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Digital Imaging in Conservation: File Storage

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The safest and most cost effective method of storing image files is to use a hard drive (HD). A modern HD will have a useful life of about 5 years before its size will become impossibly small (Moore's Law) and the data will be migrated to a new HD. Based on average MTBF data (mean time between failure), migration will occur long before the HD will fail. Even though MTBF data suggests otherwise, backup of primary storage is always recommended because the drive could fail before the predicted MTBF.

In the past CDs were considered archival, but experience has shown they have to be created carefully to be useful after 2.5 to 3 years [1]. Life expectancy (LE) predictions for optical media vary widely and are based upon multiple factors including: data density, layer bonding, dye and reflective layers and writing speed.

The current CDR manufacturing leader is MAM (formerly Mitsui), properly encoded, burned at a slow speed, Mitsui MAM-A Gold/Phthalocyanine CDR have a realistic functional life of about 15-50 years depending on storage and use, based on past NML data. DVD-R's have few independent performance records, but they are certainly not as stable as CDR because the density of data is about 6-times higher and they are not made with the most stable dye layer.

Optical disks hold only relatively small amounts of data for the effort required to make and certify the disks for archival use. Optical media is not as easy to migrate as External HDs. One just plugs in the External HD, drags the target folder(s) to the new HD and walks away while the file transfer proceeds. No additional action is required upon completion; file verification is integral to the process.

In time CDR and DVD-R drives will become obsolete. HDs will always be migrated forward, while HD formats change, the data is moved as a file. HD formats are not relevant if the HD is "always live," see below.

Recommendation
Purchase a new External HD every year, as you would a "brick" or two of film (20 rolls to a brick), for storage of the year's digital records. Backup last year's HD on this year's drive. Migrate data from older drives to a larger drive after 3 to 5 years. Notice that the purchase cost of a new HD each year is well below the cost of film and development it replaces. Any External HD can be used to back-up files on several computers or External HDs.

- new $150 External HD each year
- migrate old to new HD each year

Eventually, purchasing a new HD every year will become accepted digital documentation practice. A generic External HD in metal case with fan holding a 7200 RPM, 8-16 MB buffer, 250 GB HD is about $150; next year a 500 GB External HDs will be $150. Try using the Pricewatch website <<http://www.pricewatch.com/>> to find the best price for a HD, external case or External HD. Favor External HD enclosures that have an internal fan ($15 more expensive); metal cases transmit heat more efficiently than plastic.

Store image files as uncompress TIFF files, for the following reasons:

- **RGB values for each pixel**
- **Full spatial resolution of capture**
- **High bit depth possible**
- **250+ dedicated image tags**
- **Metadata capable**
- **Attached ICC profile(s)**

Discussion

If you are required to store your image files on an institutional server, your IT folks will give you problems over storing large uncompress TIFF and RAW files. Moving large files on an Ethernet is slow. With no other traffic on the network, Ethernet's 100Mb/s (12.5MB/s) is 20% the speed of USB 2.0 (480 Mb/s) and 12% of FireWire800 (100MB/s). In addition, uncompressed files take up a lot of expensive space on IT servers.

The only way around this problem is to store the full files locally, and send a JPEG version of the files to the IT folks to satisfy the requirements of your institution or the IT department. Fortunately, an automated routine to make JPEG image with a specific resolution, pixel width and degree of compression can be made and saved in Photoshop. Making the automated routine is similar to programming, so patients, attention to detail and debugging are required. Once created, it is used over and over. Whole group of TIFF images can have JPEG images made automatically using this process. The EMG will be posting step-by-step methods from making automated JPEG routines in Photoshop:

- **>File >Automate >Batch**
- **>File >Automate >Make Droplet**

IT Department

Many conservators are finding that the IT department has become the default curator of their images. The principal reason for this is that the IT department runs the servers that store institutional information, and, they often limit the purchase of computer equipment, forcing files to be held on their servers.

The IT Department has a very different set of working criteria than those needed for storing image files. The IT folks want small files so they can be moved around quickly on a standard Ethernet and served up quickly to the Internet. The large size of image files means they clog the Ethernet and take up a disproportionate amount of precious storage space on IT servers. The experience of the IT department is that text files can be compressed with no observable loss of information and that the heavily compressed JPEG images look fine on computer screens. They have little experience with, or appreciation for, the numerical RGB values behind the screen color in a TIFF file.

Compressing image files destroys information that cannot be restored later. Experts do not recommend image file compression. LZW lossless compression of TIFF files decreases size by no more than 30%, and often only 3-10%, depending of subject matter. This compression rate is of little value when TIFF files are 100 -1000 times the size of a JPEG file. The true value of a TIFF image is the RGB color numbers that are attached to each pixel. While this data cannot be seen on the screen or in a print, it is of immense added value over film that misrepresents color and has no numerical data that is potentially traceable to the actual color in the image. More information on this topic was presented at the AIC 2005 General Session in a paper titled, “Getting the Most from a TIFF Image,” and available in the AIC EMG Library <http://aic.stanford.edu/sg/emg/library/presentations/formats/vitale/2005-06-vitale-documentation-tiff-image/>. Also see Image “File Formats: TIFF, JPEG and JPEG2000” in the EMG Library at<http://aic.stanford.edu/sg/emg/library/pdf/vitale/2006-01-vitale-digital_image_file_formats.pdf>.

In many cases an IT Department will be using older equipment because it can still serve up information at accustomed rates. A simple solution might be to increase the storage capabilities of these older servers. However, increasing storage on older IT equipment is expensive; although modern servers can add a Terabyte (TB) for about $10K, 5-year-old equipment will cost $250K to add a TB and 10-year-old technology would run about $½ -1M.

A direct solution is to store full-sized TIFF image files locally, while sending a JPEG version to the IT Department. This satisfies institutional requirements, saves IT staff time and forestalling expensive upgrades to older IT equipment. An automated routine for making JPEG images with a specific resolution, pixel width and degree of compression can be made and saved in Photoshop (see notes at end).

Negotiating with the IT department to store TIFF image files locally will require sophistication and cunning similar to that used to keep fragile artworks from travel or display. Remember to:

- **Offer to make the JPEG yourself**
- **Use your budget for local HD storage**
- **Stress the color fidelity of the RGB numerical values**
- **Stress that you are saving IT staff time and money**

The Photography Departments at some institution have adopted digital for all photography applications, and have eliminated film altogether. This move requires all new equipment including cameras, film scanners and computers with more RAM and larger HDs. The size of these expenditures ($100-250K) has focused the IT Department on the needs of photographers. Photographers are specifying TIFF image files, with attached ICC profile and metadata (to varying degrees). In addition, many institutions are adopting institutional storage of the large numbers of, large-sized image files in modern multi-TB file servers. The large TIFF or RAW files are generated from (1) drum and flatbed scanners (40 MB to 3 GB), (2) digital scanning backs (200-1500 MB files); (3) medium-format digital backs (60-160 MB), as well as (4) standard 20-120 MB files from DSLRs. Transfer of the image files from an IT location to the Photography and Publication departments often involves installing a new, dedicated Gig-Ethernet (Giganet) network. A Giganet can range in speed from 1000 Mb/s (10x Ethernet) over wire (Category 5e, 4-twisted pair, wire <http://www.lanshack.com/cat5e-tutorial.asp>), up to 10Gb/s (100x Ethernet) to even 16 Gb/s both over optical fiber <http://www.lanshack.com/fiber-optic-tutorial.asp>. Sometimes this large bandwidth link is merely a short branch on an existing university backbone, which is already fiber. However, this new network is often attached to new file servers with large storage in a new location. Optimistic conservators are suggesting that this new commitment to imaging by some institutions will, in time, bring an understanding of image technology to all IT Departments, and then to the average user.

Internal and External Hard Drives

Most computer boxes have space for one to two additional internal HDs. One could add two internal SATA, 7200 RPM, 500GB HDs (1 TB) with 16 MB buffer for $800; this makes phenomenal economic sense. Buying large HDs from the computer vendor will be easier, but will cost you about 100% more (think "options" at the auto dealer). There is nothing easier than adding a HD to an existing computer.

External HDs are just a HD in a powered external case. Enclosures can be of three types: FireWire, USB or a combination of both FireWire and USB. The size of the HD is also significant: a 2.5" HD (more expensive HD used in laptops), often called "Pocket HD" can run from USB or FireWire bus power (greater battery drain on notebooks, however) while the larger 3.5" drives require larger enclosures with external power supplies (and a fan, if lucky). Pocket External HDs (think iPod) are easier to use but cost about 100% more. There are numerous online sources to explain the port speeds and advantages; but computers that originally supported USB 1.0, 10Mb/s, (very slow, 1.25MB/s) and FireWire400 (50 MB/s) cannot support the faster second generation port speeds without the upgrade of an internal PCI card, or PC card (notebook). If you don't know, assume the slower speed and add an extra $50-100 to your budget.

Because FireWire has peer-to-peer architecture it will perform better, especially when multiple drives are attached. USB connectivity is more common, so will be simpler to use when you need to share files with someone else.

While transferring a whole HD has never been easier using FireWire800 (100 MB/s) or USB 2.0 at 480 Mb/s (60 MB/s), moving 250 GB of files will still take hours depending on your computer's internals.

If an external HD should fail to work, check the power transformer because they fail more often than the HD, and swap out the cable from your backup supply of 2-3 extra cables. Cable failure is much more common than any other problem.
The most desirable external image storage solution is to use what digital videographers have been using for a few years: a dedicated External RAID Array running in the RAID 3 or 5 mode. The use of a modern RAID Array will generally get the attention of your IT department because it is similar to their technology, prudent redundant storage and more economical than past incarnations, which could cost thousands of dollars for a few tens of GBs of storage when using expensive SCSI dives internally. Today's RAID Arrays use inexpensive but reliable SATA or EIDE drives internally and start at $1300.

Longevity of Hard Drives

Most modern HDs have a rating of 100,000+ hours MTBF, about 11 years of continuous use, with a 5-year warranty (about half MTBF). Most HDs have MTBF data on the label physically attached to the HD; this information is commonly not found online. Modern HDs use liquid bearings and other technology to increase life substantially. Many Maxtor, Seagate and Hitachi SATA drives have a predicted life of 100,000 (11 yrs) to 600,000 hours (69 yrs); some are far higher. Some of the largest MTBF numbers I've seen are for the Seagate Cheetah 15K.4 series: 1.4 MHr (million hours between failure), 160 yrs<http://www.seagate.com/cda/newsinfo/newsroom/releases/article/0,1121,2168,00.html>.

Only 10 years ago HDs had a real life of 3 years, or less. I have used at least 25 HDs since 2000, and have not had a failure in 5 years. The HDs were migrated and retired, as too small, or they are still active. It is expected that in 5 years, HDs will have tens-of-TB capacities; this will make today's 250 GB HDs impossibly small, and therefore, inefficient in a computer or external enclosure. Expected increases in capacity and ease of transfer make the use of HD's a most efficient storage system for large files such as images.

RAID Array Systems
Consider using a RAID Array <<http://en.wikipedia.org/wiki/Redundant_array_of_independent_disks>> for image storage. RAID 0 uses all drives in the array for storage while RAID 5 uses one drive for parity storage (80% total capacity), but it can rebuild a failed drive from the redundant information. The redundant distribution of the data around a mode 3 or 5 array will allow reconstitution of the lost data when the failed drive is replaced (about $150-350).

HUGE System's SCSI RAID (0/3/5) array uses an SATA internal bus and a 320 UltraSCSI interface with the computer <<http://www.hugesystems.com/Products/>>. They use inexpensively SATA drives with 150-325 MB/s bus speed. The 320 UltraSCSI interface maintains a sustained 200 MB/s transfer rate with your computer. The 800 GB-version of the SCSI external RAID (0/3/5) Array is about $2500 and the 4.2 TB-version is about $10,000, but prices are dropping monthly. Each array appears as one drive on your computer and has a programmable RAID controller that takes care of formatting, striping, RAID functions and built-in diagnostics to monitor performance and health. A less expensive solution is the LeCie F800 external FireWire RAID Array (0/0+1/5). The 1 TB-version is $1300 and uses four internal 250 GB drives. The 1.6 TB-version costs $1700 and uses four 400 GB drives.

For the conservator in private practice, Anthology Systems has just announced its NAS (network attached storage) "Yellow Machine" with RAID 0, 0+1,1 & 5 Array with integral LAN switch using eight 12.5 MB/s (100 Mb/s) LAN ports, firewall and more. The 1 TB version is $1300, and the 1.6 TB version is $2000 <https://www.anthologysolutions.com/products/index.htm>. There is also a nice description of RAID configurations in PDF. It is significantly slower than USB and FireWire port systems because it is based on 10/100 Ethernet (12.5 MB/s) architecture.

CD and DVD Optical Storage
There are differing opinions concerning the life expectancy (LE) of optical discs. In 1996 the NML rated the average CDR at 2.5 years LE, these 10-year-old predictions have proved correct for some of the older CDR.

Joe Iraci (CCI Senior Scientist) rates the **average modern CDR** at 15 years; this has yet to be tested by time. The average CDR is assumed by Iraci to have a Phthalocyanine (green) dye layer with silver-colored backing and burned at 48x without verification.

I have several CDR that failed within 3-5 years. I also have many more CDR that are older and remain readable; the difference is that I "believe" that they are on borrowed time and have therefore backed-up the information on HDs. Odd twist, isn't it.

The NML electronic media longevity data did not remain online, and all copies were purged from the web, after manufactures objected following publication of their findings in a February 1998 US News & World Report article.*** Mitsui predicts 100+ years for their Gold DVD-R <http://www.datadirectinc.com/Products/Media/dvd-rMedia/mitsuiDVD-R.htm> not using Phthalocyanine dye layer.

With their higher data density, their DVD-R probably have a longevity that is about a third that of the Mitsui Gold CDR, or 5-17 years.

Both CDR and DVD-R have much less longevity than predicted by their manufactures. Kodak Ultima CDR, Gold-on-Gold and Silver-on-Gold with Phthalocyanine dye layer, were rated by Kodak at 217+ and 100+ years respectively [3]. The NML predicted 50 and 25 years LE, respectively [2]. The Kodak Gold-on-Gold CDR were discontinued as too expensive to make, but the Ultima Silver-on-Gold are still available. MAM (formerly Mitsui) the industry leader, rate their Gold/Phthalocyanine CDR at 300+ years <http://www.mam-a.com/technology/quality/longevity.htm>but their actual life is probably no more than 50 years. MAM predicts 100+ years for their Gold DVD-R but the actual longevity is probably 15+ years (three times less than CDR) because of higher density (6x higher) and lack of a Phthalocyanine dye layer. Many other media distributors relabel MAM disks; check the AMIA-L listserv for details.

There is no doubt that the CDR and DVD-R recording process can be made quite reliable with:

- **Outside testing of your system (optical disk test service)**
- **Slow write speeds of 2X - 8X**
- **Reliable media such as Kodak or MAM (or resellers)**
- **Phthalocyanine dye layer**
- **Gold reflective layer**
- **Committed technician**

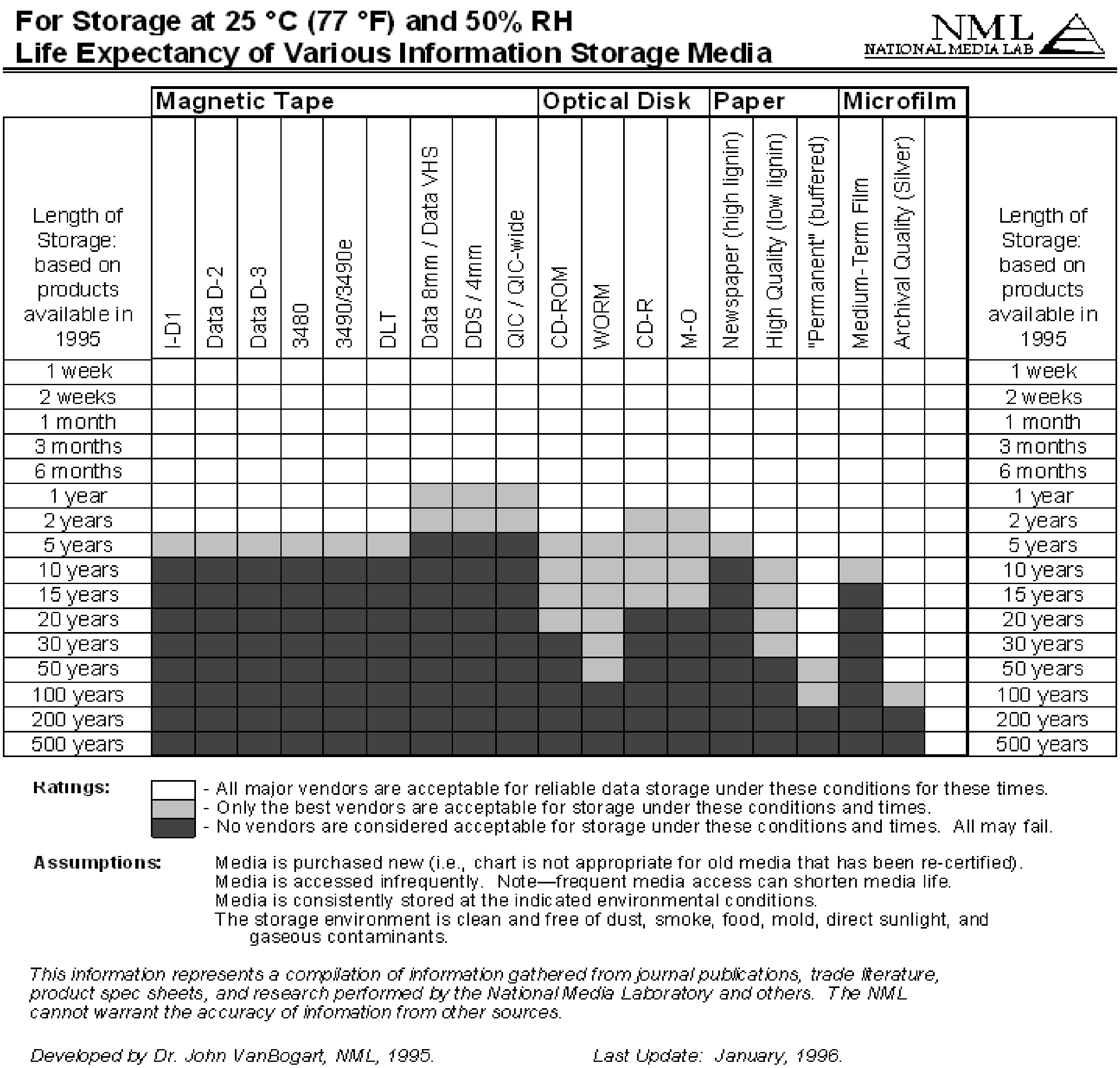
Hard Drives Always Live

Always live, is the current accepted best practice. Live means connected to a computer or a server; always accessible; always on and active. The key is to keep the HD as cool as possible. Metal enclosures transfer heat better than plastic. Stand an external case on edge with space all around. Favor larger enclosures with an internal fan, or multiple fans, even in single drive enclosures. One of the RAID systems above has multiple fans with excellent cooling capacity because it is meant for the continuous transfer of video data at 1.6 Gb/s.

Both CDR and DVD-R have much less life than predicted by their manufactures. The National Media Lab (1998), before they closed there website, rated the average CDR at 2.5 years LE. High quality media such as Kodak Ultima CDR, Gold-on-Gold and Silver-on Gold, with Phthalocyanine dye layer were rated at 25 & 50* years LE. Kodak rated them at 100+ and 217+ years** respectively, if memory serves correctly. Kodak Silver-on-Gold Ultima CDRs are still available with 25 years LE. Mitsui rate their CDR at 300 years <http://www.mam-a.com/technology/quality/longevity.htm> their actual life is probably no more than 15-50 years.

The NML electronic media longevity data did not remain online, and all copies were purged from the web, after manufactures objected following publication of their findings in a February 1998 US News & World Report article.*** Mitsui predicts 100+ years for their Gold DVD-R <http://www.datadirectinc.com/Products/Media/dvd-rMedia/mitsuiDVD-R.htm> not using Phthalocyanine dye layer. With their higher data density, their DVD-R probably have a longevity that is about a third that of the Mitsui Gold CDR, or 5-17 years.

A 1996 saved copy (thanks to Joe Iraci) of one of the relevant NML web page follows; the version where products are named has yet to be relocated:



Joe Iraci <Joe_Iraci@PCH.GC.CA> Senior Conservation Scientist at CCI has been evaluating optical disk technology for many years. He is a champion of optical disk technology and has developed methodologies for getting the longest life from CDR and DVD-R disks. He has a new article "*The Relative Stabilities of Optical Disc Formats*" in Restaurator: Vol. 26, No. 2 (2005) <http://www.uni-muenster.de/Forum-Bestandserhaltung/downloads/iraci.pdf>.

From a 2005 talk by Joe Iraci on "*Preserving and Retrieving Electronic Records*:" <http://mla.blogspot.com/2005/05/preserving-and-retrieving-electronic.html> the following scale of optical media reliability:

Joe Iraci's Optical Media Relative Stability Scale:

More Stable

CD-R (gold metal layer)
CD-R (silver alloy metal layer)
CD (read only)
DVD (movie disc)
DVD-R
CD-RW
CD-R (azo dye)
CD-R (cyanine dye)

Less Stable

CDR Longevity Web References

In a report on CDR quality <http://www.mscience.com/survey.html>, from a reliable CDR media testing service <http://www.mscience.com>, the following quotes:

"CD-R recording is a sophisticated process involving many components that can result in highly variable quality. Discs, writers, system hardware and software, and recording software can degrade quality. Extensive error correction methods in read drives can mask severe flaws; therefore, readability alone does not predict interchange and longevity. Quality can be established and maintained only through in-depth testing using properly calibrated equipment and trained personnel."

"**Lot A**, tested in 1998, consisted of 23 samples of 74 minute discs from seven different experienced manufacturers. Cyanine dye (green with gold metal or blue with silver metal) samples from Denon, Verbatim, Taiyo Yuden, and TDK were evaluated. Phthalocyanine (gold) samples from Kodak, Mitsui Toatsu, and Ricoh were tested. Ten discs passed, six were marginal, and seven discs failed."

"**Lot B**, also tested in 1998, contained twelve samples of 74 minute green discs from six manufacturers, generally from the Asia-Pacific region, including Anton, CMC, KAO, Lead Data, Mega Media, and Ritek. One disc passed, seven were marginal, and four discs failed. "

"**Lot C** used six samples of 63-minute discs manufactured by Mitsui Toatsu and TDK. These potentially had of higher quality because of lower data density associated with higher linear track velocity. All six discs passed."

"**Lot D** tests during 1999 and 2000 used 87 samples from 17 different manufacturers, adding 80 min. discs, silver discs, and 8X recording. Fifteen samples were from manufacturers represented in Lot A; seven passed, six were marginal, and two failed, one for jitter and one for length deviation. Seventy-two were from manufacturers typical of Lot B; eleven passed, 18 were marginal, and 43 failed, mostly for high radial tracking and jitter."

From a related essay on CDR <http://www.mscience.com/cdrfail.html> the following quote:

"Confidence in CD-R interchange and longevity requires comprehensive logical, visual, mechanical, and electrical testing. BLER is often mistakenly identified as the single most important quality indicator. This survey indicated that BLER tests alone would have detected only 19% of the field failures. Forty percent would have been detected by uncorrectable error tests, while the combination of jitter and uncorrectable error testing would have detected 55% of the field failures. In the absence of format, mechanical, and visual inspection, only 64% of the discs having defects would have been identified using electrical parameter and error tests alone."

CoOL has a well stocked section devoted to optical media including CDs:
<http://palimpsest.stanford.edu/bytopic/electronic-records/electronic-storage-media/>

Be sure to check the Kodak FAQ on their Ultima CDRs for valuable information on the "proven" best CDR media. Go to the lower section, titled "General Information," item #8 and below: <http://kodak.com/cluster/global/en/service/faqs/faq1630.shtml>. Note that in the Byers report below, the current version of the Kodak Ultima (silver) can be compromised by sulfide pollution.

NIST (also CLIR) report by Fred Byers on care and storage of CD and DVD media:
<http://www.itl.nist.gov/div895/carefordisc/CDandDVDCareandHandlingGuide.pdf>

The trade organization for the optical disks has a 1997 PDF with generic data and many references: <http://www.osta.org/technology/pdf/cdr_qa.pdf>

DVD-R Longevity Web References

See the excellent "***NIST Guide Care and Handling Guide to CD and DVD***:"
<http://www.itl.nist.gov/div895/carefordisc/CDandDVDCareandHandlingGuide.pdf>
and O.T. Slattery, 2004: "***Drive Compatibility Test, Phase 2***" CDR and DVD-R guide, Phase1 seems not to be published online: <http://www.itl.nist.gov/div895/docs/NIST-SP500-258.pdf>

Mitsui, MAM, host a page which shows the history of DVD formats and compatibility:
<http://www.mam-a.com/technology/dvd/index.html>

It is interesting to note the Mitsui DVD-R do not list a specific dye for the recording material, which is Phthalocyanine dye on their CDR: <http://www.mam-a.com/technology/dvd/specifications.html>.

Joe Iraci has posted the following on the AMIA-L listserv:
"I did have confirmation at one point from a MAM rep.[resentative] that the DVD-R discs do not use Phthalocyanine dye. Initially, they did not use gold metal reflective layer either, but now gold metal discs are available. Because the dye is not Phthalocyanine, this may be the reason why CD-R gold longevity is 300 years (according to the manufacturer) and DVD-R longevity is only 100 years (according to the manufacturer). Delkin discs are manufactured by MAM and rebranded for distribution."

Here are some recent references on DVD-R longevity in the Video literature:
(1) Are DVD's Archival? <http://videosystems.com/e-newsletters/Are_DVDs_Archival082505/>. One quote: "An accelerated aging study at NIST estimated the life expectancy of one type of DVD-R for authoring disc to be 30 years if stored at 25 degrees C (77 degrees F) and 50% relative humidity."
I have been unable to find the NIST reference.

(2) Second article in the series: "Archival DVDs, Part 2" <http://videosystems.com/e-newsletters/Archival_DVDs_Good_as_Gold090905/>. On DVD longevity by Joe Iraci: <http://palimpsest.stanford.edu/byform/mailing-lists/amia-l/2003/04/msg00082.html>, two quotes from the email:

"Lifetime predictions for CD and DVD media are few and almost all data is manufacturer based. There are standard test methods that can be used to predict lifetimes (CD-ROM, CD-R, MO), but these tests require the proper chambers and time (up to six months for the lower temperature aging). The value of performing these tests is very much in question considering how rapidly products change. Therefore, any results obtained will have limited value…"

"…Disc longevity can be very short (less than 10 years) if all the variables above are not followed or predicted to be long (>100 years) if the recommendations are followed. Of course, this discussion does not include storage and handling and disaster preparedness which all play a significant role in longevity."

Joe Iraci announced the publication of "***The Relative Stabilities of Optical Disc Formats***" has been published in **Restaurator** Vol. 26, No. 2 (2005). This paper summarizes his research that compared the stabilities of a variety of optical disc formats such as audio CDs, CD-Rs, CD-RWs, DVDs, DVD-Rs, and DVD-RWs. This article is not yet available on line.

Footnotes for *Storage of Image Files*

[1] Note: Iraci predicts 15-year life for the average CDR burned at 48x on the average burner, and 50 years for Gold/Phthalocyanine media. The average CDR is similar to those offered the typical "office box" on spindles of 50-100. From a private email communication October 2005, direct quote disallowed.

[2] Note: From a 1995 essay by Kodak <http://www.cd-info.com/CDIC/Technology/CD-R/Media/Kodak.html> "That model predicts (at the 95% confidence level) that 95% of properly recorded discs stored at the recommended dark storage condition (25°C, 40% RH) will have a lifetime of greater than 217 years."

[3] Note: In a Van Bogart letter to the editor <http://www.cd-info.com/CDIC/Industry/news/letter-190298.html> "The NML chart shows that best quality CD-ROM media would be suitable for storing information for 50 years, but not for 100 years. Correctly read, this indicates that the life expectancy of this media is between 50 and 100 years." He was referring to the Kodak Ultima Gold-on-Gold media, which was discontinued and replaced by Silver-on-Gold that have half the performance of Gold-on-Gold.

[4] Note: For an overview of the NML/Van Bogart controversy see: <http://www.cd-info.com/CDIC/History/Commentary/Parker/stcroix.html> and <http://www.cd-info.com/CDIC/Industry/news/media-chronology.html> and <http://www.cd-info.com/CDIC/Industry/news/email-280498.html>.

A PowerPoint presentation by Van Bogart in June 1998, go to slide 4:
<http://ssdoo.gsfc.nasa.gov/nost/isoas/dads/presentations/VanBogart/VanBogart-Unabridged.ppt>

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