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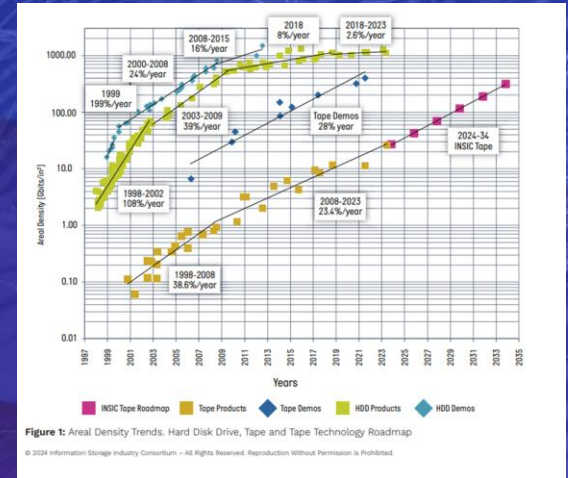
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March 15, 2025

On Getting Ready for LTO-10 the QTM way



LTO Technology Roadmap; Challenges of small dimensions

INSIC 45TB

Bit Length 42.3 nm

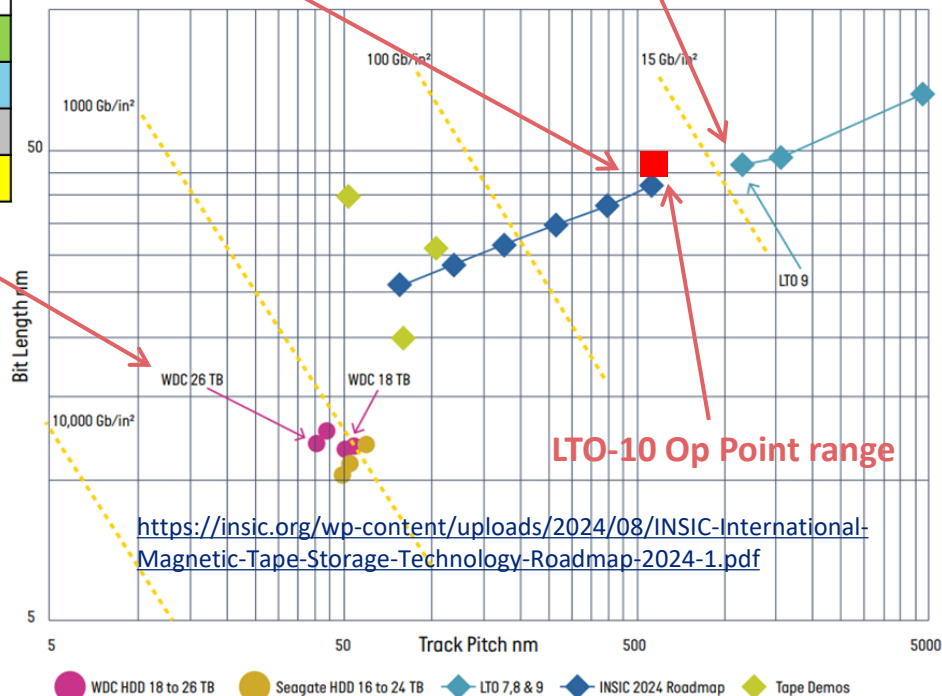
LTO-9

Track Pitch 560.8 nm

Technology	Bit Length nm	Track Pitch nm	BAR
WDC 26TB HDD	11.91	40.64	3.4
INSIC 45TB	42.3	560.8	13.2
LTO-9 18TB	46.6	1156	24.8
LTO-6 2.5TB	66.04	4750	72

Recorded Bits are getting smaller
 BAR is approaching HDD technology
 Legacy 2-copy is not sufficient to ensure high durability;
 3-copy or more is better but too costly
 Even with three or more copies, self-repair capabilities like those in the 2DEC architecture are not available.
 Additionally, there is a risk of correlated errors since the same drives may generate multiple copies, unlike the 2DEC approach, which mitigates this issue.

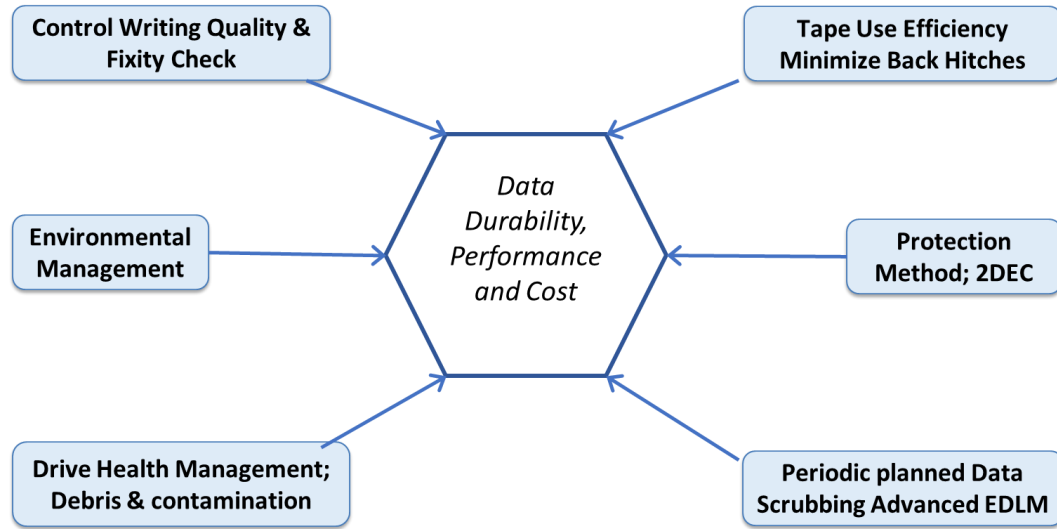
Tape vs HDD magnetic bit dimensions. Comparison based on Areal Density Roadmap



Key Features of How to Manage new generation of LTO

- Magnetic bit scaling continues to shrink, approaching the density levels seen in early 1TB HDDs.
- Environmental factors, including particulate contamination, remain critical determinants of performance.
- Optimizing tape use efficiency by minimizing back hitches and excessive tape motion is essential.
- Effective management of drive health, particularly head condition, is crucial for longevity and performance.
- Ensuring high-quality writes, managing ERP events (Soft Write Errors), and maintaining format integrity are vital.
- *Bit Error Rate (BER) serves as a key metric for evaluating the quality of data stored in offline archives but is not indicative of data integrity during restoration.
- *The durability of operational data is influenced by infrastructure, environmental conditions, and system architecture, in addition to UBER, where end-user experiences may vary.
- * Erasure-Coded tape technology leveraging encoded objects or files across multiple tapes similar to HDD applications, enhances availability via RAIL libraries while maintaining a high level of operational reliability (NINES); an excellent compliment to UBER
- SCSI Log Pages; they contain valuable information regarding tapes and drive health and condition but may require AI/ML based data analytics. <https://cds.cern.ch/record/2297174/files/pdf.pdf>

On Managing LTO Tapes the QTM way; ASCS & QTM Libraries, i7



Use of Log Pages with ML algorithms to insure write & read quality

Minimize back Hitches, under and over runs

Use of intelligent reads with efficient object orders; RAO

2DEC to provide high availability, durability NINES

Efficient Data Migration

Minimize soft ERP errors in Write and Reads

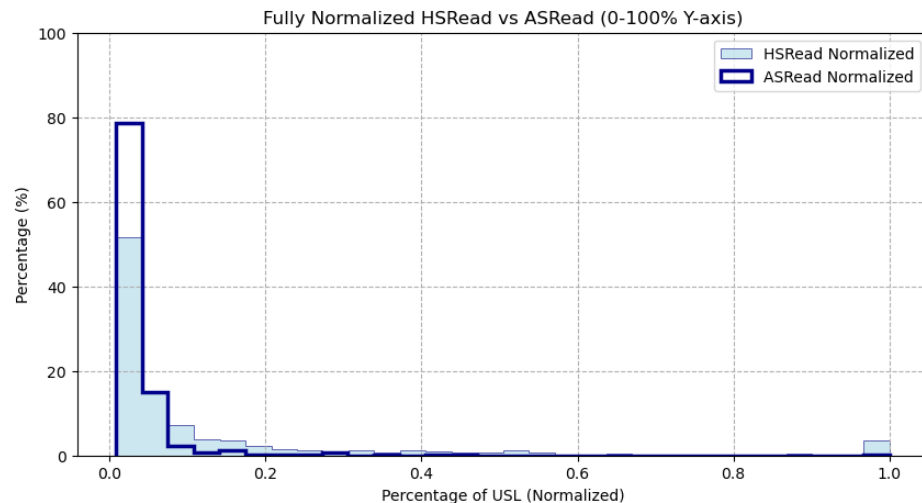
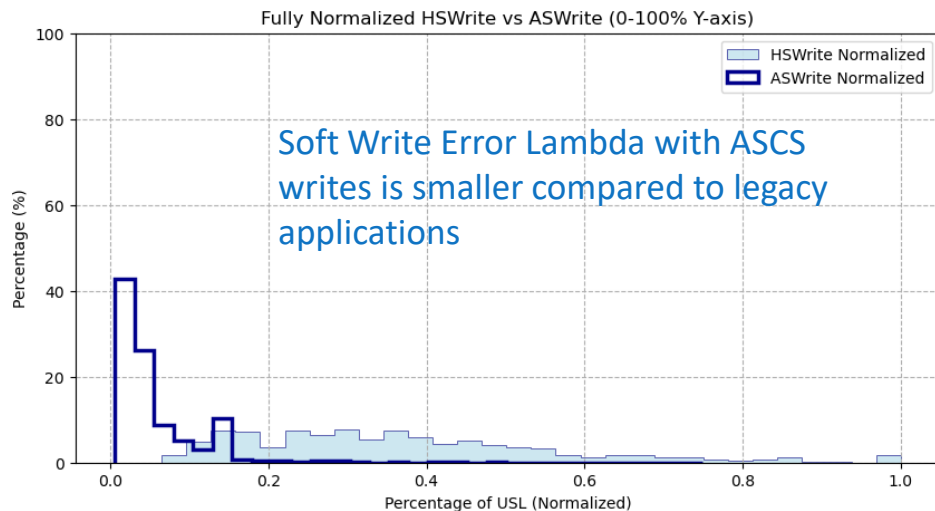
End to End Fixity checks

Periodic scrubbing with self repairs (2DEC is an enabler with Locally Self Repairable Tapes)

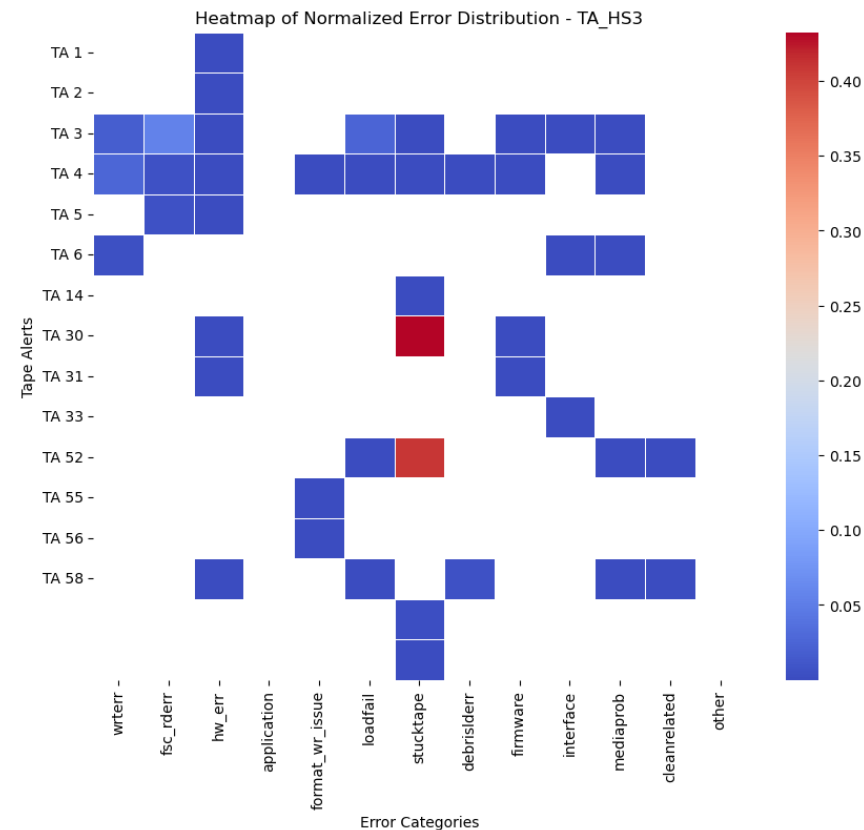
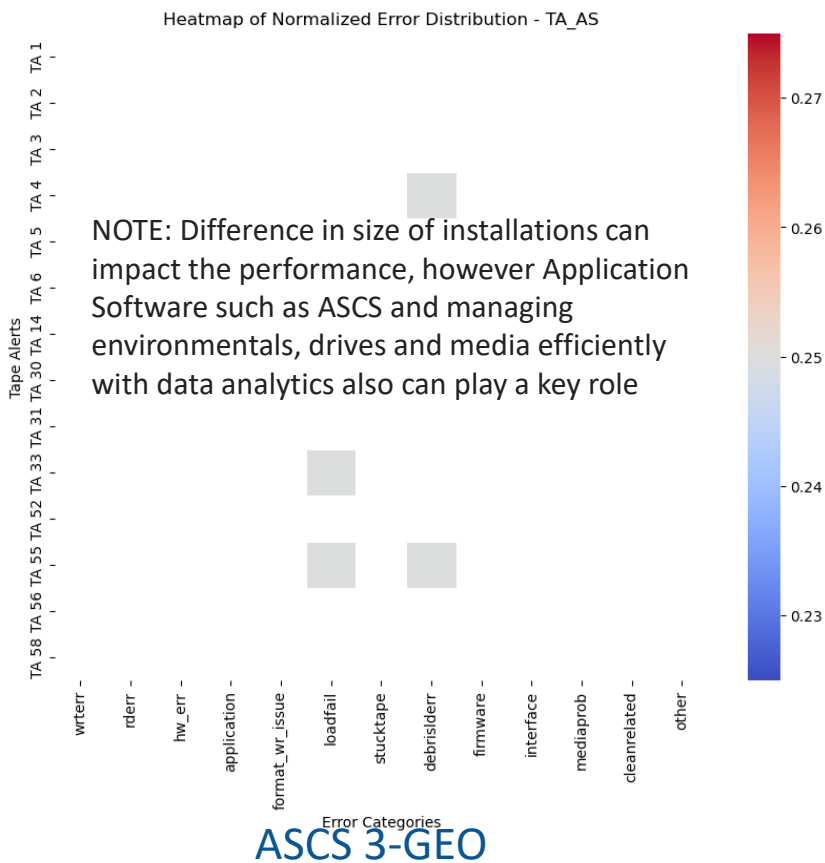
i7 based environmental management with drive health management

"To get a better understanding of Erasure Coding with Tapes, one may need to look at the revolution that has taken place in HDD servers starting late 1980's when researchers at the University of California, Berkeley, offered a more automated and efficient way to achieve redundancy and speed improvements called RAID technology. Before the widespread use of RAID, basic data redundancy often involved copying data to multiple hard drives like what current tape systems do." <https://insic.org/roadmap/> INSIC 2024 Roadmap

Comparative Analysis of Soft Error Write and Restore Performance: Large-Scale LTO-9 System vs. 3-GEO ASCS System with 2DEC RAIL Application



Soft errors are Write and Read ERP events as defined by SCSI document;
These ERP events may include occurrences from both temporary and permanent errors
As Recorded Magnetic Bit dimensions decrease, systems will experience different ERP signatures (impact of Generation)
QTM uses a normalized ERP based on Wrap/Data written & read with Historical distributions per generation based on SCSI logpage metrics

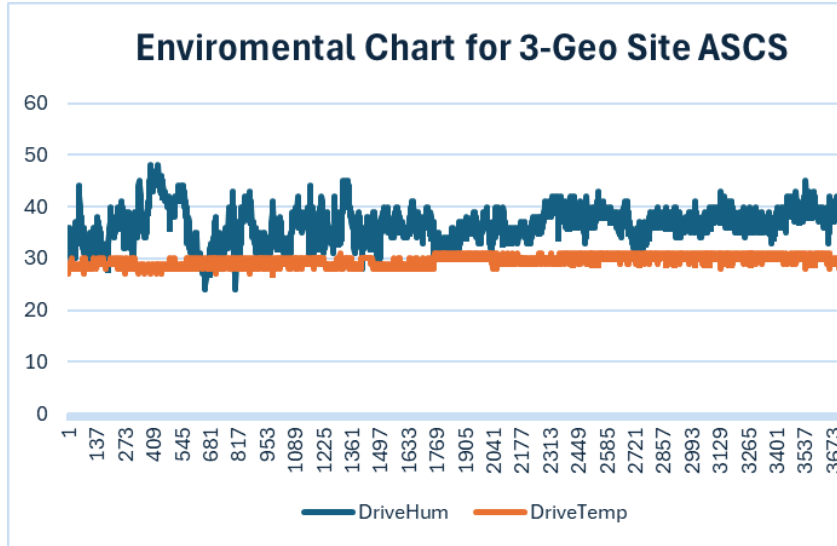


Large Scale application

Comparative Analysis of Tape Alert & Drive Error Performance:

ASCS Environmental Operation & ASHRAE Control Zones

Nearly perfect operation yet in reality outside recommended range of LTO however optimum performance. Requires close supervision and monitoring of system while operating or idle.



LTO-9 recommended Range

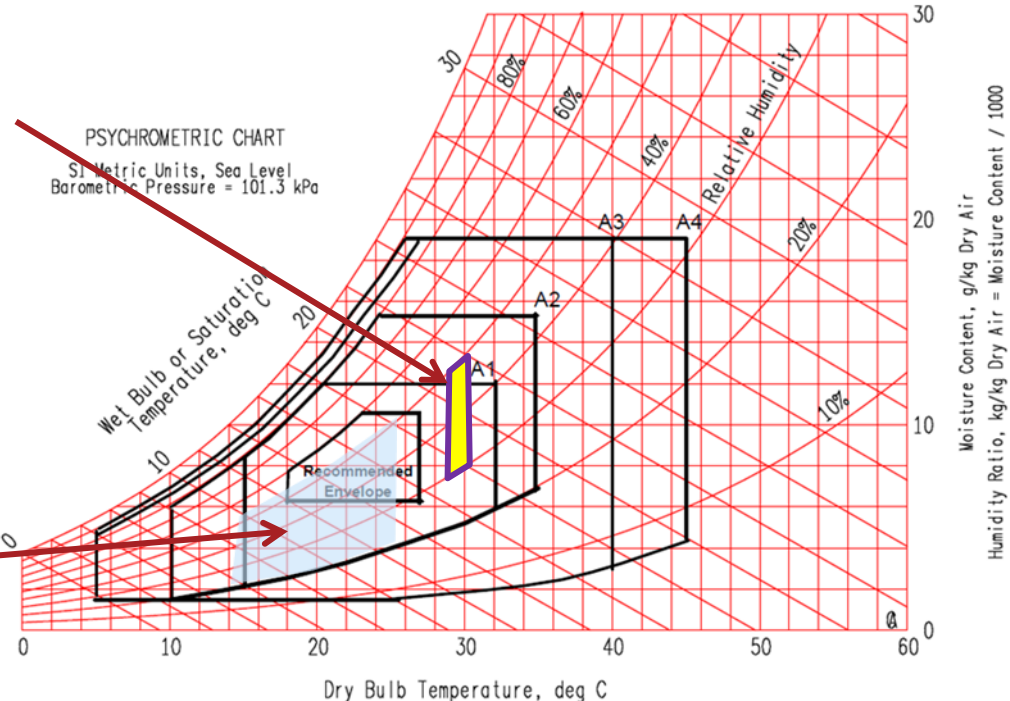


Figure 2. ASHRAE Environmental Classes for Data Centers

LRC vs 2D EC Protection Policy and why it matters?

Locally Repairable Codes (LRC) :

Locally Repairable Codes (LRC) are an advanced **error correction technique** used in **data storage systems** to enhance reliability and reduce repair overhead in the event of data loss or corruption.

LRC is widely implemented in modern **cloud storage, distributed storage systems, and HDD/SSD architectures**.

When a data block becomes corrupted or unavailable, LRC allows the system to reconstruct the missing data using fewer additional blocks, rather than requiring access to all distributed copies or parity blocks. This approach reduces repair time and minimizes I/O overhead, making it highly efficient for high-performance storage and distributed databases.

LRC in Quantum's 2D EC Protection Policy

QTM's **2D EC (Two-Dimensional Erasure Coding)** integrates **LRC principles** to:

- ✓ Ensure each **tape is self-sufficient** for most repairs.
- ✓ Reduce latency in **data migration** tasks.
- ✓ Minimize the need for **retrieving data from multiple tapes** when an error occurs.

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