Technical Report of ISO/IEC 10995 Test Program of the M-DISC Archival DVD Media

June, 2013

With the introduction of the M-DISC family of inorganic optical media, Traxdata set the standard for permanent digital data storage. As part of its commitment to setting and maintaining the highest possible standards for the longevity performance of DVD, and other types of optical media, test laboratory performed a series of tests of its M-Disc DVD conforming to the ISO/IEC 10995 Standard. This technical test report documents the results of these tests.

The scientific basis for the ISO/IEC 10995 Standard lifetime test is centered on the well-known Arrhenius and Eyring equations. These equations capture the kinetics of chemical reaction rates with regards to temperature. The Eyring equation can also be extended to include other factors such as relative humidity. These theories have long been established as an accurate method to predict long-term behavior based upon short-term testing for a variety of products. This approach is relied upon in the electronics, computer, defense, automotive, medical products and many other fields.

One of the key requirements of a scientifically valid test is the use of more than one Temperature and Humidity (T/H) condition. If only one T/H condition is used, it is not possible to fully define the chemical reaction kinetics. Therefore, it is not possible for a single, simple test to enable lifetime predictions under other, less aggressive T/H conditions. A valid test program should include at least three temperature and three humidity conditions to more fully define the behavior of the chemical reactions under all storage conditions. The ISO/IEC 10995 Standard specifies four test conditions.

Test Setup

The lifetime study conducted at the test laboratory (and reported here) followed the strict guidelines and standards that are defined in the ISO/IEC 10995 test specification. The sole variation from the method was to shorten the incubation period for each stress condition during the first few test intervals of the study. This was done to better understand any changes to the discs that might occur in the early stages of the test. The test conditions are summarized in table 1 below. (A minimum of 20 samples were tested under each stress condition to assure statistical validity of the final results in compliance with the ISO/IEC 10995 Standard).

Test Number	Test Stress Condition		Number of Specimens	Incubation Duration	Time Completed
	Temp °C	%RH		Hours	Hours
1	85	85	20	100-250	650
2	85	70	20	100-250	1150
3	65	85	30	100-250	2100
4	70	75	20	100-250	2500

Table 1 ISO/IEC 10995 Test Condition Summary

Results of the Lifetime Study

Key performance metrics measured on the test samples included Normalized Modulation, DC Jitter, and PIE Sum 8 Maximum. The ISO/IEC 10995 specification limits the method for determining projected lifetime of optical media to the evaluation of the PIE Sum 8 Maximum results. However, we found that the Normalized Modulation and the DC Jitter were also strongly indicative of overall disc quality. Each of these key values was measured initially and at the conclusion of each test interval for each disc in each of the four specified stress conditions. In addition, many other parameters were also measured. After the study was completed and the data analyzed, these three performance metrics were identified as being of the most interest and are therefore included in this report.

Measurements for this test series were taken using an AudioDev CATS DVD-Pro module and the applicable software. The module was regularly calibrated, and was found to have good repeatability in all measurements. The DC Jitter results showed a small mean shift from other, similar tools, but were very repeatable.

Normalized Modulation

Normalized Modulation is a measure derived from the reflectivity of the DVD in the written area. This is directly related to the capability of the drive reading the disc to recognize a signal from the written track. This value must be greater that 0.60 (60%) to be within the standard DVD-R/+R specification. If this value drops below 60%, the ability of a drive to read the disc may become impaired. Typical manufacturing variability will result in some drives that will read discs with a Normalized Modulation below 60%, however this capability cannot be relied upon.

The behavior of the M-Disc in this test is different from that observed when testing typical organic dye-based DVD-R discs. The typical (organic) disc will generally begin with Normalized Modulation in specification then show a steady decrease until the end of the test. For the M-Disc the Normalized Modulation begins the test above the required limit, shows an initial improvement in performance, then completes the testing with very little additional change.

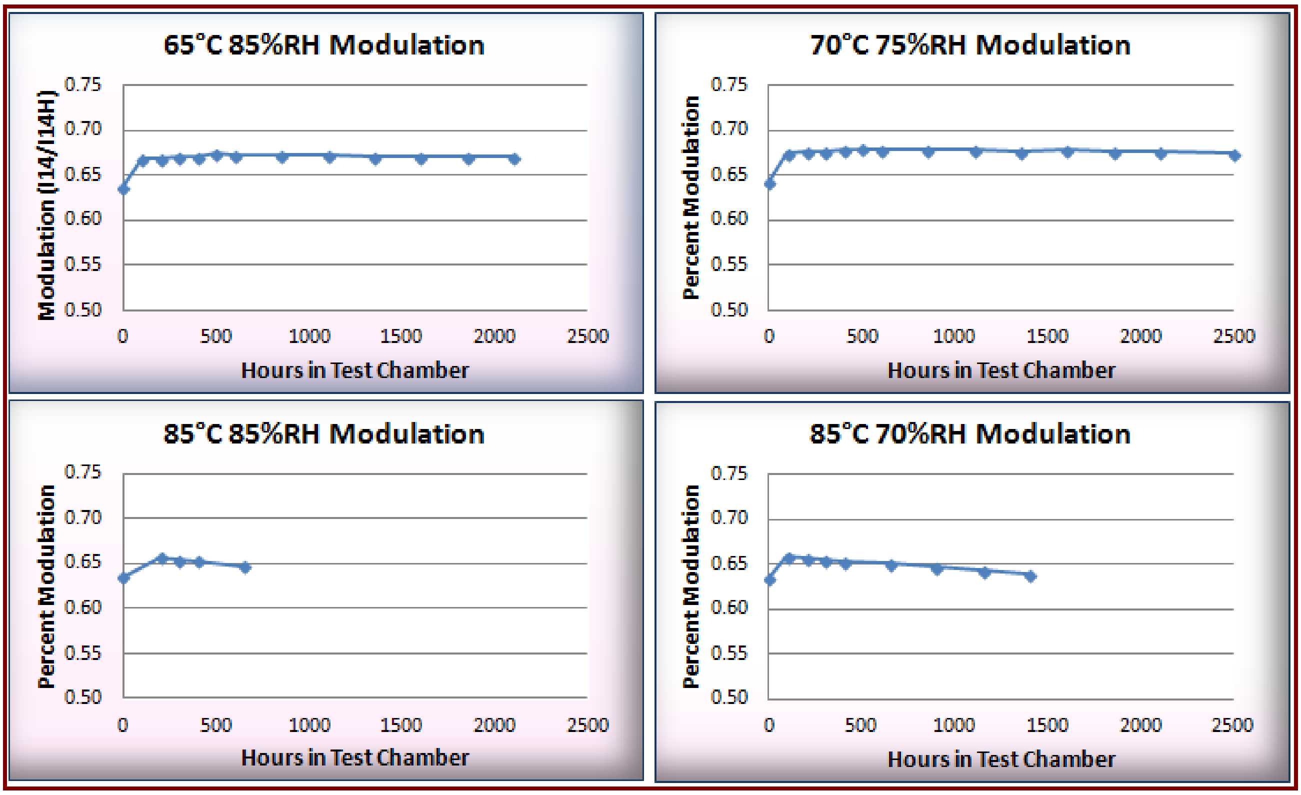


Figure 1: Normalized Modulation

In Figure 1 above we show the average of all the individual Normalized Modulation results for each stress condition. As can be seen, even when testing under the most extreme conditions, the Normalized Modulation does not fall below the specified 60% limit.

DC Jitter

DC Jitter is a measure of the variation in the beginning and end position of the data marks recorded by the laser on the written disc. The specified upper limit on a newly written disc is 9%. While an increase in DC Jitter does not directly imply a data read error, as Jitter increases, the ability of a drive to correctly determine the timing relationships of the data marks will become impaired and the digital errors will increase.

Measured values for DC Jitter were found to be highly dependent on the measurement device used to evaluate the discs. For example, the same disc might have a DC Jitter of 6.5% on measurement device "A" and 8.8% on measurement device "B".

Given the significant variation in the magnitude of the DC Jitter results even between different modules on the same DVD-CATS device, we found that it was most valuable to measure all the discs on the same module, and to report the change or delta in the DC Jitter value as the test progressed. Average values for the delta in the DC Jitter results from each stress condition are shown in Figure 2 below:

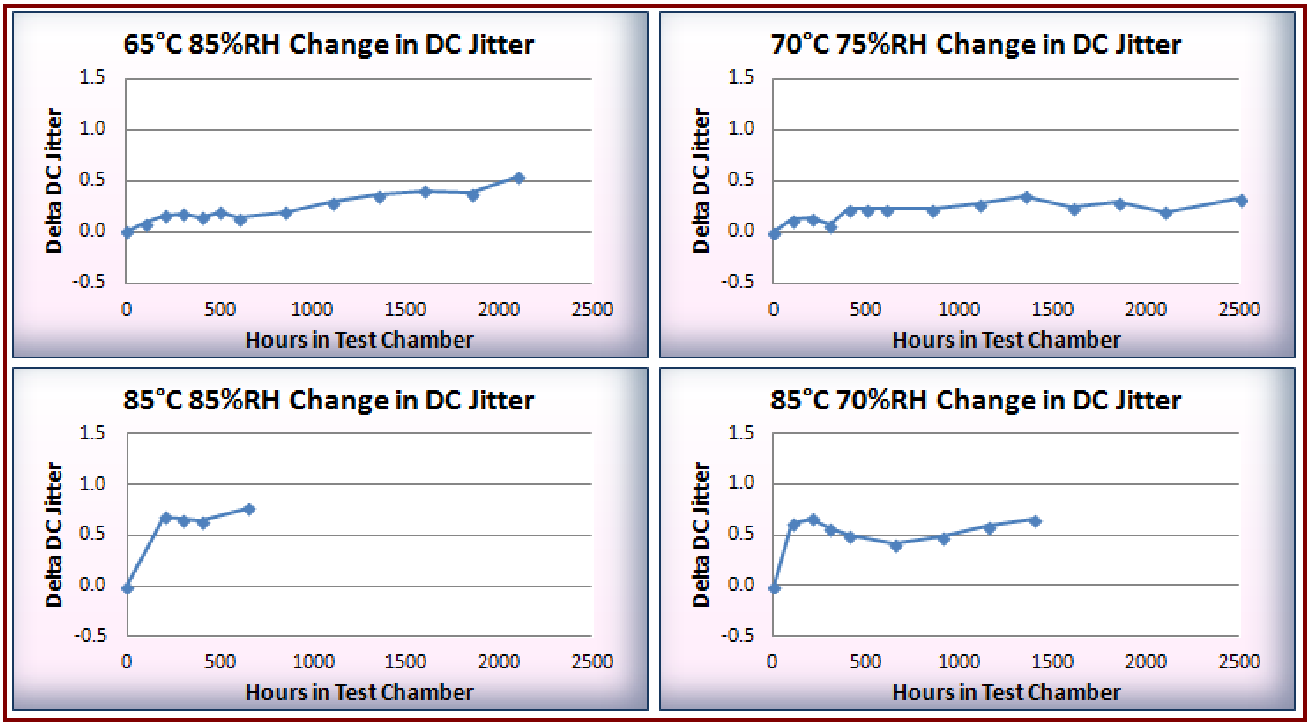


Figure 2: Delta DC Jitter

As can be seen in Figure 2 above, the DC Jitter for the M-Disc show a total change through all the testing of less than 0.75%. This indicates a remarkable level of stability in the critical write-layers on the disc.

PIE Sum 8 Maximum

PIE Sum 8 Maximum is a measure of the data read error rate for a DVD disc. The limit value specified in the ISO/IEC 10995 Standard is 280. All DVDs have a measurable error rate that is usually automatically corrected by the drive using the error correction encoding designed into the DVD. While the typical DVD player will successfully read and correct errors on a disc with several times the 280 error rate, this value is specified in the ISO/IE 10995 Standard. Also note that the PIE Sum 8 values used are the maximum for each disc, not the disc average values.

In order to understand the over-all behavior of the PIE Sum 8 Maximum values during the course of the study, the average value of PIE Sum 8 Maximum for all the discs at each stress condition (over time) is shown in Figure 3 below. Each of these curves represents a large number of discrete data points.

As expected, the PIE Sum 8 Maximum values increase more rapidly for the discs subjected to the more aggressive temperature and humidity conditions. The discs in the lower-stress conditions do not exceed the 280 threshold at any time during the entire test period specified by the ISO/IEC 10995 Standard. This means that a curve must be fit to the data, and a failure time projected for each of the discs in the lower stress condition tests as part of the data analysis process reported below:

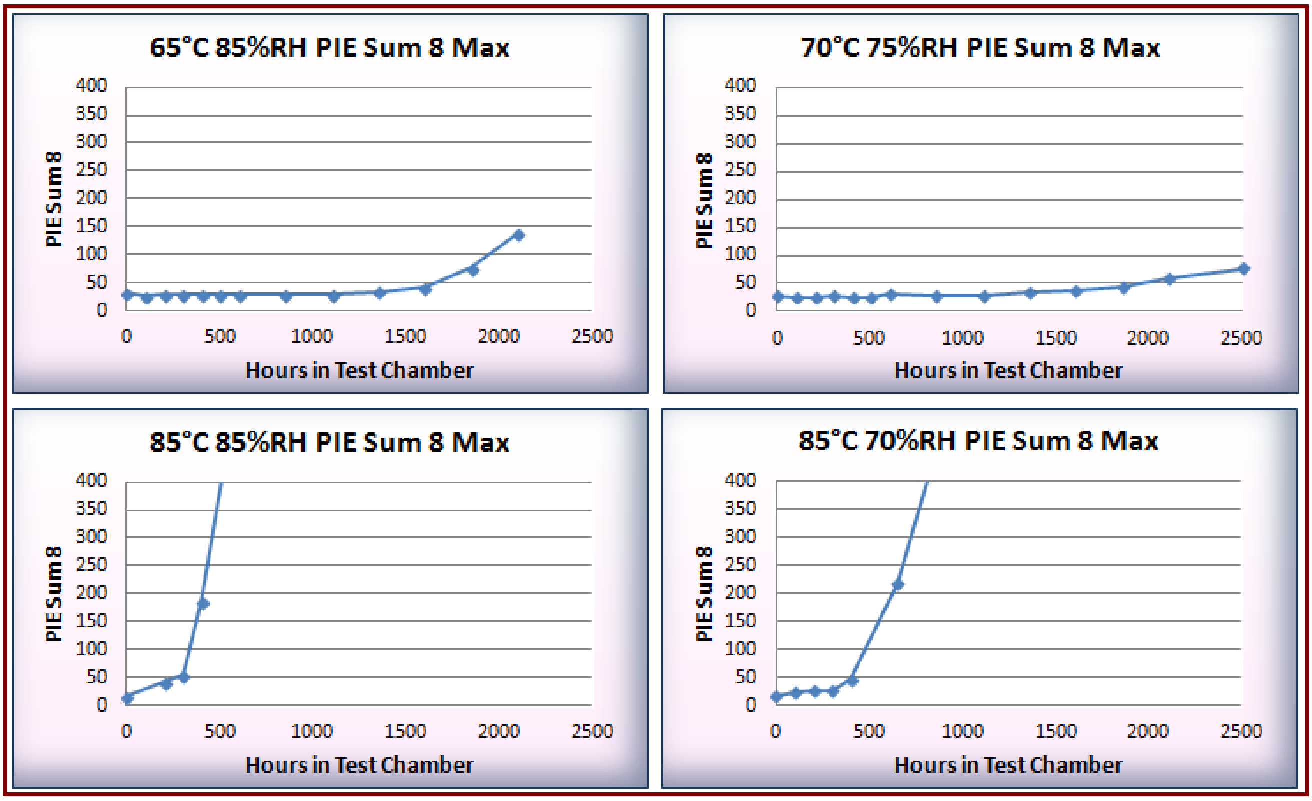


Figure 3: PIE Sum 8 Maximum

The PIE Sum 8 Maximum data is used to project a data lifetime for the discs under normal storage conditions. Normal storage conditions are generally accepted as 25°C and 50% Relative Humidity. The method used for this projection is defined in the ISO/IEC 10995 specification.

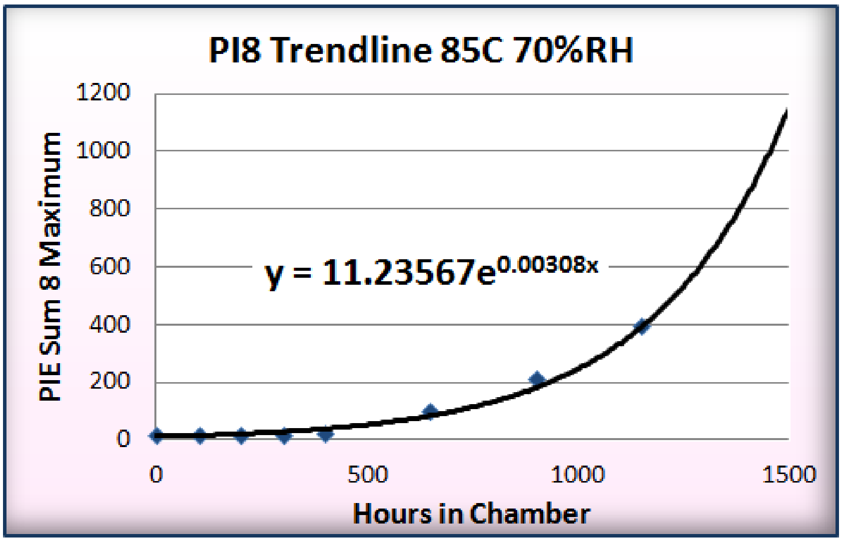
The ISO/IEC 10995 Data Analysis Procedure

The data analysis steps required by the ISO/IEC 10995 Standard can be summarized as follows:

1) Plot the PIE 8 Maximum data for each individual disc vs time (hours) in the test chamber.
2) Fit an exponential curve to the data for each disc.
3) Use the fitted curve to determine the intercept with the 280 error rate limit. The intercept point will be the estimated number of hours to failure for each disc under the specified test condition.

4) Plot the estimated hours to failure on a log scale vs the critical value of the median rank to confirm that the failure times are approximately normally distributed.
5) By applying the log values for the median time to failure, the temperature (kelvin) and the relative humidity for each of the 4 stress conditions to the reduced Eyring equation, create a least-squares-fit surface for these data.
6) Using the surface equation generated in step 5, calculate the acceleration factors for each of the four stress conditions.
7) Using the acceleration factors generated in step 6, predict the mean data lifetime for the discs under normal storage conditions (25°C and 50% RH).
8) Using the acceleration factors generated in step 6, create a table of "normalized" lifetime values for all the discs used in the study. Calculate an estimate of standard deviation for the log values of the entire data set.
9) Using the calculated standard deviation, one can predict the time at which 5% of the discs are predicted to have failed. This is the 95% data survival lifetime.

An example of **analysis steps 1, 2 and 3** for a single disc is shown in Figure 4 below, which is a screenshot taken from Microsoft Excel:



Exponential equation solver	
Coefficient A	11.23567
Coefficient B	0.00308
Hours to 280:	1044

Figure 4. PIE Sum 8 Maximum vs. Time

This process is repeated for all the discs under all the stress conditions. All these individual times to failure are plotted vs the critical value of the median rank per **analysis step 4** as shown in Figure 5 below.

The data groups show a reasonable linearity, as required in the data analysis procedure specified in the ISO/IEC 10995 Standard. Therefore, we can assume that the distribution of the log failure times is approximately normal for these data sets. It should be noted that the failure times in hours will not be normally distributed, only the *natural log* of the failure times shows normality.

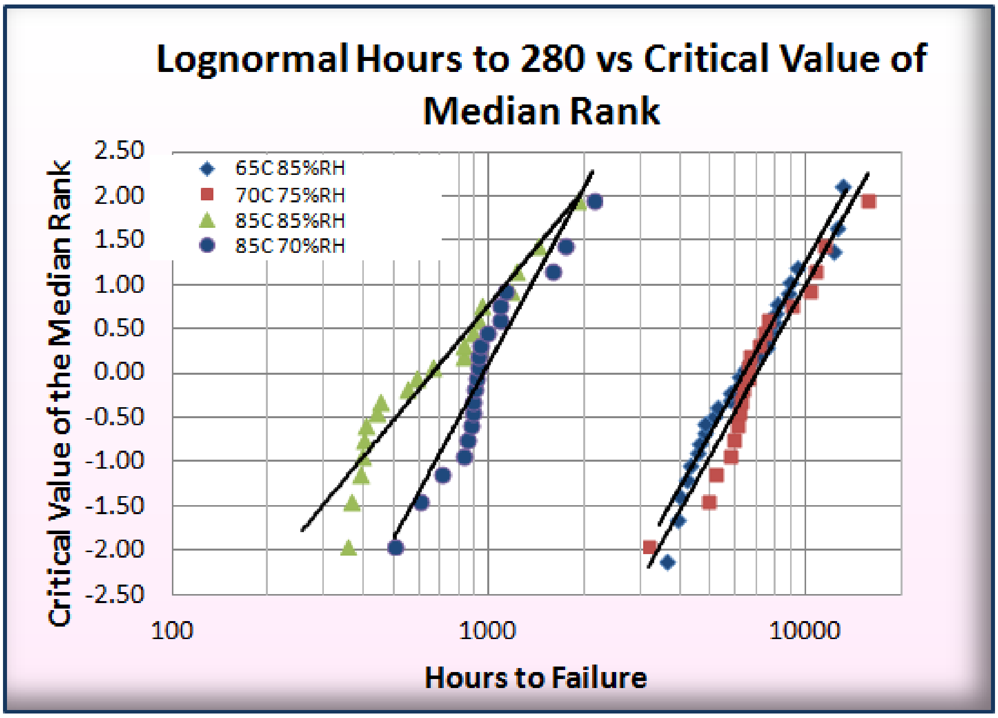


Figure 5: Lognormal Hours vs Critical Value of the Median Rank

Using the data from the study and the reduced Eyring equation, we use a least-squares-fit to get the 3 unknown coefficients, ln(A), DH, and B. The Data Analysis add-in which is available on the Data tab within Excel is used with a regression fit to find these coefficients. This is **analysis step 5** as shown in Figure 6 below.

Temp	log median time	1/Temp (k)	RH
85	6.4327	0.00279213	85
85	6.8118	0.00279213	70
65	8.7403	0.00295727	85
70	8.7880	0.00291418	75

Reduced Eyring Equation: **ln(A) + DH (1/T) + B(RH) = ln(time to failure)**

ln(A) = -32.957
DH = 15251
B = -0.03845

16.3200 - (1.65 * 0.4475) = 15.5846

= 5848061 hours

= 667 years

Figure 6: Coefficients per Regression Fit

These coefficients enable the user to generate acceleration factors for each of the 5 stress conditions in **analysis step 6** as shown in table 2 below:

	Median Hours to Failure	Acceleration Factor	
85°C/85%RH	577.0	20233.67	
85°C/70%RH	1027.0	11367.90	
65°C/85%RH	7161.0	1630.34	
70°C/75%RH	5452.0	2141.38	
25°C/50%RH	**11674830**	1	**(Predicted from surface fit)**

Table 2: Calculated Acceleration Factors

Thus **analysis step 7** yields a predicted median life of the M-Disc under normal storage conditions of 25°C and 50% RH of 11,674,830 hours, or 1,332 years.

Because the log failure times were found to be approximately normally distributed in analysis step 4, we can take all the measured failure times from the 4 stress conditions, and apply to each the appropriate acceleration factors per **analysis step 8**. This creates an overall predicted failure lifetime dataset for the M-Disc at normal storage conditions. Using the log values of this (large) dataset we can then generate an estimate of the standard deviation for the log failure time.

Finally we apply **analysis step 9** by using the log mean of the failure time for the M-Disc dataset at normal storage conditions (which value is 16.3200) and the estimate of standard deviation calculated in **analysis step 8** (which was determined to be 0.4475). Using these values we then subtract 1.65 standard deviations from the log mean failure time to determine the time that 5% of the discs will be projected to fail, which is defined as a measurement higher than 280 PIE Sum 8 Maximum. (See the calculations below):

This means we can expect that 95% of M-Discs will still measure below the error threshold of 280 PIE Sum 8 Maximum after 667 years, when stored under normal room conditions. In other words, 95% of M-Disc DVDs will reliably retain data for more than 667 years.

A table of the expected mean lifetime for the M-Disc under varying storage conditions may be seen below:

Predicted Lifetime (years)

	15°C	20°C	25°C	30°C	35°C
20% RH	24,908	10,099	4,221	1,815	803
35% RH	13,992	5,673	2,371	1,020	451
50% RH	7,860	3,187	1,332	573	253
65% RH	4,415	1,790	748	322	142

Table 3: Predicted Lifetime of M-Disc at Different Storage Conditions

* 25°C and 50% Relative Humidity is considered typical

Conclusion

An M-Disc lifetime study conducted according to the ISO/IEC 10995 Standard indicates that the expected mean life is 1,332 years and that the expected 5% failure time is 667 years. The ISO/IEC 10995 Standard is based on well-accepted scientific principles that are routinely used to evaluate the expected lifetime performance of products in a variety of industries and applications. Experience over the last 50 years in which this testing approach has been applied has shown the results to be reflective of experience in actual use. Furthermore, no better method for estimating lifetime performance is available today.

The documented results of this study have important implications for the long-term retention of digital data. Current data archiving practice requires the frequent migration of data to replacement storage media due to the significant probability of data loss within a period of a few years. Typical data migration times are on the order of 5 years for most technologies. Such practices lead to significant expense just to retain data.

Clearly, with an estimated 5% failure time of 667 years, the M-Disc DVD can be expected to retain data reliably for at least a few hundred years. A reliable data retention lifetime on the order of 200 years or more enables a new paradigm in the preservation of digital data for the long term. No longer is frequent and repetitive data migration required or desirable. The proper approach for long-term data retention is to permanently save data for the long term using a storage medium that is secure and reliable.