
IEEE
computer
society
MASSIVE
Data Storage
Achieving 1000-Year
Data Persistence –
"Engraved in Stone"
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CTO
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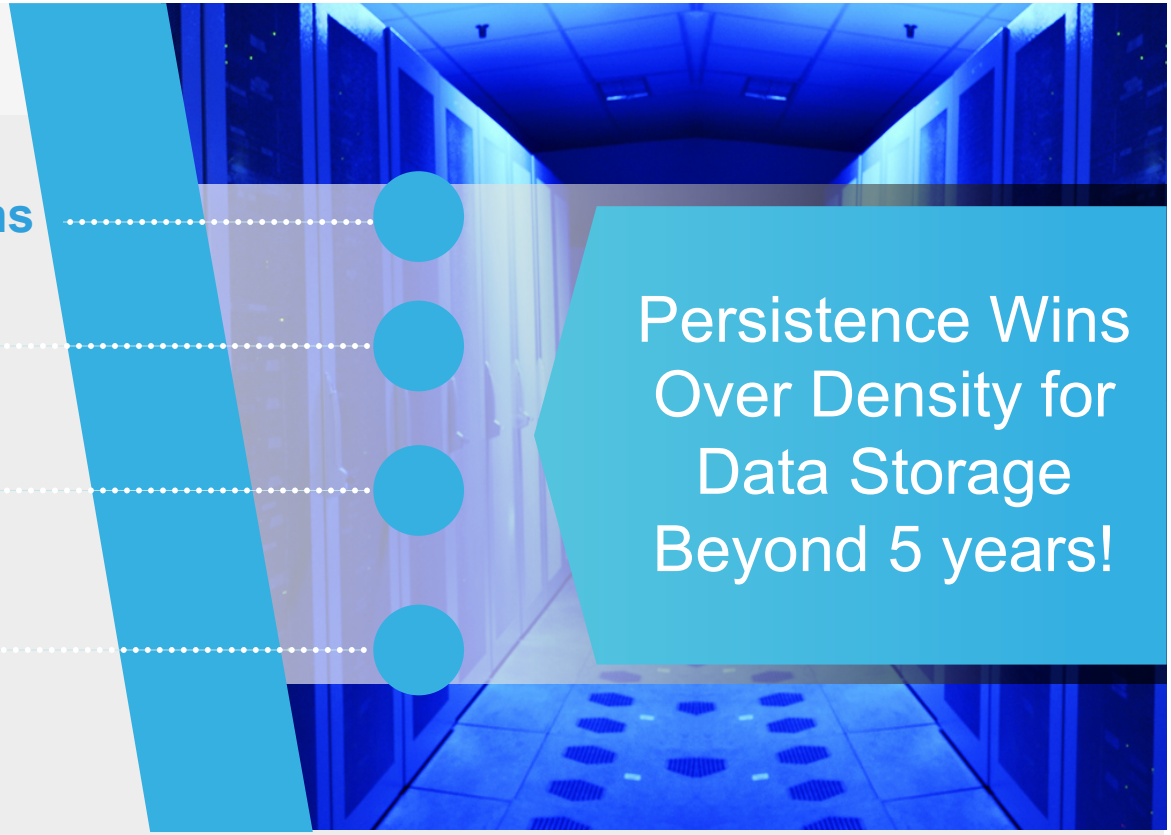
Density vs Persistence: THE RIGHT CHOICE?

Tradition: Data Density Wins

Problem: Bit Density Sacrifices Persistence

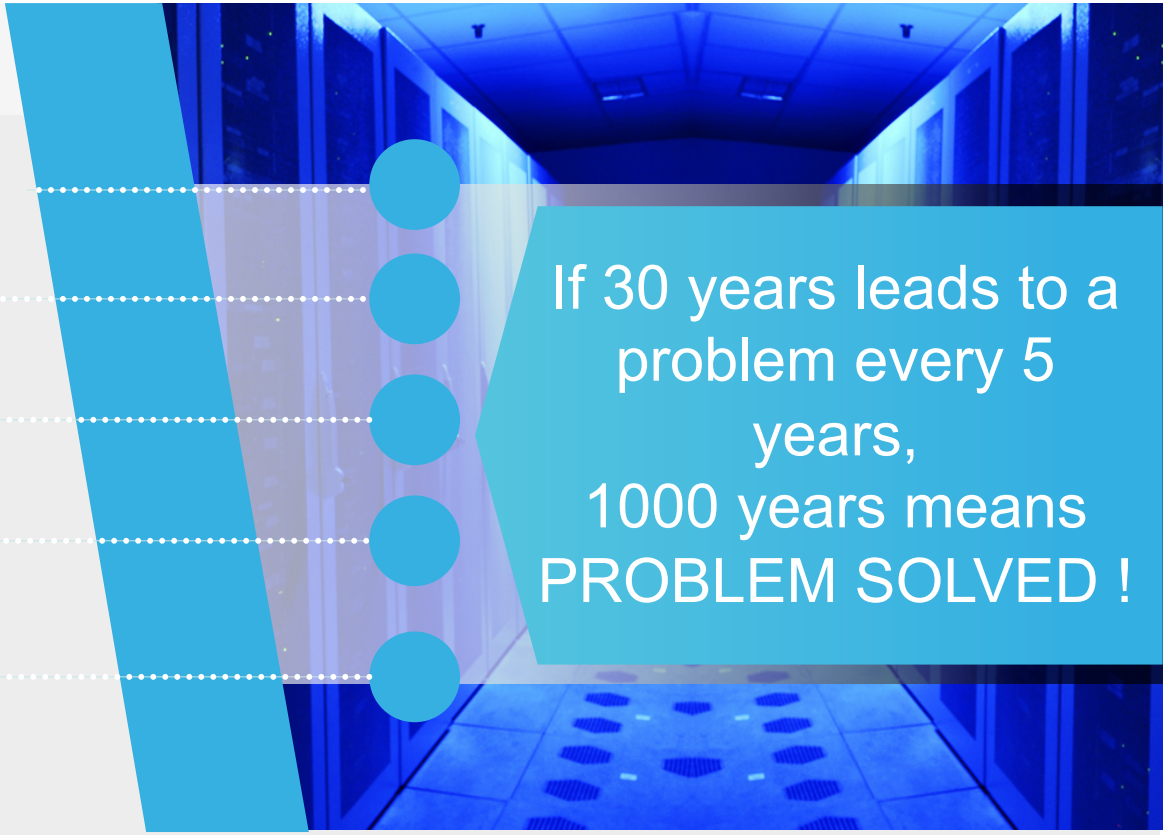
Data Explosion Drives COO Concerns

Is Bit Density Still the Way to Win?

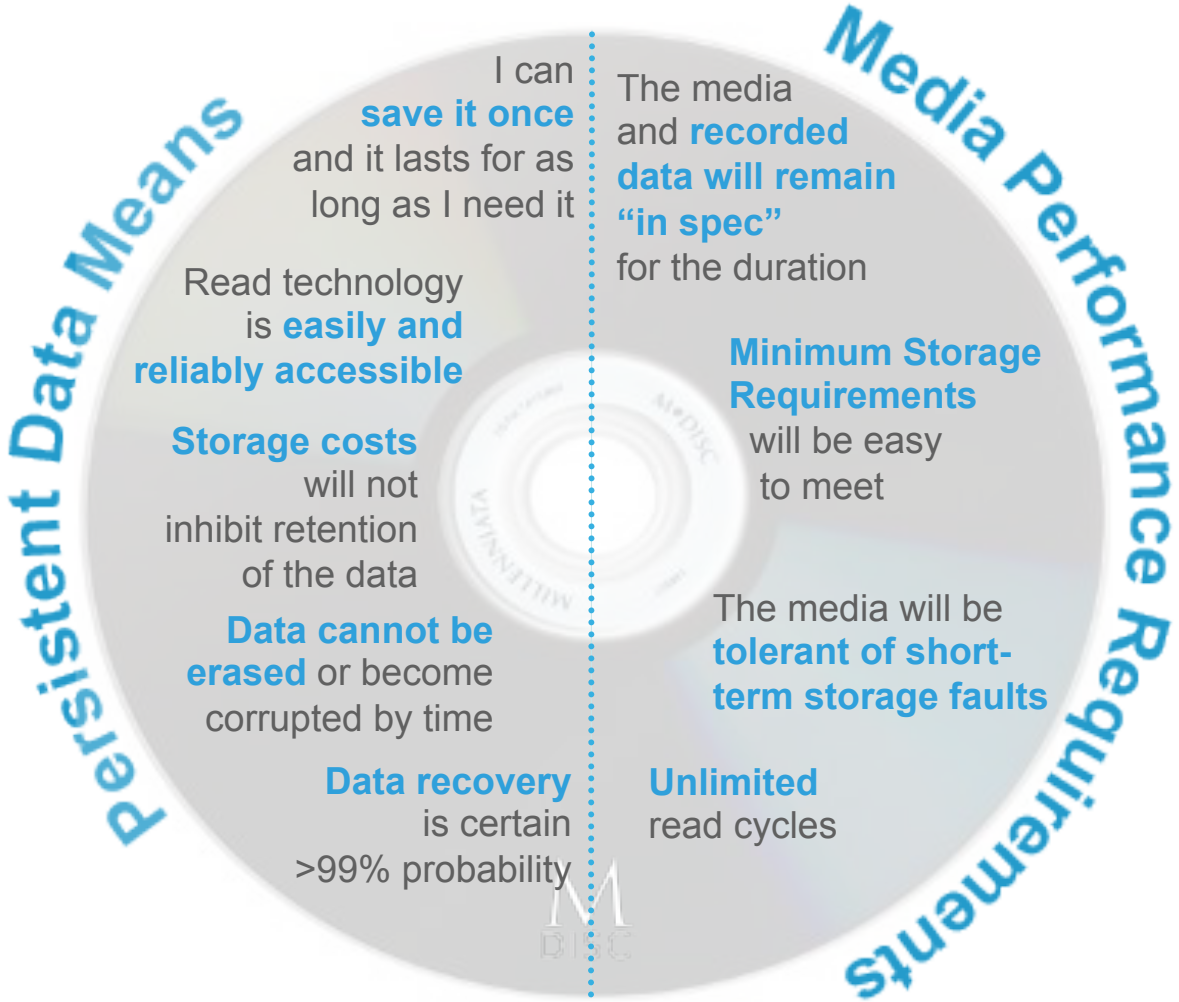


What Does Data Persistence Get Me?

- Lower Cost of Ownership
- Media and Hardware are Separate
- Green Technology
- Confidence in Data Recovery
- Near-Zero Maintenance Costs & Worries



If the bits aren't there,
NOTHING ELSE MATTERS!



No special HVAC, packaging, EM field controls, or other requirements)

Flooding, humidity & temperature

Why Do Things Endure?

Storage Conditions?

No. Many of these examples survive storage in the open for centuries.

Advanced Technology?

No. Clay pots, rock walls, and stone engravings are ancient technology.

Materials?

Yes. The most successful examples of persistent data storage utilize inert or fully-oxidized (or otherwise fully reacted) materials.

Stone and Inert Metals

Digital Records in Stone: How?

The Challenges

- Change the media – Change the materials
- Don't change the core technology
- Reasonable cost

Solid State

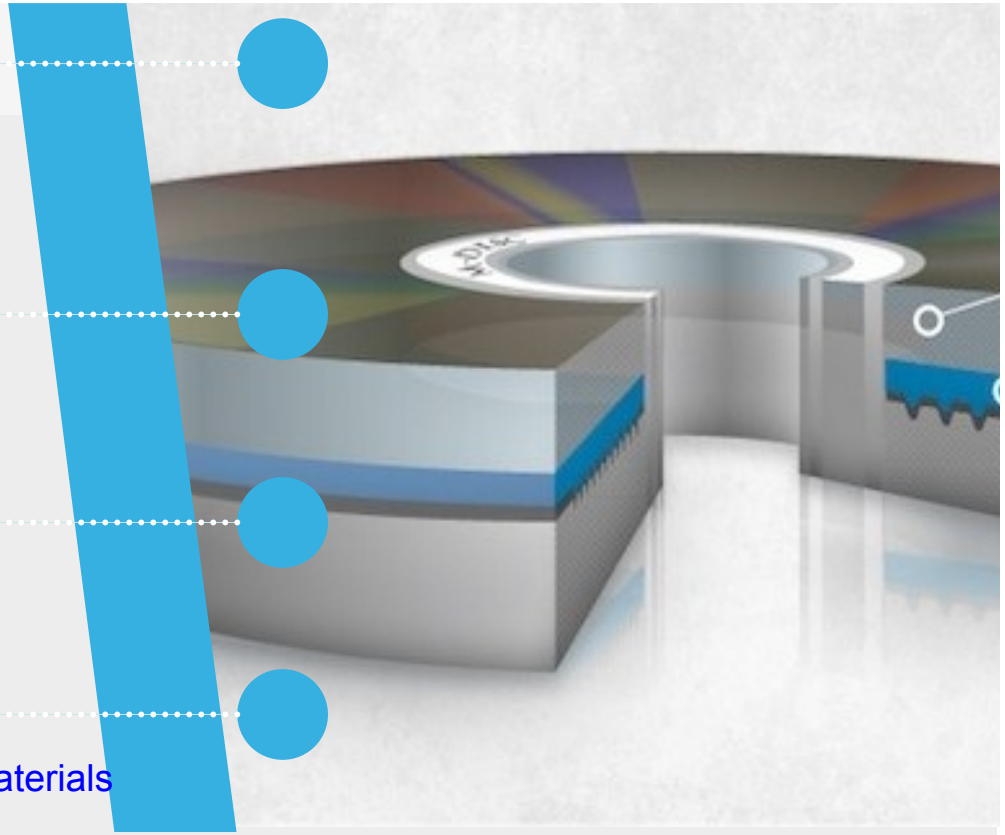
- New Materials in the semiconductor fab?

Magnetic

- Required magnetic behavior limits choices

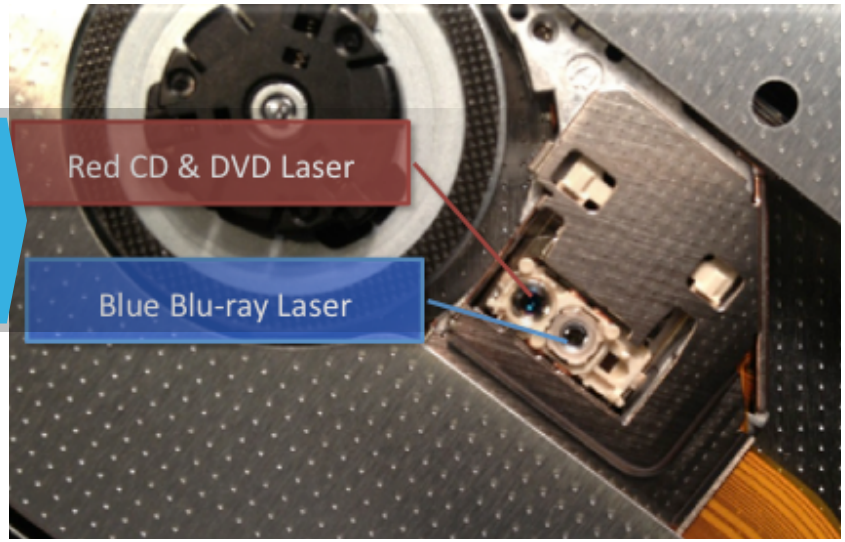
Optical

- **LIGHT:** a flexible way of interacting with materials



Digital Records in Stone: How?

Optical is the Only Choice for Fundamentally New Materials



- Well Developed, Non-Proprietary Hardware
- Extremely Wide Adoption
- Hardware is “Media Agnostic”
- Media Formats can be Adapted to New Materials

Technical Requirements

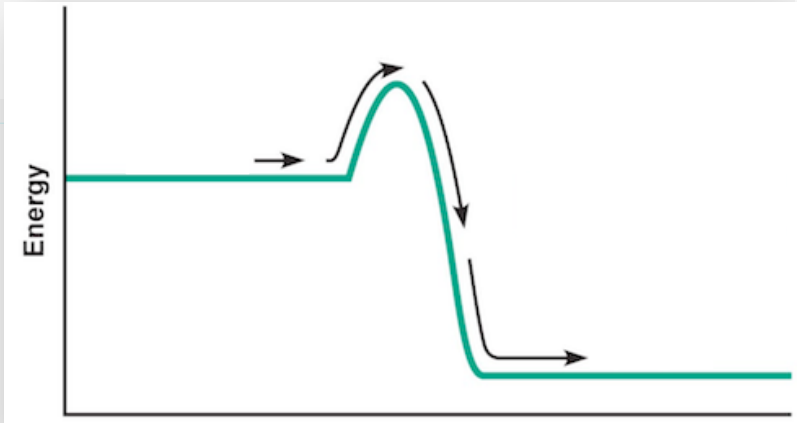
- Reflectivity & Light-driven Contrast Mechanism
- Ablation, melting, phase change, photo-chemistry, etc
- Nano-scale Dimensional Stability
- Laser Diode Power Levels in the low 10’s of mWatts

The Physics of Persistent Data

Energy Barriers are Important

Stability ⇒ High Entry Barrier

Persistence ⇒ Even Higher Exit Barrier

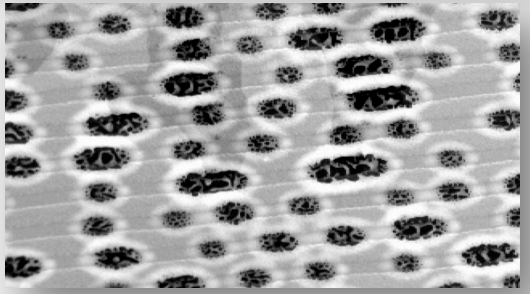


Make Entropy Your Friend

Irreversible Processes Can't Undo

Get into a Low Energy State And Stay There!

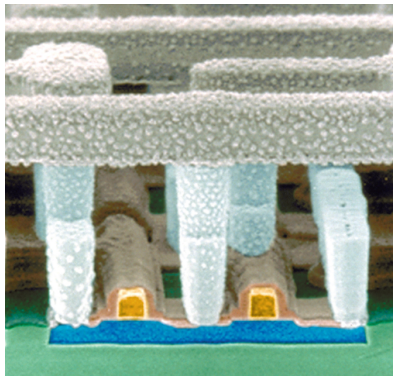
Melt & Move is Low Energy and Irreversible



The Physics of Persistent Data

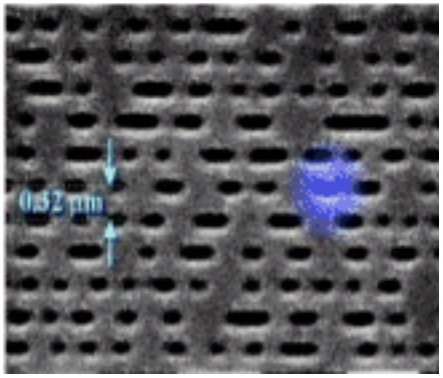
Data Storage is Nano-scale Engineering

Solid State



Min. Dimensions: ≈ 25 nm

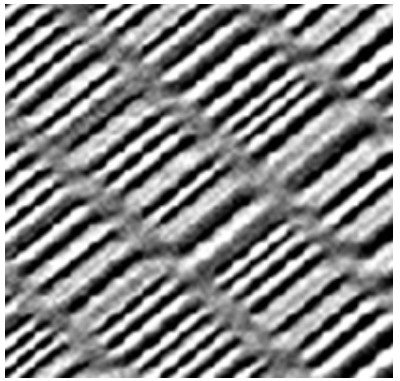
Blu-ray



Track Pitch: 0.32 μm
Min Mark Length: 0.15 μm
Storage Density: 14.73 Gb/in^2

blu-raydisc.com

Magnetic



Min Mark Length: 0.067 μm
LTO-5 Storage Density: 1.2 Gb/in^2

Quantum Data Sheet
IEEE Bulletin 2010

Nanometers Matter!

The Chemistry of Persistent Data

Nanometers Matter

No

The Key Drivers of Degradation Over Time

- Residual Stress
- Photons
- Oxidation
- Temperature
- Humidity

Chemically Inert (or Rock-like) Materials

- Eliminate all the issues except Residual Stress

Eliminate Stress Through Process Control

The Implementation of Persistent Data

The Importance of Ubiquitous Technology

The Advantages of Building on Existing Technology Foundations

Millions of copies in consumer's hands means:

- A lot of engineering has been done correctly
- Users are familiar with the technology and have access to it

Data and Media Formats that are Not Proprietary

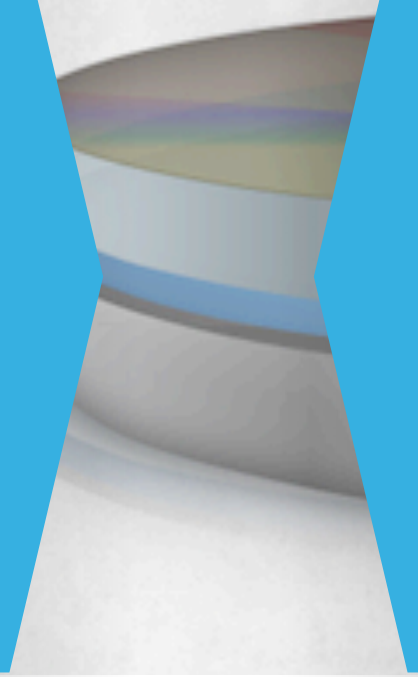
- Today's Optical Disc Drives are compatible with media written over 30 years ago.
- Massive consumer markets will continue to drive this trend.

Introducing the M-Disc

M-Disc — Both DVD and Blu-ray

Key Considerations

- Mechanical Stability
- Chemistry of Materials
- Polycarbonate
- Hard Coats & Adhesives
- UV Barrier
- Water/Humidity Barrier



Manufacturability & Costs

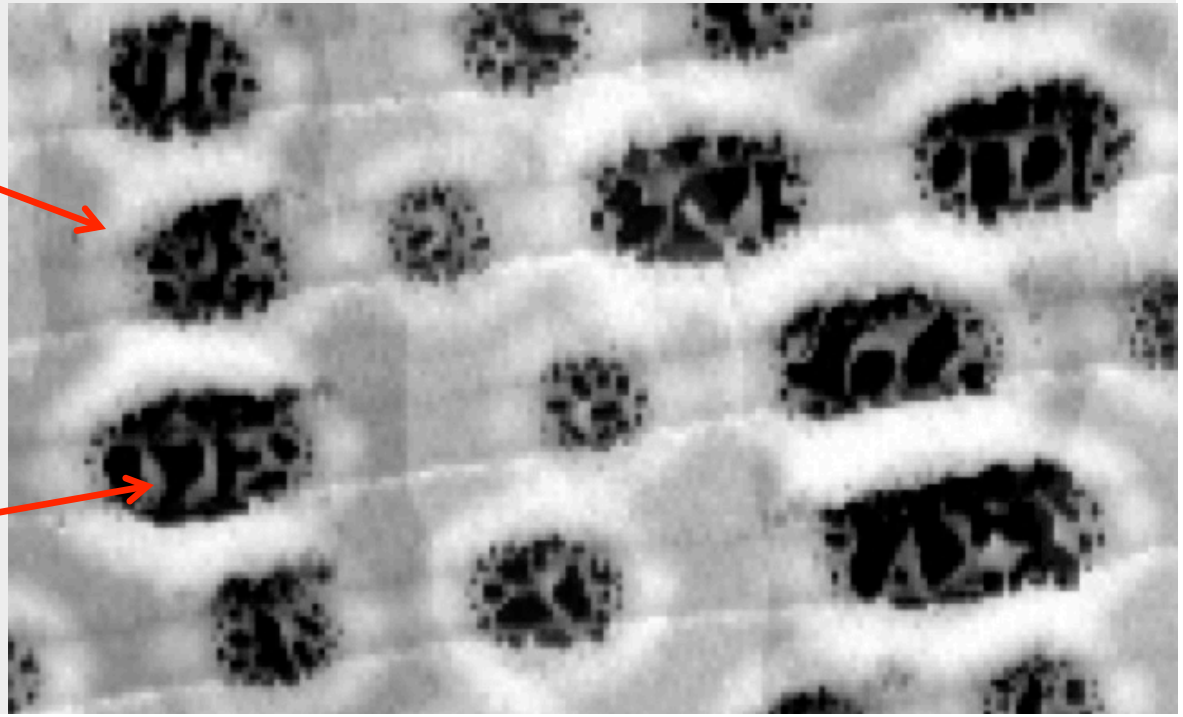
- The key difference is in the deposition of the data layer materials
- All other processes are compatible with industry-standard practices and equipment.

The Advantages of Moving Material

Nanometers and Edges Matter

Material Moved to the Perimeter Defines and Strengthens the Edge

Dark Regions Indicate an Absence of Material



TEM Micrograph of Written M-Disc

How Do We Know M-Disc Persists?

The Challenges of Longevity Testing

- Good tests & multiple conditions take a **LONG TIME**
- Statistically Valid Samples ⇒ Lots of Data
- How well do the test results correlate with real life?

The Eyring Equation and what it means

- Applies ONLY to Chemical Reactions and Rates
  - Driven by Heat and Humidity
- Does not address other failure mechanisms
- **Well suited to Archival Storage Conditions**

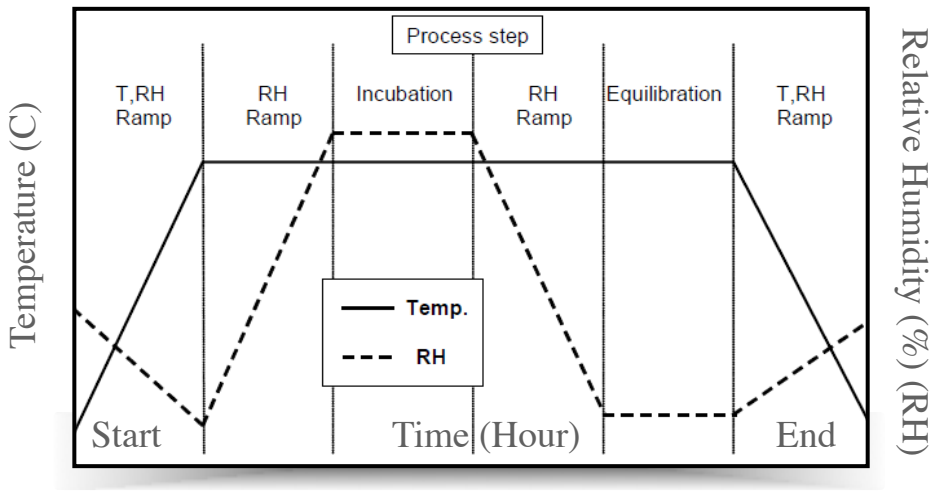
What Eyring Doesn't Mean

- Longevity is **NOT** Durability
- Media can still be destroyed

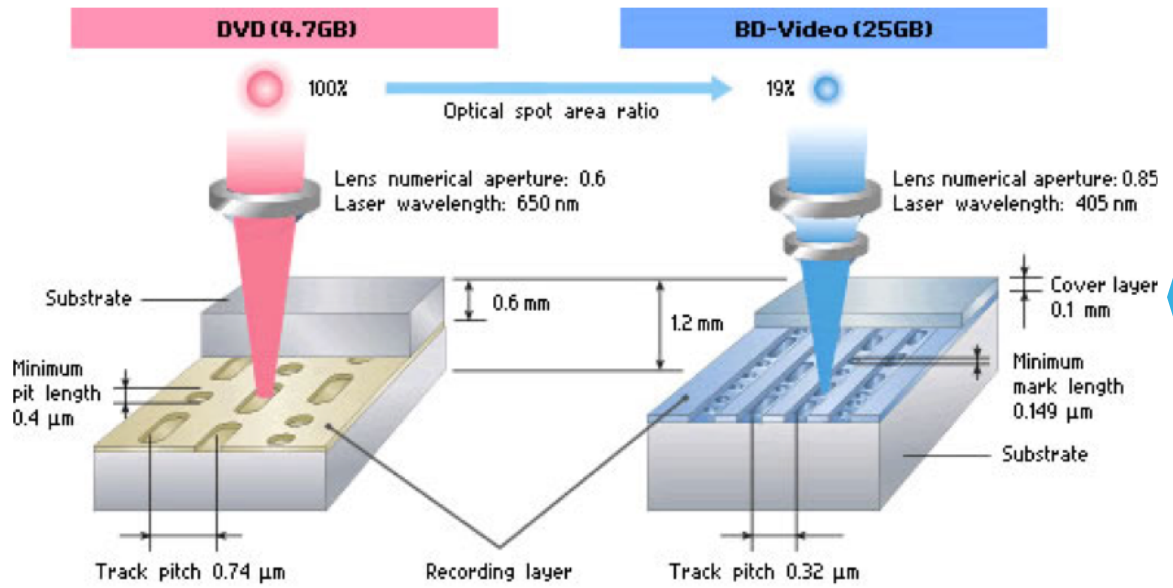
How Do We Know M-Disc Persists?

ISO 10995 Life Time Test Requirements

Test cell Number	3Test stress condition (incubation)		Number of specimens	Incubation duration	Minimum Total Time	Intermediate RH	Minimum equilibration duration
	Temp	%RH		Hours	Hours	%RH	Hours
1a	85+	85	20	250	**1000**	30	7
2a	10%	70	20	250	**1000**	30	6
3a	10%	85	20	500	**2000**	35	9
4a+	24%	75	20	625	**2500**	33	11



M-Disc DVD & M-Disc BD Comparison



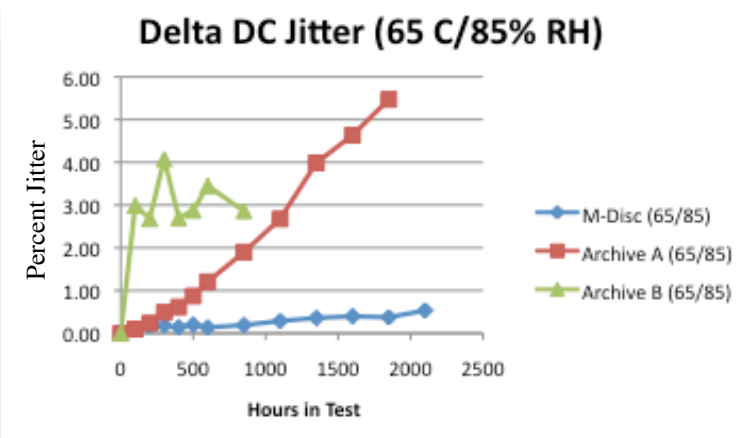
Key Points of Comparison

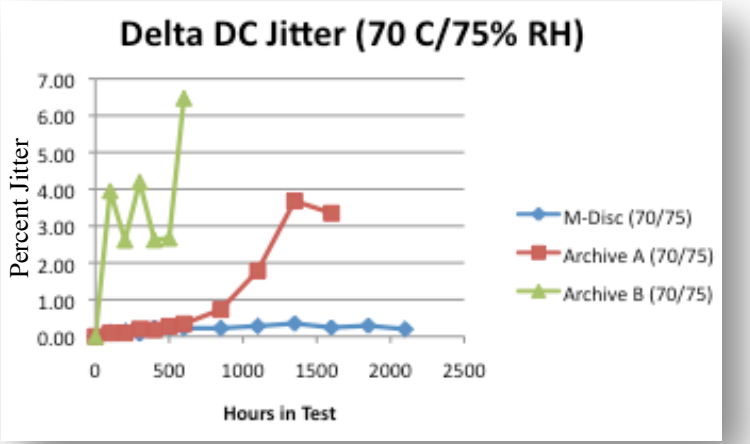
- Both Data Layers ≦ 100 nm thick
- Polycarbonate is NOT a Gas Barrier
- BD Cover Layer IS a Gas Barrier
- BD Data Layer Better Isolated Chemically than DVD

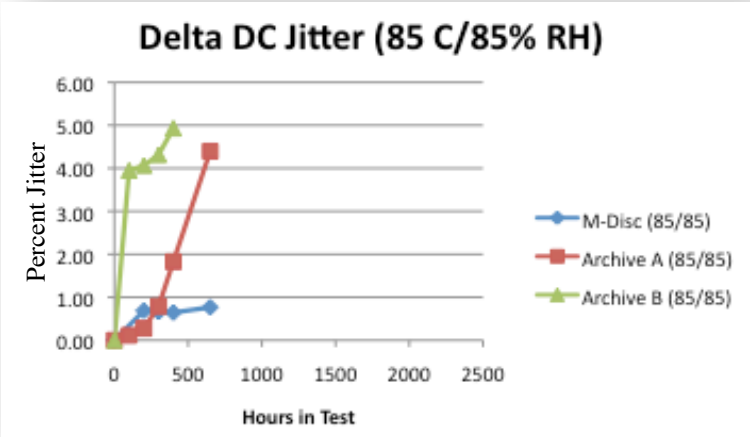
Structural Differences Between DVD and Blu-ray Should make BD Lifetime as Good as Or better than DVD

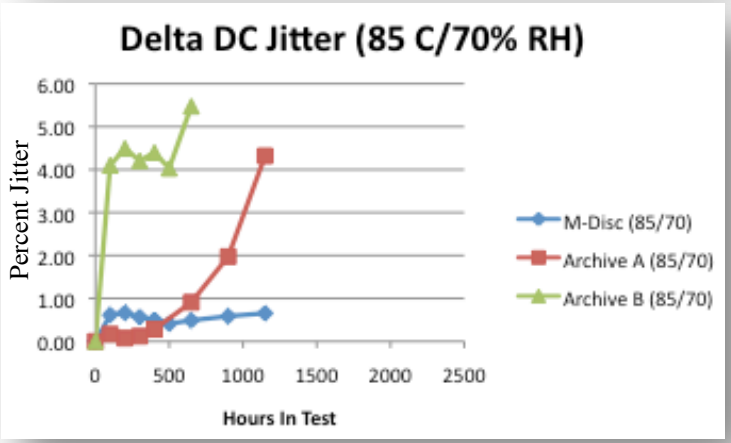
Data-to-Clock Jitter Decay (ISO 10995)

The M-Disc Data-to-Clock Jitter is Remarkably Stable Under Test





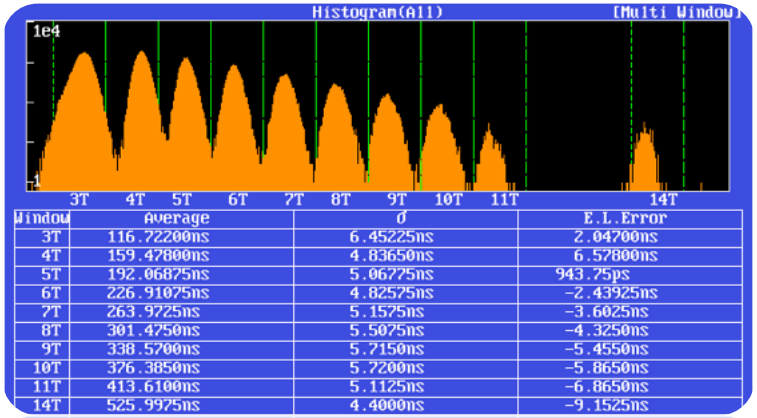




Data-to-Clock Distributions (ISO 10995)

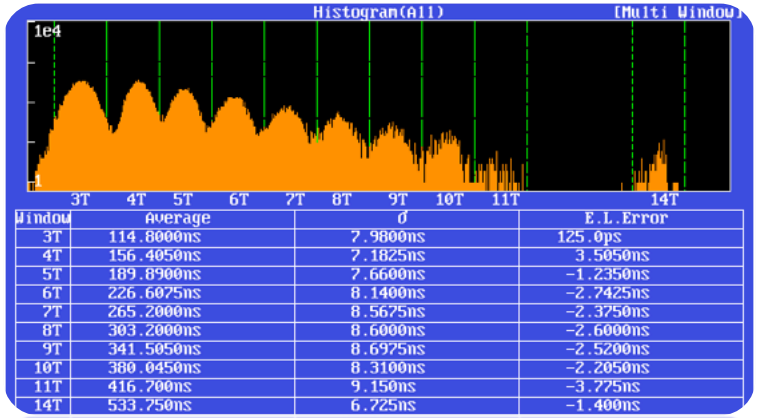
Data recorded on the M-Disc is still readable under all 4 test conditions

M-Disc



Window	Average	σ	E.L.Error
3T	116.72200ns	6.45225ns	2.04700ns
4T	159.47800ns	4.83650ns	6.57800ns
5T	192.06875ns	5.06775ns	943.75ps
6T	226.91075ns	4.82575ns	-2.43925ns
7T	263.9725ns	5.1575ns	-3.6025ns
8T	301.4750ns	5.5075ns	-4.3250ns
9T	338.5700ns	5.7150ns	-5.4550ns
10T	376.3850ns	5.7200ns	-5.8650ns
11T	413.6100ns	5.1125ns	-6.8650ns
14T	525.9975ns	4.4000ns	-9.1525ns

Archive A

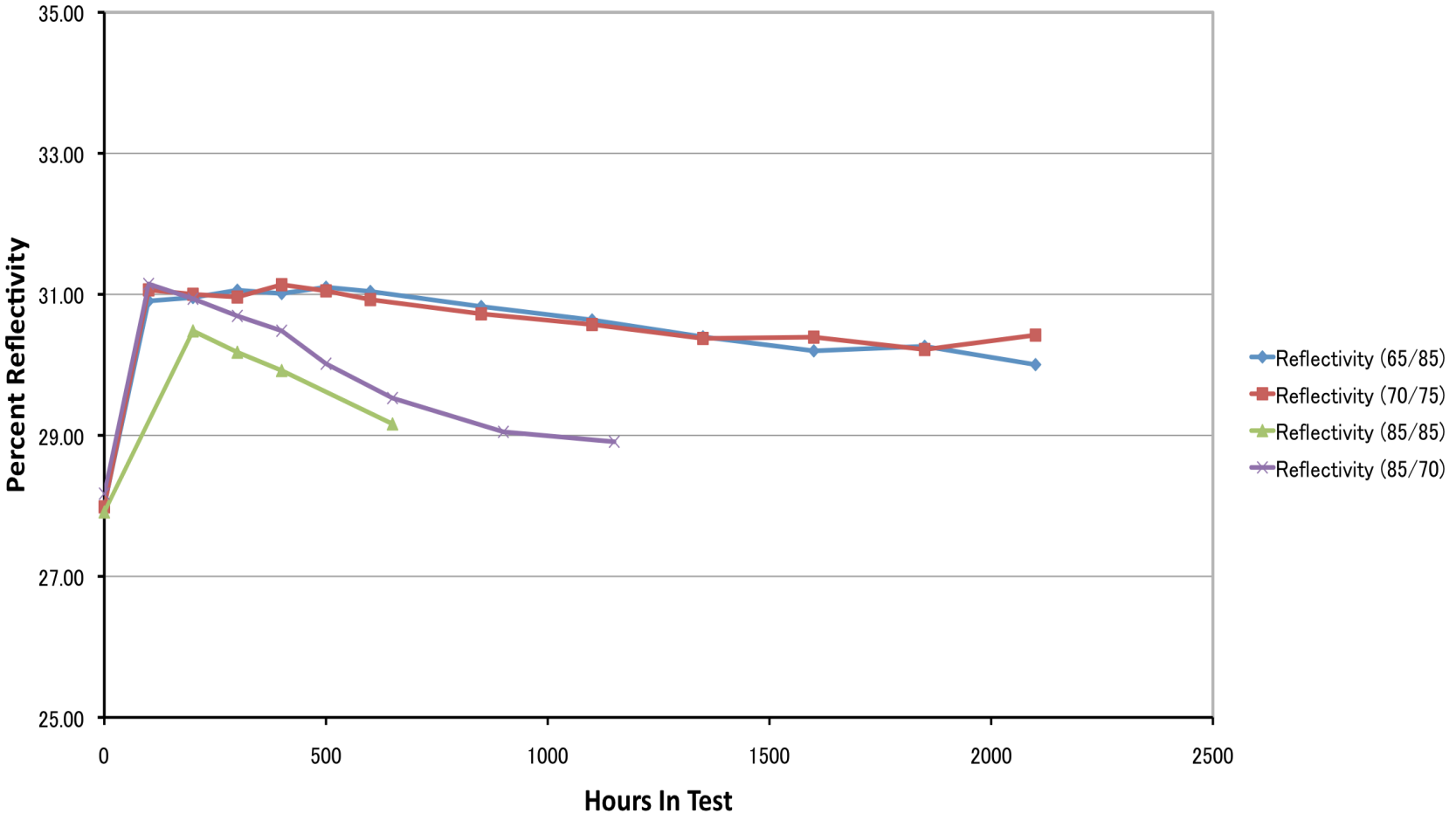


Window	Average	σ	E.L.Error
3T	114.8000ns	7.9800ns	125.0ps
4T	156.4050ns	7.1825ns	3.5050ns
5T	189.8900ns	7.6600ns	-1.2350ns
6T	226.6075ns	8.1400ns	-2.7425ns
7T	265.2000ns	8.5675ns	-2.3750ns
8T	303.2000ns	8.6000ns	-2.6000ns
9T	341.5050ns	8.6975ns	-2.5200ns
10T	380.0450ns	8.3100ns	-2.2050ns
11T	416.700ns	9.150ns	-3.775ns
14T	533.750ns	6.725ns	-1.400ns

Test Condition: 65 C – 85% RH
Time in Test: 2100 Hours
Radius: 50 mm

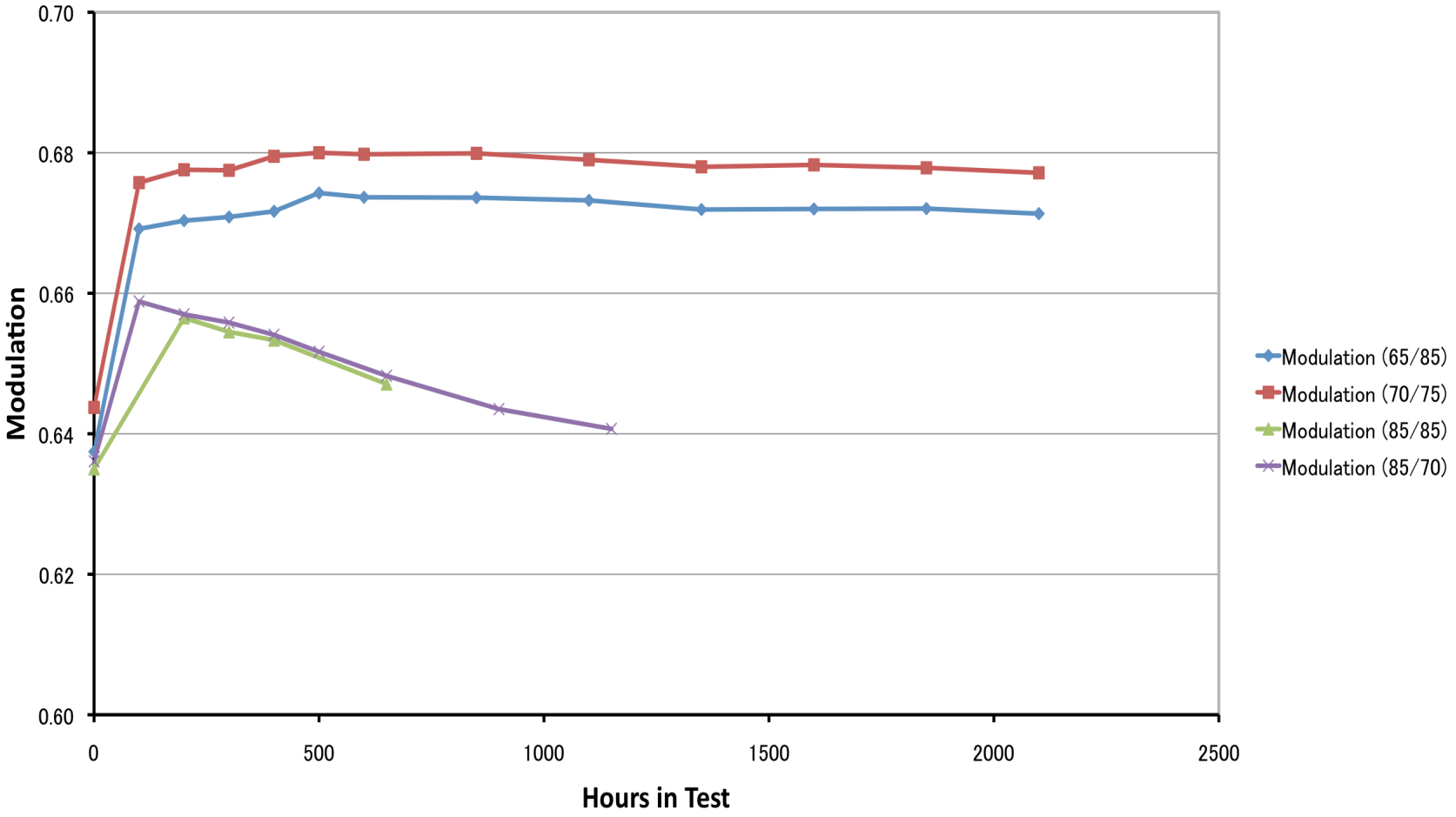
M-Disc Reflectivity (ISO 10995)

The M-Disc ends the test still in spec under all 4 test conditions



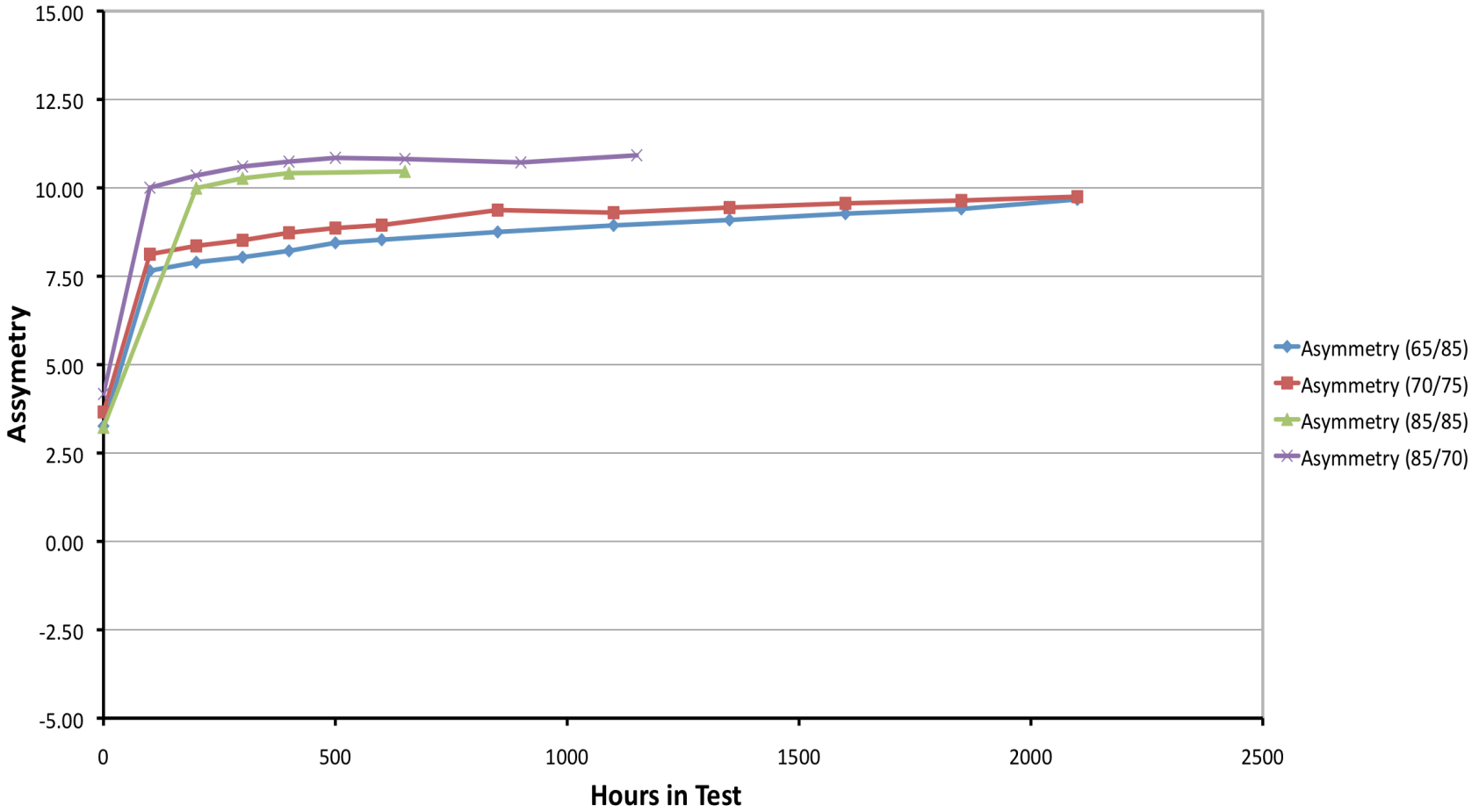
M-Disc Modulation (ISO 10995)

The M-Disc ends the test still in spec under all 4 test conditions



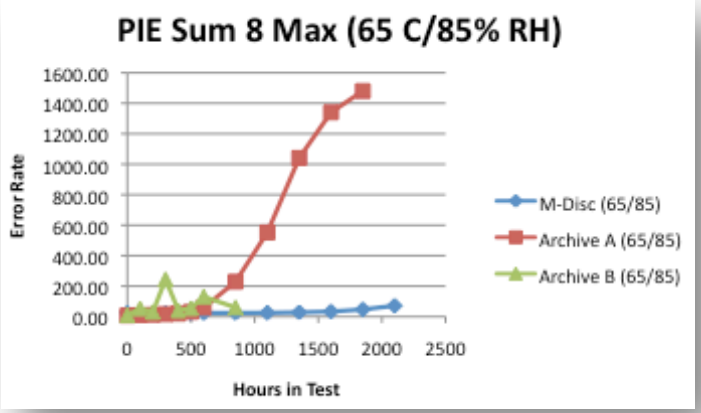
M-Disc Asymmetry (ISO 10995)

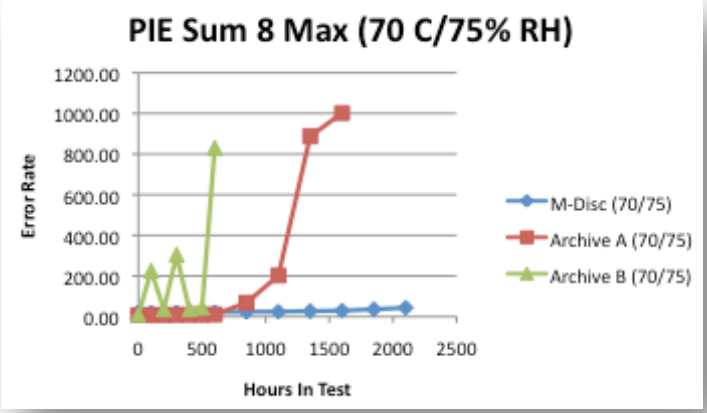
The M-Disc ends the test still in spec under all 4 test conditions

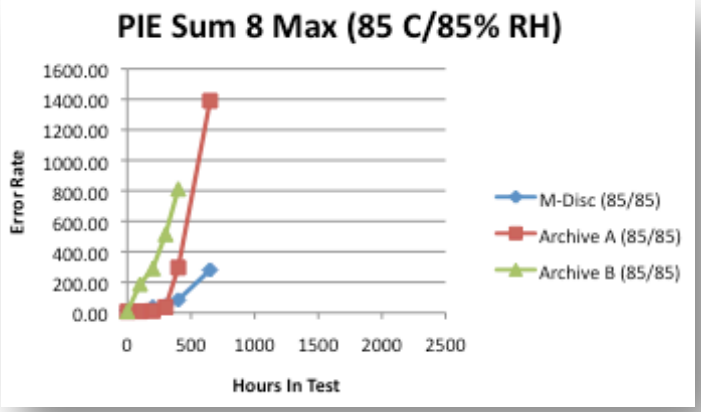


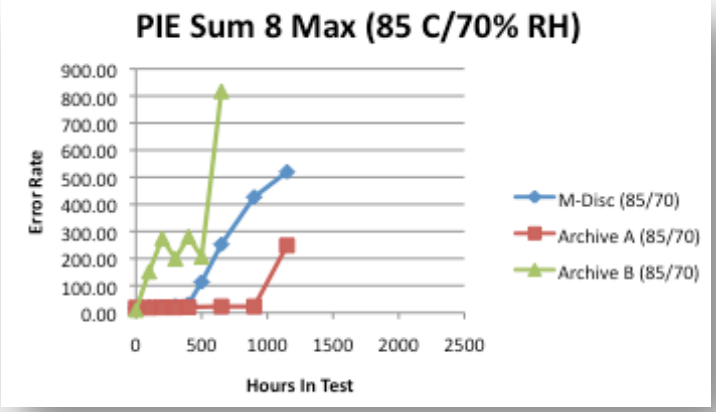
PIE Sum 8 Error Rates (ISO 10995)

The Test Results Indicate an Average Lifetime Well Over 1,000 years







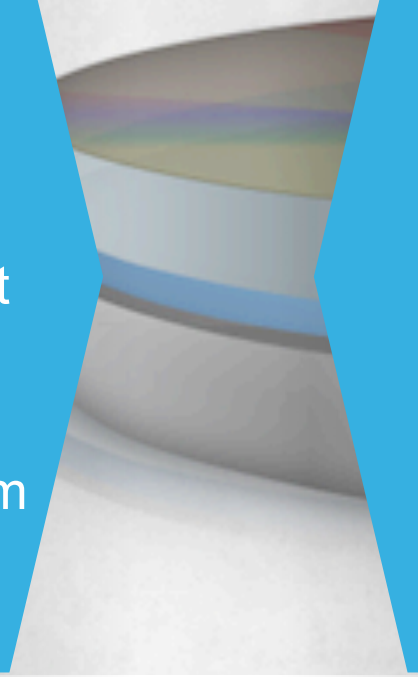


The M-Disc Age Acceleration Factor with Temperature is Significantly Better

Key Conclusions and Summary

Key Conclusions:

- Persistent Data Impacts
  - The Bottom Line
  - Data Security
- Excellent Materials Science Makes Persistent Data Possible!
- M-Disc DVD and BD Introduce a New Paradigm in Data Archiving



Summary:

- Optical Storage Offers A Unique Value Proposition
- The World-wide Data Explosion Will Drive New Solutions to Massive Data Archiving
- Persistent Optical Storage Hardware, Software & Media Can Handle Massive Data