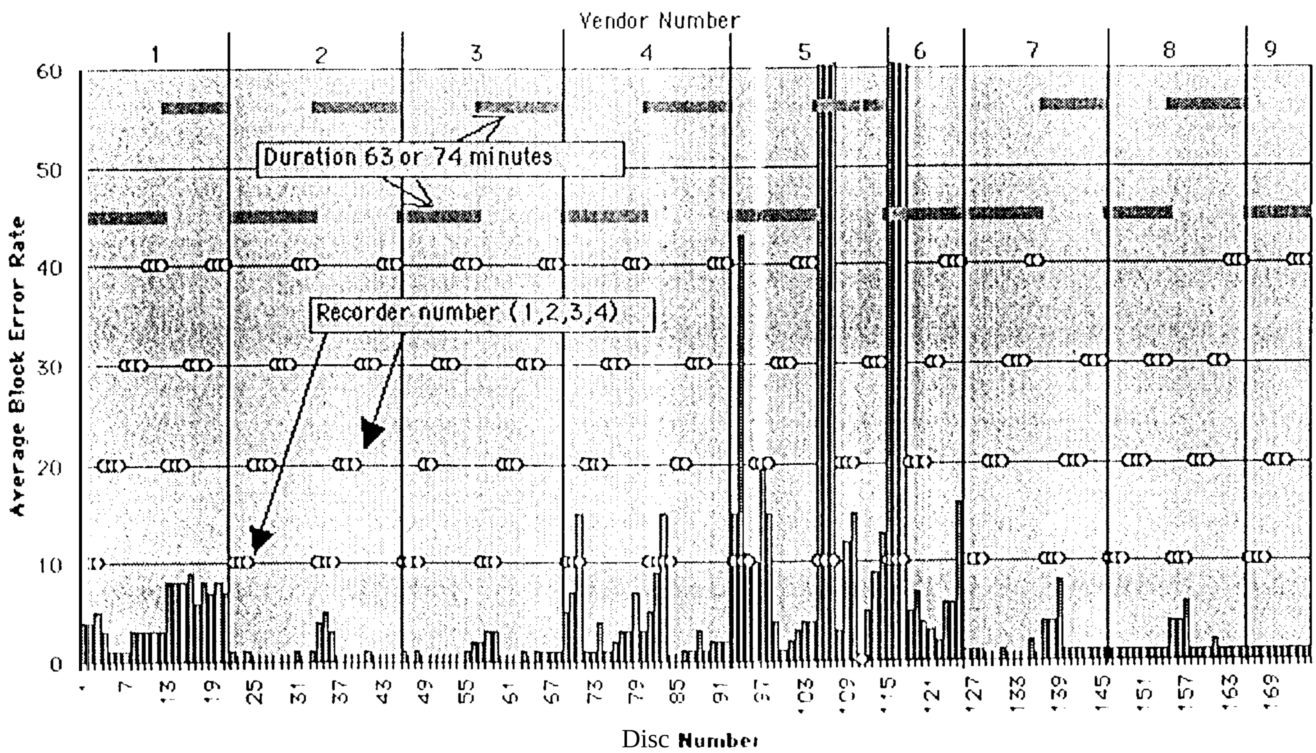


Table 1. BLER Test Results from Three CDCATS SA-3 Devices

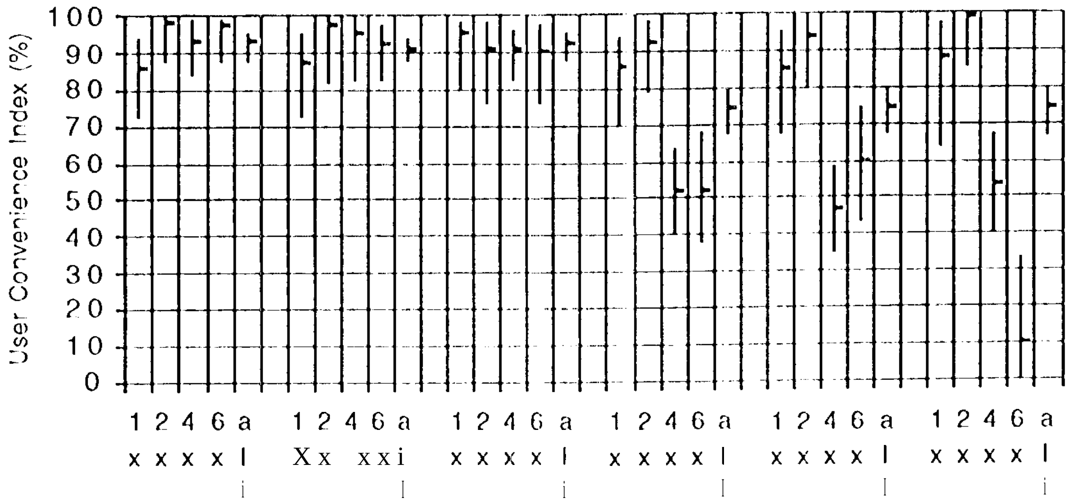
Disc Id	Tester #1	Tester #2	Tester #3	"Tester #3 (Recalibrated)
1	17	13	195	136
2	18	10	187	184
3	18	3	26	25
4	5	3	22	27
5	4	4	19	4
6	5	4	18	4
7	5	4	14	4

Table 2. CD-ROM Reader Test

Disc Number	Disc 1	Disc2	Disc3	Disc4	Disc5
Number of E32s	500000	300"	68	10	4
Reader 1 (1x)	OK	OK	OK	OK	OK
Reader 2 (1X)	ERROR	ERROR	OK	ERROR	OK
Reader 3 (2X)	OK	OK	ERROR	OK	OK
Reader 4 (2X)	OK	OK	OK	OK	OK
Reader s (3X)	ERROR	OK	OK	OK	OK
Reader 6 (4X)	FATAL	FATAL	FATAL	FATAL	OK

Kodak has carried out an extensive evaluation of media, recorders and CD-ROM readers. More than ?50 discs from six different vendors were written in ten different recorder/speed environments and tested on ten different readers. The results are summarized in Figure 3, providing an overall "user convenience" level for each media/recording speed combination. The six groups of results represent media from different CD-R vendors. The parameters used to produce this value include retries on insertion of the disc, data or file access retries, data miscompare on readback and excessive playback time. The figure reinforces the observation there are still substantial incompatibilites between media/recorder/reader combinations.

Figure 3. Media/Reader Convenience Levels



Another set of statistics provided by Kodak shows timing tests of discs recorded with various media. They show a wide range of read times for 2X readers from different vendors as well as some readers cycling down to lower read speeds. These statistics reflect our own experiences and we are concerned that the interplay of CD-ROM readers and CD-R media are not well understood.

5.0 CONCLUSIONS.

Given that the media study was conducted when the industry was in its infancy we feel that the overall performance of CD Rs from all vendors is exemplary. Every single byte of every single disc recorded in the study is recoverable, even when the discs are orders of magnitude beyond the Red Book specifications for BLER or E32 errors. We believe that existing test devices provide gross indications of the quality of CD-R media. We are not convinced that they provide information which might be required to predict the performance of a CD-R disc with CD-ROM readers.

We are very concerned with the wide range of performance of ('1) -ROM readers when reading CD-R media. We recommend that the industry develop a specification for CD-R readers that is tied to the differing specification of the Orange Book vs the Red Book. These readers may be of little interest [0 the consumer market but will be extremely important 10 the government community which will produce millions of archival CD-R discs over the rest of the decade.

While we did not conduct any longevity tests on the media from these tests, our media research leads us to recommend phthalocyan ine-based dye media for applications where longevity and resistance to heat or light exposure is important, but only if dout)lc-speed or higher speed recorders are used. If single speed recording is mandatory then we recommend cyanine dye-based media.

6.0 ACKNOWLEDG MENTS

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7.() REFERENCE

[I]Recordable Compact Disc System "Orange Book" standard from Philips and Sony
[2]Compact Disc Technology, Heitaro Nakajima, Hiroshi Ogawa, translation by Charles Aschmann, 10S Press, Inc., Burke, Virginia
[3] QA- 101 Compact Disc Analyzer Operating Manual Version 1.2; May 1, 1995; Clover Systems, Laguna Beach, Ca

APPENDI X A. CD-R MEDI A CHARA CTERI STICS

CD-ROM and CD-R discs are quite different media types. The CD-ROM master is produced using an expensive and technically sophisticated recorder (lathe) and the quality control of the replication process can be guaranteed to produce good results, JPL's Planetary Data System has delivered nearly 100,()()()" CD-ROMs to its customers without a single substantiated case of an unreadable. CD-ROM. The CD-ROM reader uses a laser beam 10 focus 011 the spiral of pits beneath the surface. of the disc. The pits arc less reflective than the. lands between them and the reader interprets the differences in reflectivity as the recorded signal. CD-R media is manufactured with a wobble groove (necessary for tracking during recording), with an organic dyc within the groove. The ('1)-1< recorder tracks the wobble groove and burns the dyc along the wobble groove, reducing the reflectivity along the groove. A CD-ROM reader senses these changes in reflectivity to track the recorded signal in the wobble groove and sense the differences in reflectivity as the recorded signal. '1'here are two major differences in specifications for CD-ROM and CD-R media which relate to these physical differences These arc the reflectivity (70 % for CD-ROM and 65% for CD-R and push-pull (.70 max for CD-ROM vs .90 for CD-R). Thus CD-R discs wili demand the same recognition of pits and lands from a CI)-ROM reader even though it is provided with a lower signal amplitude and more difficult tracking requirements.

Aside from these differences, other causes of errors in CD-Recordable media can be classified as manufacturing defects, handling defects and recording defects. WC. have seen manufacturing defects occasionally, including problems with printable coatings, scratches caused by disc labelling systems, and discs which can not track all the way to the outside edge of the disc. Handling defects (scratches, moisture, dust) can be avoided with modest precautions, in particular, operators should be warned to avoid sneezing on an unrecorded disc. Recording defects stem from the tracking servo mechanism, optimum laser power control (01'(') and the write strategy. These factors create jitter, asymmetry (or ß value), and peak shift which combine to translate into high block error rate.

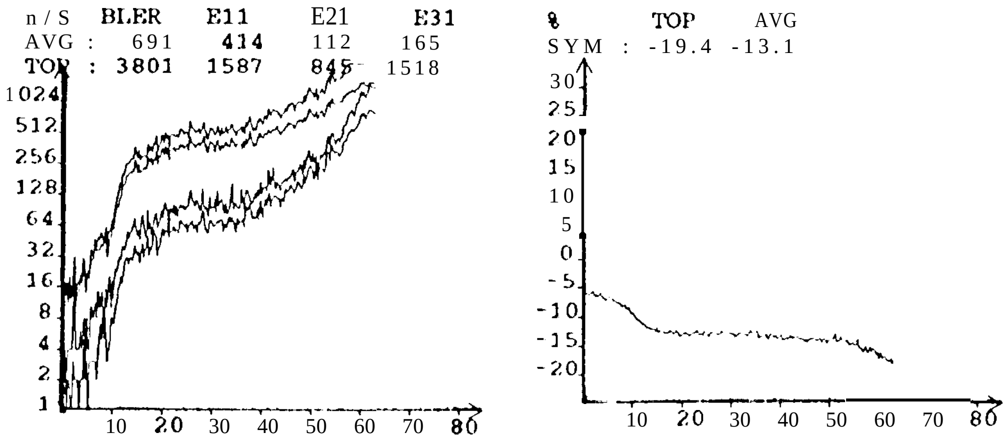
There are three major categories of CD-R media including data capacity (63 minute VS. 74 minute media), dye compound (phthalocyanine vs. cyanine-based dye), and value-added capabilities (printable or bar-coded media). Each category may influence the reliability of the media.

In our study 63 minute media have have a slightly lower BLER than 74 minute media (3. I vs 3.3 in our sample). This phenomenon is attributed 10 cleaner grooves and a better OPC process for 63 minute media. As can be seen in Figure 2, deviations in symmetry and high BLER are noticable toward the outside of the. disc. The optimum power control process is called "Running OPC". A "Running OPC" should work will with any types of media theoretically. It should also cope with changes in laser wavelength while writing a disc, media variations on the surface and disc warping. However, for earlier models of recorders we have notice.cf a run-away condition in the OPC which causes high asymmetry, especially for 74 minute media. Figure 4 shows an example of this phenemenon.

The pregroove in the disc is not a clean spiral but is wobbled with a specific amplitude and period. The 74 minute media requires a tighter period for the wobble groove and thus a lighter manufacturing specification. In the case of one of the single speed recorders there appears 10 be a deficiency in [racking a less than perfect wobble groove beyond 63 minutes.

The different dyes used by different vendors have an important impact on recording. Media with cyanine-based dye seems 10 work better with 1X recorders, while media using phthalocyanine-based dye seems 10 work better with 4X and 6X recorders. Both dyes are equally compatible with 2X recording. Phthalocyanine-based dye. works better with higher power lasers in the range of 6 to 8 mW while cyanine based dye works in the range of 5 to 7 mW. However, a high-speed recorder with a OPC process calibrated to cyanine-based dye showed as good result as phthalocyanine-based dye. One recommendation of the media study is to encode a dye type on media for recorders to recognize and to use the correct write-strategy. In Japan, OSJ (Orange nook Study Group in Japan) is proposing to put dye type and manufacturer type code in lead-in area to help to select an optimum write strategy and a ß value. This obviously requires a new type of a recorder which can adjust a recording power and a writing strategy.

Figure 4 BLER and Symmetry Vs. Recording Time



APPENDIX B. CD-R RECORDER CHARACTERISTICS

Several recorder related factors contributed to errors in our study and in follow-up testing on high-speed recorders. These include the recording speed, the optical power control process (described above), the write strategy (described above), and the disc recording sequence.

In general, high-speed recorders worked better with phthalocyanine-based dye over cyanine assuming both media types were manufactured under optimum conditions. They were also more susceptible to manufacturing defects such as poor groove or wobble, bad compound dye, or poor substrate. This may call for much tighter quality control in producing high speed recordable media.

Most discs written with a certain recorder showed E32 flags at 3, 63, and 74 minutes. The count of errors (102, 104) indicated that these errors were caused by link points and did not represent real data errors. Certain recorders write the program area, then the lead-in, and finally the lead-out in sequence which can result in slight overlap or gaps. These deviations can produce "E-32 errors" which are outside the data area and of no consequence when reading the disc. This does not happen to recorders which write "Disc at Once", where data is recorded from lead-in to lead-out at once without any overlap or gap. Another recorder wrote extra information for mastering purposes at the end Of lead-out causing some discs to running out of space and emit an error message even though it had recorded all 74 minutes of data successfully.

APPENDIX C. CD TESTER CHARACTERISTICS

There has been on-going controversy over two aspects of the CD-CATS devices used for our tests. These include the frequency of the clock recovery circuitry and the use of a single-beam player.

There is a difference in the clock recovery circuitry between CD-CATS devices and CD-Readers. As a disc rotates, there needs to be a mechanism to correct errors in rotation speed. The clock recovery circuitry detects these errors and corrects them. However, older audio CD players such as the one used in SA3 systems use 1.5 kHz circuitry instead of 2.5 kHz. Thus, it takes longer to correct a rotation speed error, and this causes higher BLER. Nearly all currently manufactured CD players (including audio players) use 2.5 kHz clock recovery circuitry. Therefore, it is possible that some BLER is introduced by the slow clock recovery circuitry and does not reflect true disc quality. However, having too stringent a test device should not be an major issue.

There is also a difference in CD-ROM player servo mechanisms of single-beam phase differential tracking (used in the CD-CATS device) vs. three-beam tracking. It would be expected that the wobble groove of the CD-R might be more challenging for a single-beam system to track, again potentially producing more errors when tested on the CD-CATS device.