International Standards and off Line Archiving Through the use of Recordable Optical Discs

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Abstract

What does the phrase "CD-R, DVD-R Recordable Optical Discs" bring to mind? Does it have negative connotations like "old technology", "limited capacity" or "unreliable archiving?" If it does, then you need to take another look at this technology. Recordable optical disc technology is an established technology that is widely regarded as a state-of-the-art solution used on servers, medical instrumentation and for "must not be altered" data storage needed for trials and law enforcement records. Furthermore, DVD-R capacity (4.7 GB) is enough to store approximately 20,000 PDF pages, assuming 250 KB per page (up to 50,000 pages with compression). It is also enough capacity for 120 minutes of digital master sound data (24-bit, 96 kHz). DVD-R's are an excellent storage solution and provide sufficient capacity when organization size and purpose is taken into consideration. DVD-R is also a solution for long-term archiving. We will discuss three extremely important things you should know about archiving using recordable optical discs.

1. Introduction

First, one of the benefits of optical discs archiving is that the recorded condition of the data or digital signal can be verified by measuring the disc error rate. Unreadable data can be detected before it is too late. The error rate can be periodically measured and verified from the time of writing throughout long-term storage. Error rate levels are defined clearly in an international standard **ISO/IEC 29121**, enabling anyone to determine if migration is required or the medium needs refreshing by monitoring the error rate escalation. Long-term archiving operations can be easily managed and made compliant with ISO standards.

Second, the longevity expectancy test method is also defined by an international standard, ref. **ISO/IEC 10995**. This method uses multiple samples and multiple conditions. The results of each of the samples are statistically processed to more accurately estimate the longevity of discs at ambient temperature and humidity. In order to comply with ISO/IEC 29121 with minimum effort and cost, it is always important to select discs that have been manufactured with certain production controls, such as, 1) minimized initial defects, 2) minimized initial occurrence of error rate, and 3) minimized time dependent decomposition.

Third, DVD-R has very little risk of format obsolescence. A successful strategy for long-term archiving and migration should include mitigation of format obsolescence risk as well as longevity of the medium itself when off-line archive/redundant copies are created. Optical disc technology including DVD-R has the largest playback infrastructure ever. Approximately 300 million units (players/drives/recorders) were shipped in 2012 (total shipped is 4 billion units). This number has not declined even after the introduction of the tablet PC in 2008. DVD-R format is a general standard that many major manufacturers use.

In conclusion, DVD-R archiving is a suitable solution when considering offline archiving. ISO/IEC 29121 defines the safe level of error rate of the discs and ISO/IEC 10995 defines the test method to estimate DVD-R longevity, which enables user compliance with ISO/IEC 29121 in combined use with a properly designed drive and error checker, with minimum effort and cost.

Table 1: Comparison of data media

	OPTICAL DISC	HDD	Magnetic Tape LTO(5)
Capacity	DVD:4.7GB	3TB	3TB
Transfer Rate [MB/S]	10MB/s	200MB/s	300MB/s
Random Access[msec.]	200	<10	8000
Life Time [year]	30	5	10
Security	Best (Write Once)	Poor	Better
Energy Consumption	Best	Poor	Better
Disaster managements	Best	Poor	Poor

Finally, optical discs have a much higher degree of long-term archival potential when compared with conventional magnetic recording media (LTO, HDD, etc.).

Table 1 shows a comparison of data archive media. The Optical Disc is an ideal choice for offline archiving because of its high archive capability.

2. Importance of Initial Performance in DVD-R Archiving

As discussed above, DVD-R archiving is a suitable solution for offline archiving. To put it to practical use, it is required to optimize the design of both the recorder and the DVD-R disc.

(1) Initial recording performance

Table 2 shows the initial recording errors made using commercially available recording drives and DVD-Rs. The initial occurrence of the error rate should be less than 140.(According to ISO/IEC29121) As an error value of 140 or less is achieved by only about 38%, it is clear that selecting a DVD-R and drive that can keep initial errors to a minimum is critical to successful long-term archiving.

Table 2: Recorded Round robin test results for DVD-R

		Drive_A	Drive_B	Drive_C	Drive_D	Drive_E	Drive_F	Drive_G	Drive_H
8XDVD-R	Disc_A	Very Good	Good	Good	Poor	Good	Very Good	Poor	Poor
	Disc_B	Very Good	Very Good	Good	Good	Poor	Poor	Poor	Good
	Disc_C	Poor	Very Good	Good	Good	Very Good	Good	Poor	Good
	Disc_D	Very Good	Poor	Good	Good	Good	Poor	Poor	Good
	Disc_E	Poor	Very Good	Poor	Very Good	Poor	Good	Good	Very Good
	Disc_F	Poor	Very Good	Poor	Poor	Poor	Good		
	Disc_G	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good	Very Good
16XDVD-R	Disc_A	Good	Good	Good	Very Good	Poor	Very Good	Good	Very Good
	Disc_B	Very Good	Very Good	Good	Very Good	Poor			Very Good
	Disc_C	Very Good	Very Good	Very Good	Very Good	Poor	Good	Very Good	Very Good
	Disc_D	Poor	Very Good	Poor	Poor	Poor	Good	Very Good	Very Good
	Disc_E	Good	Poor	Poor	Poor	Poor	Good	Good	Very Good
	Disc_F	Good	Very Good	Very Good	Very Good	Poor	Very Good	Poor	Poor
	Disc_G	Poor	Poor	Poor	Poor	Poor	Very Good	Very Good	Very Good
	Disc_H	Poor	Good	Very Good	Poor	Poor	Very Good	Very Good	Very Good
	Disc_I	Poor	Poor	Poor	Very Good	Poor	Poor	Poor	Very Good
	Disc_J	Very Good	Poor	Good	Very Good	Poor	Poor	Poor	Very Good
	Disc_K	Poor	Very Good	Very Good	Poor	Poor	Very Good	Poor	Very Good
	Disc_L	Good	Poor	Poor	Poor	Poor	Poor	Poor	Very Good

Very Good : <140(PIEsum8)
Good :140~280(PIEsum8)
Poor : >280(PIEsum8)

(2) Storage characteristics under high-temperature/high-humidity conditions

Fig. 1 shows the results of error rate degradation measurements after storing DVD-R discs under high-temperature/high-humidity conditions (80°C, 85%). DVD-R reliability varies widely depending on the brand. This difference derives from how the discs are designed. For archiving, the design of the recording and reflective layers is most important. Escalation of errors is actually not observed with discs specially designed for long-term archiving.

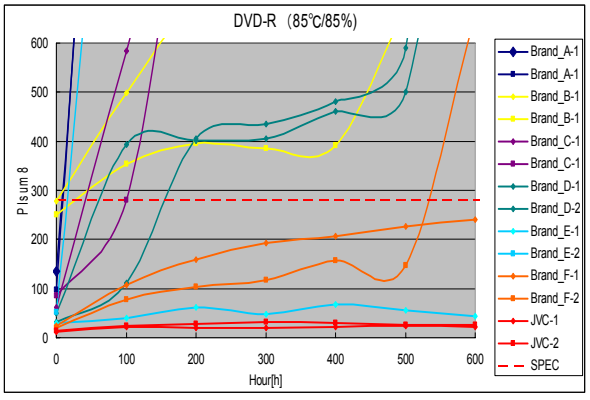


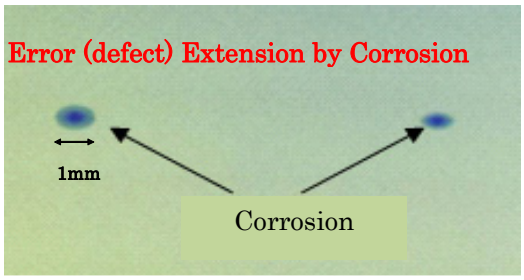
Fig. 1: *Error rate after 80℃ 80%*

3. Basic Disc Design for Long-Term Archiving

To ensure successful archiving, the disc must have very high performance. The properly designed DVD-R is a medium that is extremely well suited to archiving which includes the margin in stability design of the entire recording and playing systems, the low-error design of the disc, and the life design. The technologies critical in the disc design are the substrate material and recording layer designs. In the following, we will discuss the orientation of designs.

(1) Recording layer (Dye design)

Since the recording layer uses an organic dye, it is important to design the stability and high purity proper to the organic material. Fig. 2 shows the defects of a recording layer with insufficient purity design after accelerated deformation testing.



■ ***Light stability***

The light stability of an optical disc can be expressed with the Blue Wool Scale international standard. The Blue Wool Scale uses blue wool strips dyed in eight different steps of light stability as standards, and every color-degraded sample is rated according to the blue wool strip presenting equivalent color degradation to the sample. The blue wool standards are assigned ratings of 1 to 8 in ascending order of light stability. Optical discs commonly available on the market have a Blue Wool Scale rating of 4 or 5, which is equivalent to the light stability of dye inks used by ink jet printers and considered adequate for ordinary storage (indoor storage). For reference, JVC Archival grade disc has a Blue Wool Scale rating of 6 or higher, while the rating of the pigment ink generally used with an ink jet printer considered to have high light stability is around 6.

The graph in Fig. 3 shows the results of exposure testing of optical discs using an acceleration sunlight stability testing chamber that irradiates light by reproducing the spectrum of the solar light. The result after 44 hours of irradiation is equivalent to the Blue Wool Scale rating 5. With the developed pre-production disc (before optimization), the PI errors were above the limit defined in ISO/IEC29121 (< 280) so it cannot meet the requirement of rating 5. The increase in errors due to light is caused by degradation with light of the dye used in the recording layer. When developing a disc for archiving, it is necessary to evaluate the light stability of the dye and set the result as the index for dye development.

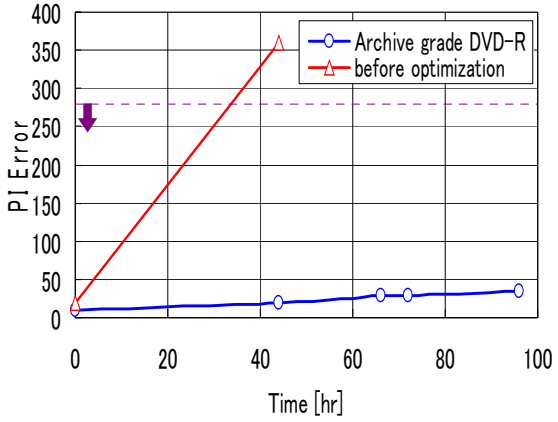


Fig. 3: *Disc Photo exposure acceleration test results by Sunshine weather.*

As shown in Fig. 4, some dyes have very low ("Bad") light stability. At JVC, we have improved the light stability by tuning up the dye layer during development and trial manufacturing process. With the archiving-dedicated DVD-R, PI errors are below 50 after 72 hours of light irradiation corresponding to a Blue Wool Scale rating of 6 even after 96 hours. This high light stability means that is suitable for long-term storage of data.

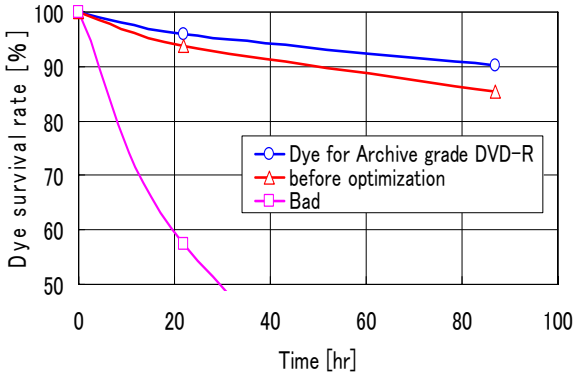


Fig. 4: *Dye degradation test results by Solar simulator .*

■ *Heat/humidity resistance and life*

● Substrate material

While the glass transition point Tg of the polyethylene terephthalate (PET) used as the substrate material of magnetic tape is 80°C, that of the polycarbonate (PC) used as the substrate material of an optical recording disc is 144°C, which means that the disc is superior in heat resistance to the tape. Recording media are exposed to the recording system's environment for long hours and, in general, an environment between 50°C and 70°C is considered normal. One of the characteristics of plastic materials that is important in this context is thermal stability. So we pay attention to the glass transition point that determines this. When the glass transition point is reached, the mechanical properties of the disc are altered. The mechanical properties of the disc are the characteristics represented by the tilt and birefringence (anisotropy) of the disc, and determine the initial recording characteristics. This naturally suggests the superiority of the PC because of its high glass transition point.

● Dye

To improve the high-temperature storage stability of recorded data, we use a dye with high resistance to hot water.

The dye's resistance to hot water is tested as follows: After forming a dye film on a polycarbonate testing substrate, the substrate is dipped in hot water (75°C) for 30 min. If the temperature/humidity resistance of the dye is low, it will dissolve in the hot water. If such a dye is used in the recording layer of an optical recording disc, the disc's performance will drop noticeably after storage in a high-temperature/humidity environment. To ensure that disc performance is up to standard after storage in an 80°C, 80% environment, it is important that the positions where the dye film is dipped in hot water do not change after this test and that a dye that can satisfy the above condition is used.

■ *Dye purity*

The dye layer is formed by coating the substrate with a dye solution in a suitable solvent by means of spin coating method. If the dye synthesis process is unsuitable, the solubility of the solvent drops due to adverse crystalline systems and fine dye crystals may remain in the dye solution. If the dye layer of optical disc is formed using such a solution, the disc will have a high error rate. In addition, when the disc is stored in a high-temperature/humidity environment, the increase of errors will be faster than with normal discs.

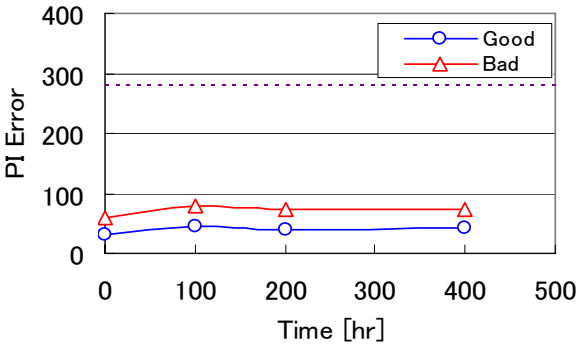


Fig. 5: *Dye synthesize dependency with 80℃80% chamber test.*

Fig. 5 shows the results of chamber tests of a disc with optimum crystalline synthesis ("Good") and a disc without optimized synthesis. With the archiving disc, it is necessary to use a dye with optimum crystalline system in order to improve the dye solubility, reduce disc errors and achieve favorable recording performance and data maintainability.

(2) Reflective layer design

(Reduction of silver film quality change using alloy reflective layer)

Reflectivity is one of the important properties of a disc. The higher the reflectivity, the higher the stability of reproduction on the drive. The margin against the contamination of the drive pickup and disc is increased when the reflectivity is high.

Among metallic materials, the one that presents the highest reflectivity for a wavelength around 650 nm is silver. On the other hand, silver has very low environmental stability, and this becomes an issue when it is used in an archiving medium. Considering these

points, we alloy Ag by using an Ag-stabilizing additive under the conditions that do not spoil the reflectivity of Ag.

The Ag alloy used in JVC archiving discs features an anti-corrosion design made possible by taking advantage of the world's most advanced inorganic and ceramic material technologies.

Fig. 6 shows the results, which were achieved by depositing silver and silver alloy on a Si substrate by means of spattering and exposed it to an 80°C, 80% humidity environment. We can show that Dense & Fine structure by adding stable impurity. Keep Ag Atomic stable.

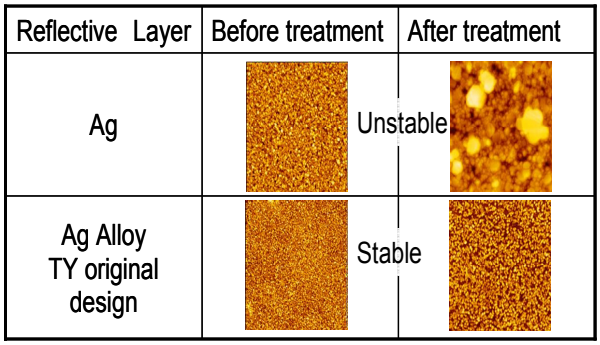


Fig.6: *Morphology change of Ag/Ag alloy surface by heat treatment (80℃80%Rh_100hr).*

4. Methods of Long-Term Archiving and Disc Migration with International Standards

ISO/IEC 29121 defines that, for the long-term storage of optical discs, the recording quality should be managed by means of initial and periodical performance tests.

1). Initial performance test result evaluation

After recording data on an optical disc, the initial performance of the entire data recording area should be tested. The DVD-R should be evaluated at three levels – Level 1, Level 2 and Level 3 – by using the maximum value of PIE SUM 8 as the evaluation index (Table 3).

Table 3: Category of initial performance test result evaluation

Level	DVD-R, DVD+R, DVD-RW, DVD+RW	Status
1	<140	Recommended
2	140-280	Should not be used
3	>280	Shall not be used
Recording performance indicator	PIE SUM 8 max	

An optical disc for use in long-term storage is required to have an initial recording performance with errors within Level 1.

2). Periodical performance test result evaluation

An optical disc used for long-term storage should be subjected to periodic tests at optimum intervals. The interval of periodic tests should generally be no more than three years, but testing at a shorter interval is desirable depending on the achievements and expected service life of the disc in use.

Table 4: Category of periodical performance test result evaluation

Level	DVD-R, DVD+R, DVD-RW, DVD+RW	Status
4	<200	Use as it is
5	200-280	Migrate data as soon as possible
6	>280	Migrate data immediately
Recording performance indicator	PIE SUM 8 max	

The DVD-R should be evaluated at the three levels of Level 4, Level 5 and Level 6 by using the maximum value of PIE SUM 8 as the evaluation index (Table 4).

If the recording performance is within Level 4, the performance of the disc is good enough to continue being used.

If the recording performance is within Level 5, the data stored on the disc should be migrated to another disc as soon as possible.

If the recording performance is Level 6, the data stored on the disc should be refreshed to another disc immediately if the data can be retrieved.

3). Data migration flow

Data migration flow of the initial performance test and periodical performance test is shown in Fig. 7.

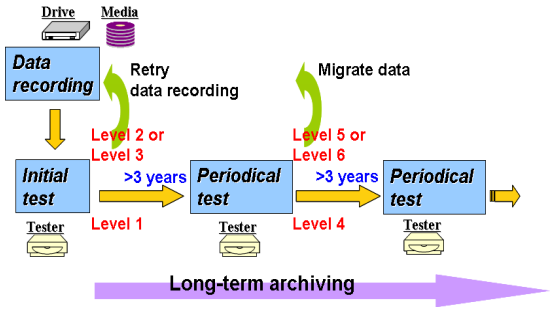


Fig. 7: Data migration flow the initial performance test and periodical performance test

If disc performance is not within Level 1 in the initial performance test immediately after data recording, record the data on another disc and apply the initial performance test. A disc that meets the Level 1 requirement can be considered suitable for long-term storage of data.

Any disc used for long-term storage should be subjected to periodic performance tests at intervals of less than three years. If the disc rates higher than Level 4, the data should be migrated to another disc. A disc rated within Level 4 can continue to be used for long-term storage and should be tested periodically (at intervals of no more than three years) until a result corresponding to Level 5 or Level 6 is obtained.

The procedures described above facilitate safety management of the optical disc archive compliant with the safety guidelines defined by international standards. It is **the sole medium for which all of the medium standards, operation standards and life estimation test standards are available**.

In addition to safety management, optical discs offer advantages in a number of other areas. Costs are reduced because a permanent power supply is not required, the risk of data leak due to network connection (security management) is eliminated, while the WORM characteristic prevents accidental/intentional data erasure/alteration. The energy-saving nature of this form of archiving is also reduces potential harm to the environment.

4). Evaluation system

Since the recording quality of an optical disc is determined by the combined characteristics of the recording drive and disc, it is desirable to use an archive-dedicated product with an appropriate level of basic performance and variance characteristics. Similarly, the tester for use in the initial and periodic performance tests should also be a dedicated product capable of meeting appropriate standards of error measurement and accuracy, and that is able to reliably perform testing compliant with ISO/IEC 29121.

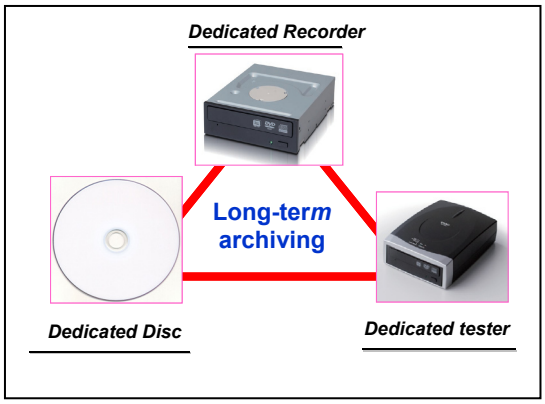


Fig. 8: *Long-term archiving solution*

The dedicated recorder and dedicated tester shown in Fig. 8 are developed based on general recording/reproduction drives. They are provided with **specifications limited to the functions required for operation** compliant **with ISO/IEC 29121** to enable system implementation at a lower cost. This allows users to significantly reduce initial introduction costs compared to the purchase of ordinary evaluation equipment. In addition, the ease of equipment operation has also been improved considerably.

▼ *Application*

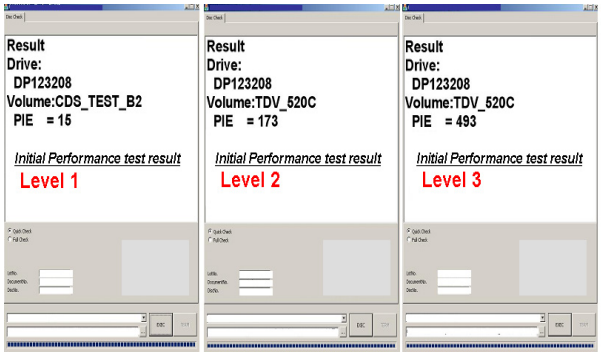


Fig. 9: *Results of initial performance test*

The tester mentioned above requires software that can be controlled easily in the tests and measured data management conducted by connecting it to a PC. Fig. 9 shows the measurement results obtained using a test application that can execute the initial/periodic inspections and display the measurement results as well as show the **evaluation results in accordance with the error standards of ISO/IEC 29121**. The measurement results can also be saved on the PC as a CSV file (shown in Fig. 10) or in another format, which makes it possible to develop materials using the measurement results or to use the data on the changes of recording quality together with the measurement time/hour data in data management.

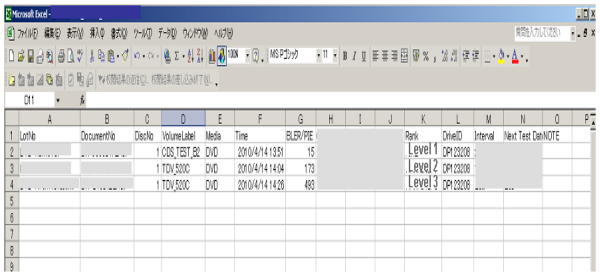


Fig. 10: *Save file (.csv)*

▼ *Calibration*

ISO/IEC 29121 mentions the necessity of test drive calibration using a calibration disc.

The dedicated recorder and dedicated tester shown in Fig. 8 incorporate a self-diagnostic function so that the user can calibrate them as required. They also incorporate an alarm function that automatically notifies the user when calibration should be executed based on the number of equipment operations, time and period. This ensures a stable long-term storage env ironment by preventing

the continued use of equipment whose recording or inspection performance has deteriorated because calibration has not been performed for a long period.

Estimated life and ISO/IEC 10995

(Concept of longevity)

The life refers to the period until a recorded DVD-R becomes unplayable when stored in an environment with a temperature of 25°C and 50% relative humidity (or 30°C and 80% relative humidity). Whether or not the disc is unplayable is determined by measuring the errors. **ISO/IEC 10995** sets the PI error threshold at 280. A disc with PI errors over 280 is considered unplayable.

(Model of degradation)

The error increase rate is associated with the speed at which the dye used in the recording film and the reflective film are degraded by chemical reactions due to the stress of temperature and humidity, and the life is estimated by means of the Eyring or Arrhenius method.

(Evaluation method according to ISO/IEC 10995)

For the estimation of life, an acceleration test is conducted under the specified temperature/relative humidity conditions and the time until the errors exceed the threshold is calculated. Then, statistical processing is applied and the time at which the failure rate reaches 5% is defined as the estimated life. The detailed methods of this test are described in ISO/IEC 10995.

5. Conclusion

This paper has looked at various aspects of DVD-R disc design for archival purposes, highlighting the stability of the dye and substrate material as of particular importance in ensuring secure, long-term storage. In addition, since the total system design including the drive is also important, we discussed specific methodologies based on assuring compliance with 1) ISO/IEC 10995 international standard defining the life measurement method, and; 2) ISO/IEC 29121 international standard that defines the safe error rate levels for writing and storage. By utilizing these standards together with properly designed tools based on these standard, users can safely implement a long-term archive without using complex IT programs. As such a recording medium cannot be found anywhere else and it is a true WORM (Write Once Read Many) medium, this medium very clearly provides a superior archiving solution.

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