Technical Support Services Contract (TSSC)					
USGS EROS	140G0121D0001	Deliverable ID	128-5.110.1.W01.7-A3560		
FY25 Offline Archive Media Trade Study		Date	05/30/25	Version No.	1.0

Archive and Records Management

Fiscal Year 2025
Archive Media Trade Study

This delivery is official submission to the USGS under the TSSC contract 140G0121D0001

TSSC Fiscal Year 2025
Offline Archive Media Trade Study

Remote Sensing, Committee on Earth Observation Satellites (CEOS), and Archives Coordination Project

By Tom Bodoh[1]

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Contract: 140G0121D0001 **Date Modified:** 05/30/25

[1] KBR, Inc., contractor to the U.S. Geological Survey, work performed under U.S. Geological Survey contract 140G0121D0001

Abstract

This document is a trade study comparing offline digital archive storage technologies. The document compares and assesses several technologies, and recommends which technologies could be deployed as the next-generation standard for the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center.

Archives must regularly migrate to the next generation of digital archive technology, and the technology selected must maintain data integrity until the next migration. This document is the Fiscal Year 2025 revision of a study completed in Fiscal Year 2001 and revised in Fiscal Years 2003, 2004, 2006, 2008, 2010, 2012, 2014, 2016, 2018, 2020 and 2023.

Preface

This document contains the Offline Archive Media Trade Study prepared by KBR, Inc. for the U.S. Geological Survey. It presents background, technical assessment, test results, and recommendations as a result of the study.

The U.S. Geological Survey uses trade studies and reviews for internal purposes and does not endorse vendors or products. The results of the study were determined by criteria weights selected by the U.S. Geological Survey to meet its unique requirements. Other organizations could produce different results by altering the criteria weights to meet their own requirements.

Acknowledgement

The author would like to thank the following staff who provided input and review: Kim Brown, Brent Nelson, Greg Land, and Sheri Evenson.

Revision History

February 2004
Added revision history page. No revision history is available for the FY03 revision.
Changed to allow for consideration of helical scan if certain performance criteria are met.
Added LTO2 as a current archive technology.
Added SAIT-1 and SDLT 600 as considered drives.
Replaced IBM 3590 with IBM 3592.
Removed LTO1 and SDLT 320 from the study.
Considered all drives in the study.
Increased the minimum specifications for capacity and transfer rate.
Revised cost scenarios and reduced the number of cost scenarios to three.
Removed transfer-time scenarios.
Removed maintenance from cost scenarios.
Removed criteria indicating multi-vendor availability as an advantage.

September 2006
Overall refresh of study.
Revised description of drive classes (enterprise, backup).
Added LTO3, TS1120, T10000, and DLT-S4 as current technologies and removed drives they replaced.
Added LTO4 and SAIT2 as future technologies.
Made vendor analyses formula more equitable by increasing weighting of company age.
Added citation appendix.

June 2008
Overall refresh of study, removing most references to older technologies.
Added disk as a dismissed technology.
Changed LTO4 to a current technology.
Added T10000B, LTO5, and TS1130 as future technologies; deleted LTO3, SAIT1, and SAIT2.

Modified so that future technologies are no longer scored.
Decreased the number of drives for scenarios 2 and 3.

June 2010
Overall refresh of study, removing most references to older technologies (T10000, LTO4, DLT).
Changed T10000B, LTO5, and TS1130 to current technologies.
Added T10000C, LTO6, and TS1140 as future technologies.
Removed maintenance costs because of lack of data.
Adjusted minimum transfer rate and capacity to be considered for the study.

June 2012
Overall refresh of study, removing most references to older technologies (T10000B, TS1130).
Changed T10000C and TS1140 to current technologies.
Added T10000D and TS1150 as future technologies.
Removed references to CD-ROM, DLT 8000, QIC, Mammoth, Erasable Optical (EO), HD-DVD, and 9840 under dismissed technologies.
Removed row from table that showed all drives use the same offline storage shelving.
LTO drive price is now for robotic drives.
Removed future drives from analysis tables.
Removed drive warranty row from table.

August 2014
Overall refresh of study, removing most references to older technologies (T10000C, LTO5)
Removed most mentions of DLT.
Added mention of cloud.
Changed T10000D and LTO6 to current technologies.
Added T10000E and LTO7 as future technologies.
Increased the minimum criteria for the study to a capacity of 2 TB and a transfer rate of 150 megabytes per second (MB/s).
Increased the number of passes in the design criteria formula to accommodate increasing pass specifications.
Tape-drive cost estimate now includes 1-year warranty/support.

Increased the total capacity for each of the three scenarios.
Changed the drive compatibility table and calculation to improve applicability to archiving.

July 2016
Overall refresh of study, removing most references to older technologies.
Changed LTO7 and TS1150 to current technologies.
Added LTO8 and TS1160 as future technologies.
Removed reference to Tandberg VXA-320, which is retired.

July 2018
Overall refresh of study, removing most references to older technologies.
Changed LTO8 and TS1155 to current technologies.
Added LTO9 as a future technology.
Oracle T10000D changed to non-evaluated status since Oracle has ceased further tape drive development. For this iteration of the study, the T10000D will be left in the specification table since it is still sold.
Cloud was added to the specification table but is a dismissed and non-evaluated technology in this iteration of the study.
In the Vendor Analyses criteria calculation, adjusted the start of the IBM TS11 technology line to begin with the model 3592 tape drive in 2003 instead of the model 3590 tape drive in 1995.

August 2020
Overall refresh of study.
Noted that Oracle has exited the tape drive market, thus removed the T10000D from comparison.
Noted the pending transition from an Oracle SL8500 robotic tape library with Oracle T10000D, LTO7, and LTO6 drives, to a Spectra Logic TFinity ExaScale robotic tape library with IBM TS1160 and IBM LTO8 drives that were moved from the SL8500.
Replaced TS1155 with TS1160 as a current technology and added TS1170 as a future technology.
Replaced AWS Glacier with AWS Glacier Deep Archive.
Increased the minimum criteria for the study to a capacity of 10 TB and a transfer rate of 300 MB/s.

May 2023
Overall refresh of study.
Removed Tape Velocity (Read) as a specification, since it’s not available for LTO or TS11 drives.
Removed references to the retired Oracle SL8500 robotic tape library.
Added LTO9 to the list of drive models in use in the TFinity robotic tape library.
Increased the minimum criteria for the study to a capacity of 15 TB and a transfer rate of 350 MB/s.
Increased the total storage for each of the three cost scenarios.
Changed measured capacity from TB to TiB.

May 2025
Overall refresh of study.
Added TS1170 as a current model, and TS1180 as a future model.
Removed tape drive pricing since LTO and TS11 robotic drives have been similar in the past, there is no list price, and no actual pricing is available without a proprietary quote.
Removed reference to disk stiction, since modern hard drives prevent the head from resting on the platter.

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Section 1 Introduction

1.1 Purpose and Scope

Typically, the purpose of a trade study is to analyze several courses of action and to provide the necessary information for the sponsor to reach a conclusion. In other cases, a trade study may revalidate an ongoing course of action.

This document assesses the options for the next generation of offline digital archive storage technology to be used for the digital archives of the U.S. Geological Survey (USGS). The selected technology must be capable of safely retaining data until space, cost, and performance considerations drive the next media migration. Data must be migrated before integrity degrades.

Most of the USGS working archive holdings reside on nearline robotic tape storage and are backed by an offline master copy. The nearline copy is referred to as the working copy. An ongoing need exists for offline storage for infrequently used working copies and for master and offsite copies, where the working copy is stored nearline. An offline copy stored in a secure offsite location reduces the chance of corruption or tampering; online or nearline methods are susceptible to intentional or unintentional corruption, regardless of the probability.

Linear Tape-Open (LTO) has been the offline archive media of choice at the USGS Earth Resources Observation and Science (EROS) Center since 2003. There is no compelling reason for the USGS to change technologies at this time and given the advantages of intergeneration read compatibility in an offline archive environment, there will be a continued interest in “staying the course” with LTO technology for the foreseeable future.

The predisposition to use LTO technology does not negate the need to periodically revisit offline storage technologies to stay informed of changes. When, or if, LTO no longer meets EROS requirements, this study (in future revisions) will show the way to the emerging replacement.

This study does not advise the online and nearline technologies used at EROS. The current nearline mass-storage system at EROS contains a Hierarchical Storage Management (HSM) system using a Spectra Logic TFinity ExaScale robotic tape library, IBM TS1160 tape drives, IBM LTO8 tape drives, IBM LTO9 tape drives, Versity Storage Manager (VSM) HSM software, Linux/Intel based servers, and a multi-vendor disk cache. A separate trade study using a different set of requirements determined the architecture of the HSM system.

The HSM system generates the offline and offsite archives using drives recommended in prior versions of the Offline Archive Media Study. This study determines the best offline archive media to meet EROS requirements. The findings of this study should not be misconstrued as an analysis of any specific technology for other purposes, such as enterprise backup or robotic nearline storage. Changing the criteria-weighting factors would produce different findings tailored to other specific circumstances.

1.2 Background

The USGS EROS Center near Sioux Falls, South Dakota, continues to archive offline datasets using several technologies. Table 1-1 shows the offline archive tape media used at EROS since tape archiving began, with the currently used media shown in bold.

Tape drive technology	Years used at EROS	Native capacity	Native transfer rate	Type
HDT	1978–2008	3.4 GB	10.6 MB/s	Analog
3480	1990–2003	200 MB	2.0 MB/s	Digital
DCT (Ampex DCRsI)	1992–2007	45 GB	12.0 MB/s	Analog
3490	1995–2003	900 MB	2.7 MB/s	Digital
DLT 7000	1996–2006	35 GB	5.0 MB/s	Digital
SuperDLT 220	1998–2008	110 GB	10.0 MB/s	Digital
Oracle 9940B	2002–2011	200 GB	30.0 MB/s	Digital
HPE LTO Ultrium 2	2003–2007	200 GB	40.0 MB/s	Digital
HPE LTO Ultrium 3	2005–2010	400 GB	80.0 MB/s	Digital
HPE LTO Ultrium 4	2008–2015	800 GB	120.0 MB/s	Digital
HPE LTO Ultrium 5	2010–2017	1.5 TB	140.0 MB/s	Digital
HPE LTO Ultrium 6	2013–2020	2.5 TB	160.0 MB/s	Digital
IBM LTO Ultrium 7	**2016-present**	**6.0 TB**	**300.0 MB/s**	**Digital**
IBM LTO Ultrium 8	**2018-present**	**12.0 TB**[2]	**360.0 MB/s**	**Digital**
IBM LTO Ultrium 9	**2022-present**	**18.0 TB**	**400.0 MB/s**	**Digital**

Table 1-1 Recent and current offline archive technologies used at EROS. (Currently used offline/offsite media in bold).

As technology advances, as datasets grow and media age, and as USGS Digital Library space fills, the USGS must migrate data to newer, more cost-effective, more physically compact, and higher-performing storage technologies.

1.3 Data Integrity

Because the foremost goal of an archive is data preservation, data integrity must be the primary criterion for selecting the drive technology. The following elements contribute to data integrity:

[2] Most of the LTO8 media written at EROS is actually LTO7 M8 media with a native capacity of 9 TB, written on LTO8 drives

- **The number of archival copies.** USGS archives must have working and master copies, and an offsite copy is desirable. The master and working copies will ideally use different media types so that media or drive issues do not risk both copies.
- **Drive reliability.** A slightly less reliable drive technology can be used, but only with a sufficient number of copies in the archive.
- **Storage location and environment.** Storage location and environment are a constant for all the technologies assessed because all EROS media are stored in a secure and climate-controlled environment.
- **Media composition.** Some media compositions last substantially longer than others, but all the technologies in this study use similar long-lasting media compositions.
- **Tape handling within the drive.** This characteristic defines how a tape is handled by the drive: whether contact is made with the recording surface, how many serpentine passes are required to read or write an entire tape, and the complexity of the tape path.
- **Error handling.** Drives typically minimize data loss through Cyclic Redundancy Check (CRC) or other data recovery methods, and allow data to be read after skipping past an error. Though error detection on write is required, additional attention to data recovery on read is a higher priority because media degradation will eventually lead to read errors.
- **Primary market**. This criterion describes the target market of a drive and the characteristics of drives in that market:
    - A drive targeted to the backup market is designed for write many/read rarely and depends more on write-error detection because the data are typically still available and can be easily rewritten. Backup drives are typically built for speed, capacity, and low cost.
    - A drive targeted to the enterprise market is designed for write many/read many use in a robotic library or auto-stacker, and equal emphasis is placed on detecting errors on read and write. Enterprise drives are typically built for reliability and speed, with capacity a secondary factor. Cost is not a primary consideration.
    - A drive targeted to the archival market would be designed for write once/read rarely, and equal emphasis would be placed on detecting errors on read and write; however, no drives are currently designed or marketed primarily for archiving. Most vendors would argue that their products are archive devices, but if forced to choose their primary market, no vendor would choose the limited archive market over the lucrative backup or enterprise markets.

Primary market	Reliability	Usage	Driving design factors
Backup	Moderate	Write many, read rarely	Low cost, high capacity, high speed
Enterprise	High	Write many, read many	High-duty cycle for drives and media used with robotics
Archive	High	Write once, read rarely	Long-term reliability

Table 1-2 Tape drive markets and characteristics.

The reliability of a long-term archive technology relates primarily to the long-term viability of the recorded media. Reliability in technology is difficult to determine except in retrospect, because a technology needs to be implemented early enough in the lifecycle so that drives can be kept working during the lifetime of a given media (or replaced with newer backward-compatible models).

This study bases its reliability assessment on experience with the vendor and its products, on specifications, on the experiences of others, or on experience gained from benchmarking.

1.4 Selection Criteria

The following criteria were used to determine which offline technologies should be considered:

1. The technology must be currently available, and it must be the most recent generation in a technology lineage which has ongoing development and a roadmap. Drives that are anticipated/announced but not available are mentioned but not ranked in the final analysis.
2. The technology must have a capacity of at least 15 terabytes (TB) [15,000 gigabytes (GB)] of uncompressed data.
3. The technology must have an uncompressed write transfer rate of at least 350 megabytes per second (MB/s).
4. The technology must use media that can remain readable for at least 10 years in a controlled environment. A lifetime of 10 years was selected because 10 years is the longest that a media technology would conceivably be used before space and transfer rate concerns would dictate a move to a new technology. Maintaining obsolete drives also becomes difficult and expensive after 10 years.
5. The technology must not be hampered by a poor reliability or performance history.

1.5 Drive technologies considered

The following currently available drive technologies were selected for consideration:

- LTO9 (Linear Tape-Open)— International Business Machine (IBM) representative of models by Quantum and Hewlett Packard Enterprise (HPE).
- IBM TS1170

The following future drive technologies are mentioned but cannot be considered since they are not available yet:

- IBM LTO10
- IBM TS1180

1.6 Dismissed Technologies

The following technologies were dismissed from analysis or consideration.

1.6.1 Magnetic Disk

Disk prices continue to drop; whereas reliability, performance, and capacity increase. Cost, management overhead, cooling, and power are considerations in using disk technology to archive large datasets. In the past several years, it has become feasible to store the working copy of some datasets, or parts of datasets, on disk as long as archive copies are retained, typically on tape. Although tape media could remain viable for as many as 10 years, the costlier disk typically is replaced every six or seven years to maintain supportability, reliability, space density, and performance. Disk is not designed, or often used, for offline storage.

1.6.2 Solid State Disk (SSD)

SSD prices continue to decrease; whereas reliability, performance, and capacity increase. It is expected that SSD will continue to gradually replace magnetic disk. SSD does offer some benefits regarding archive storage; it is expected to tolerate long shelf storage better than magnetic disk, which suffers from coating deterioration. Though SSD could become an option for future offline archive storage, it is too expensive to compete at this time and is not intended for offline storage.

1.6.3 CD, DVD, Blu-ray

Compact Disc (CD), Digital Video Disc (DVD), and Blu-ray consumer-grade optical technologies once seemed promising from the standpoint of expected longevity of the media; however, low capacity per media, low transfer rates, lack of media protection (no shell), no single standard, and high media costs describe a product that simply will not work for high-volume archival use.

CD, DVD and Blu-ray do not meet the evaluation criteria for this study. The market for optical disc is driven by entertainment but is nearly deprecated as the entertainment industry has largely transitioned to online content.

1.6.4 Newer Storage Technologies

Several high-capacity optical disk technologies have been in the development phase for the past few years. Of the technology proposals that have appeared in trade journals and at conferences, none are currently available.

Optera recently announced development of Fluo-ray optical disks, with a predicted initial cost of $1 per TB, and $1 per 10 TB by the end of the decade (Williams, 2025).

In 2022, Folio Photonics announced development of a new optical storage media, with an initial capacity goal of 1 TB per disk and 10 TB per cartridge. There are plans to increase capacity using multiple layers, and they anticipate product release in 2026 (StorageReview, 2022). On the Folio Photonics site, they anticipate 16+ layers, a 100+ year lifespan, and a media cost of $3/TB with a roadmap to <$1/TB. For comparison, they cite an LTO media cost of $8/TB, though this study shows a current LTO9 media cost of $5.00/TB in Table 3-4, based on current cartridge costs in quantity 20.

One high-tech example of future technologies is holographic storage. Products have been repeatedly announced, specifications advanced, and subsequently delayed. Holographic Versatile Disc (HVD) specifications indicated a planned capacity of 6 TB per disk, but lack of funding halted the effort. (Sioni, 2019).

In 2018, RMIT University in Australia and Wuhan Institute of Technology in China announced development of a next-generation optical disk that would hold 10 TB of data and last longer than 600 years (Zhang, Q., 2018). There has been no further mention of the technology.

In 2016, Sony released its petabyte-scale Everspan Optical Robotic Library. The website later shut down, and there is no indication that the technology ever shipped.

Another example of potential future developments is a 2020 announcement by Fujifilm and IBM of Strontium Ferrite (SrFe) coating technology which could result in a tape product with a capacity of up to 580 TB (Zhang, M., 2020). Since IBM develops both the LTO and TS11 tape technologies, any new tape technology investigation IBM is involved in could ultimately benefit both LTO and TS11 evolution. The tape composition of the IBM TS1170 JF media utilizes a hybrid of Barrium Ferrite and Strontium Ferrite (BaFe + SrM) to achieve a 50-TB capacity per tape.

1.6.5 Cloud Storage

Though not an offline media, cloud storage is a potential offsite storage alternative, which could be used as one copy of an archive. There is no stated Bit Error Rate (BER) for Amazon Web Services (AWS) Glacier Deep Archive, but it is advertised as having 99.999999999 percent availability. Currently online public cloud storage has significant cost considerations for petabyte-scale datasets but could be leveraged as a working copy of limited datasets. Current Glacier Deep Archive cost is $.00099/GB/Mo. Other considerations include data integrity, location, security, and contract termination. Public cloud storage would currently cost considerably more than storing tapes at the National Archives and Records Administration (NARA). Cloud storage would not eliminate the mandate for deep archive storage at NARA.

Section 2 Technical Assessment

2.1 Analysis

This technical assessment includes drives selected for final evaluation (LTO9 and TS1170) and drives anticipated to be released in the next few years (LTO10 and TS1180). LTO drives are available from multiple vendors (Quantum, IBM, and HPE), with an IBM drive selected to represent LTO technology in this study. The following offline storage technologies will be evaluated, but only the drives shown in bold will be included in the analysis and final evaluation:

- **IBM LTO9**
- IBM LTO10
- **IBM TS1170**
- IBM TS1180
- AWS Glacier Deep Archive

Specification	LTO9	LTO10	TS1170	TS1180	AWS S3 Glacier Deep Archive
Uncompressed capacity	18 TB	30 TB	50 TB	80 TB	Unlimited
Uncompressed transfer rate	400 MB/s	400 MB/s	400 MB/s	1000 MB/s	Unknown
Recording technology	Serpentine	Serpentine	Serpentine	Serpentine	Unknown
Tracks	8,960	TBD	18,944	TBD	NA
Channels (tracks at once)	32	32 or 64	32	32 or 64	NA
Passes[3]	280	TBD	592	TBD	NA
Usage type	Backup	Backup	Enterprise	Enterprise	Enterprise
Encryption support	HW built in	HW built in	HW built in	HW built in	None
Buffer size	1 GB	1 GB or 2GB	2 GB	2 GB or 4 GB	NA
Adaptive speeds	Dynamic 12	Dynamic 12	Dynamic 12	Dynamic 12	NA
Previous generations read	1	TBD	0	TBD	NA
Previous generations written	1	TBD	0	TBD	NA
Residual Bit Error Rate (RBER)	$1x10^{-19}$	$1x10^{-19}$	$1x10^{-20}$	$1x10^{-20}$	Unknown
Drive manufacturers	3	3	1	1	NA
First availability	Sep 2021	Jun 2025	Aug 2023	2027 or later	2019

Table 2-1 Technology comparison.
(Yellow-highlighted columns indicate unverified information.)

[3] As reported by vendor or calculated by dividing tracks by channels.

2.2 IBM LTO9

The LTO9 is the most recent available generation of the LTO tape family. EROS has ten LTO9 drives installed in the Spectra Logic TFinity robotic tape library. No non-robotic LTO9 drives have been deployed.

2.2.1 Advantages

- LTO has enjoyed phenomenal growth from the day of release in 2000. LTO has driven several competing technologies from the market, including Digital Linear Tape (DLT), Sony Super Advanced Intelligent Tape (SAIT), and Oracle T10000.
- Native capacity is 18.0 TB and native transfer rate is 400 MB/s.
- The LTO9 drive can adapt the transfer rate to match the streaming speed of the source.
- LTO9 is backward read/write compatible with LTO8, but not the LTO7 M8 media written by LTO8 drives.
- LTO was developed by a consortium of HPE, IBM, and Quantum and is licensed to others, including media manufacturers. This wide acceptance has introduced competition which has, in turn, controlled costs. Compatibility tests are performed by the vendors.
- The LTO9 has a 1-gigabyte (GB) buffer that prevents occasional data starvation from reducing the transfer rate.
- Hardware encryption is built in.
- Supports Linear Tape File System (LTFS).
- The Barium Ferrite (BaFe) tape media formulation used by LTO7 and later drives has proven much more stable than the previous metal particle (MP) media, minimizing labor for problem analyses.

2.2.2 Disadvantages

- LTO9 requires calibration on first insertion into an LTO9 drive. This should be done in the environment where it’s intended to be used, though some vendors are pre-calibrating tapes since it can take 35 to 120 minutes per tape.
- LTO is targeted to the backup market where speed, capacity, and cost are more important than long-term integrity of the data. Because backup tapes are write many/read rarely, errors would likely show up in a write pass where the errors can be worked around (rewrites) or the media discarded.
- Frequent end-to-end use of a tape would be a concern because one end-to-end read/write incurs 280 passes (8,960 tracks divided by 32 channels). Multiple passes should not be a concern for archive operations because use is limited.
- Each generation of LTO requires new media to attain the rated capacity, ensuring that media costs will be higher until market saturation drives the price down.
- LTO was designed as moderate-use storage media, with the tape cartridge and drive not built to withstand constant enterprise/robotic use.
- IBM, HPE, and Quantum co-develop LTO. With this kind of partnership, each vendor might interpret the specifications differently and might design drives that may have incompatibilities, though compatibility tests are performed.

- The LTO9 is backward-read compatible with only one generation (LTO8), not two generations as with LTO3 through LTO7. Notably the LTO9 will not read LTO7 M8 media written by LTO8 drives.

2.2.3 Summary

LTO9 drives have been tested at EROS, and the capacity and read/write performance information was used in the upcoming sections.

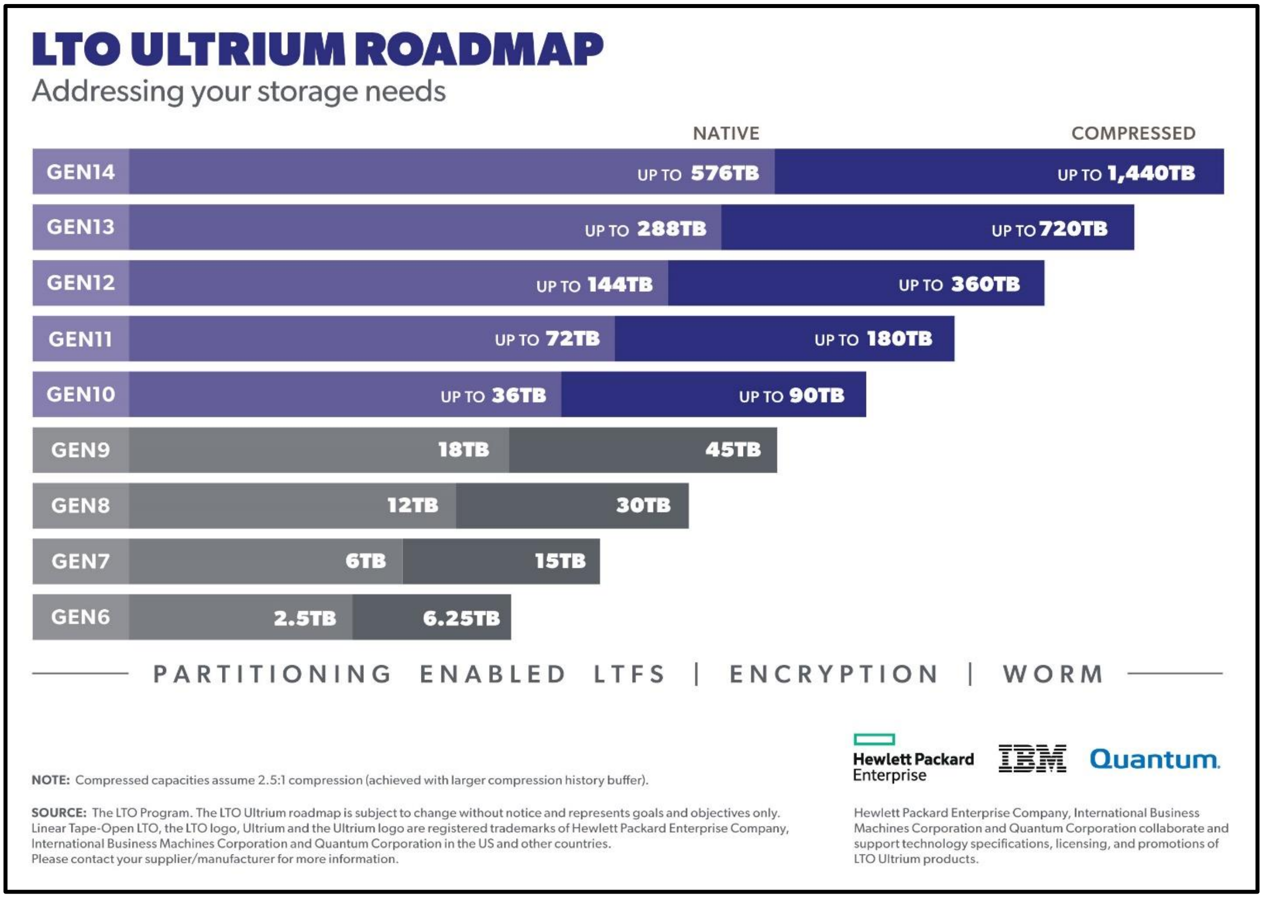

Figure* 2- *LTO Roadmap (source: LTO Consortium).

2.3 IBM LTO10

The LTO10 is the next anticipated generation of the LTO tape family, with release in June of 2025.

2.3.1 Advantages

- LTO has experienced phenomenal growth.
- Native capacity is 30 TB and the native transfer rate is 400 MB/s.
- The LTO10 drive is anticipated to use an adaptive transfer rate to match the streaming speed of the source.
- The LTO10 may be backward read compatible with LTO9 media, unless there are major technology changes such as tape composition or number of channels.
- LTO was developed by a consortium of HPE, IBM, and Quantum and is licensed to others, including media manufacturers. This wide acceptance has introduced competition, which has, in turn, controlled costs. Compatibility tests are performed by the vendors.
- Hardware encryption is anticipated.
- LTFS support is anticipated.

2.3.2 Disadvantages

- LTO is targeted to the backup market, where speed, capacity, and cost are more important than long-term integrity of the data. Because backup tapes are write many/read rarely, errors would likely show up in a write pass, where the errors can be worked around (rewrites) or the media discarded.
- Frequent end-to-end use of a tape would be a concern because one end-to-end read/write incurs at least 280 passes. Multiple passes should not be a concern for archive operations because use is limited.
- Each generation of LTO requires new media to attain the rated capacity, ensuring that media costs will be higher until market saturation drives the price down.
- LTO is a moderate-use storage media, with the tape cartridge and drive not built to withstand constant use.
- IBM, HPE, and Quantum co-develop LTO. With this kind of partnership, each vendor might interpret the specifications differently and might design drives that may have incompatibilities, though compatibility tests are performed.

2.3.3 Summary

LTO10 drive and media shipments will begin in June 2025. Since LTO10 is not yet available, full specifications are unknown, and it was not assessed in the final evaluation.

2.4 IBM TS1170

The TS1170 is an enterprise-class tape drive, used primarily in IBM and Spectra Logic robotic libraries and autoloaders.

2.4.1 Advantages

- Lineage includes the reliable 3480, 3490, 3590, 3592, TS1120, TS1130, TS1140, TS1150, TS1155, and TS1160.
- Supports dual 16-gigabits-per-second (Gbps) Fiber Channel interfaces, or dual 12-Gbps SAS interfaces.
- Native capacity is 50 TB and native transfer rate is 400 MB/s.
- The TS1170 drive can adapt the transfer rate to match the streaming speed of the source.
- The TS1170 has a 2-gigabyte (GB) buffer that prevents occasional data starvation from reducing the transfer rate.
- The TS1170 is a robust storage technology, with the tape cartridge and drive built to withstand constant, or frequent, use in a robotic environment.
- Hardware encryption is built in.
- Supports LTFS.
- The tape composition of the IBM TS1170 JF media utilizes a hybrid of Barrium Ferrite and Strontium Ferrite (BaFe + SrM) to achieve the 50-TB capacity per tape.

2.4.2 Disadvantages

- Frequent end-to-end use of a tape would be a concern because one end-to-end read/write incurs 592 passes. Multiple passes should not be a concern for archive operations because use is limited.
- The TS1170 is not backward read-or-write compatible.

2.4.3 Summary

IBM TS1170 drives have not been tested at EROS. TS1170 drive specifications for capacity and read/write performance were used in the upcoming sections.

2.5 IBM TS1180

The TS1180 is anticipated to be the next major generation of the 3592-tape family, with release expected in 2027 or later.

2.5.1 Advantages

- Lineage includes the reliable 3480, 3490, 3590, 3592, TS1120, TS1130, TS1140, TS1150, TS1155, TS1160, and TS1170.
- Should support dual 16-gigabits-per-second (Gbps) Fiber Channel interfaces, or dual 12-Gbps SAS interfaces. Faster interfaces may be offered.
- Native capacity is expected to be up to 80 TB and native transfer rate is anticipated to be as high as 1000 MB/s.
- The TS1180 is expected to be a robust storage technology, with the tape cartridge and drive built to withstand constant, or frequent, use in a robotic environment.
- The TS1180 may be backward read compatible with the TS1170 JF media, unless there are major technology changes such as tape composition or number of channels.
- A hardware encryption feature should be included in the drive.
- Expected to support LTFS.
- The tape composition of the IBM TS1180 media may utilize a hybrid of Barrium Ferrite and Strontium Ferrite as with the TS1170, or may utilize Strontium Ferrite only.

2.5.2 Disadvantages

- Frequent end-to-end use of a tape would be a concern because one end-to-end read/write incurs many passes. Multiple passes should not be a concern for archive operations because use is limited. If the number of channels doubles to 64 tracks per pass in the TS1180, it would cut the number of passes in half as compared to 32 tracks per pass.

2.5.3 Summary

IBM has not provided a tape drive roadmap for future TS11 drives, though there have been specifications floated for a likely TS1180 in the IBM 3592 Wikipedia page. Enterprise-class robustness is not required for the archive copy when the working copy of a dataset is on enterprise-class TS1160 technology in the EROS robotic library. Since TS1180 is not yet available, it was not assessed in the final evaluation.

2.6 AWS Glacier Deep Archive

Amazon Web Services (AWS) is the leading cloud vendor. In 2019, AWS released Glacier Deep Archive. Comparing a storage service to storage media is difficult, and the results of the comparison may not be useful.

2.6.1 Advantages

- The service has been in operation since 2019 and there is no indication that it will be retired in the near future.
- Capacity is theoretically unlimited as AWS has constantly grown total capacity, apparently staying ahead of demand. A customer with exabytes of data would almost certainly need to wait for resources to be added, but a planned move of petabytes of data should be possible if plans are shared with AWS in advance.
- Glacier Deep Archive could provide a strategically-placed copy of very infrequently used data, if the application is also on the cloud.
- All data is stored with redundancy.
- Migration to new media is automatic, at no charge, and disposal of the old media is the responsibility of AWS.
- The cost of Glacier Deep Archive is substantially cheaper than legacy Glacier.

2.6.2 Disadvantages

- Data recovery from a public-cloud archive, such as Glacier Deep Archive, would present challenges, such as retrieval fees, egress fees, and potential long delays.
- Data is not stated as being encrypted at the hardware level.
- Retrieval times are significantly longer than standard Glacier.
- AWS Glacier Deep Archive storage fees of $.00099/GB/month are lower than some competitors, but still substantial for large archives. An archive containing 20 PB (petabytes) would cost approximately $237,600/year, not including retrieval fees or egress fees.

2.6.3 Summary

While there is increasing use of public cloud for strategic applications, archiving solely on the cloud would effectively delegate archive responsibility to the cloud vendor, which is a responsibility they might not accept. While there might be a benefit to strategically placing a copy of an archive on the cloud, retaining the primary archive copy at a government site is advisable. Costs would be a significant consideration, particularly if distributing from deep cloud storage such as Glacier. AWS Glacier Deep Archive was not assessed in the final evaluation.

Section 3 Tables

3.1 Design criteria

The design criteria and target market of a drive are interrelated (Table 3-1). LTO9 is targeted to the backup market, as demonstrated by LTO marketing. The TS1170 is targeted to the enterprise (data center) market.

A drive targeted to the backup market is designed for write many/read rarely and depends on write error detection because the data are still available and can easily be rewritten. Backup drives are typically built for speed, capacity, and low cost.

A drive targeted to the enterprise market is designed for write many/read many use in a robotic library, and equal emphasis is placed on detecting errors on read and write. Enterprise drives are typically built for reliability and speed, with capacity as a secondary factor. Cost is not a primary consideration to enterprise users willing to pay for quality.

A drive targeted to the archival market would be designed for write once/read rarely, and more emphasis would be placed on detecting and correcting errors on read; however, there are currently no drives designed or marketed primarily for archive use.

The following formula ranked design criteria:

(((1000 - serpentine passes) /10) +

(absolute value of error rate exponent / 2) +

(construction 3=moderate usage, 5=high usage))

/ 8.45 (to adjust the highest rank to 10)

Technology	Tracks/Serpentine Passes	Target Market	Tape Composition	Uncorrected Error Rate	Cartridge Construction Rating	Head Contact	Ranking
IBM LTO9	8,960/280	Backup	BaFe	$1x10^{-19}$	Moderate usage	Contact	10.0
IBM TS1170	18,944/592	Enterprise	BaFe + SrM	$1x10^{-20}$	High usage	Contact	6.6

Table 3-1 Design criteria and target market.

3.2 Transfer Rate

Transfer rate is important because it establishes how quickly the migration and verification of an archive dataset may be completed and how fast a recovery can be completed. The minimum write transfer rate requirement is 350 MB/s, with 375 MB/s desired. Much of the data archived at the USGS are raster imagery that typically lacks repeatable patterns that would compress well; therefore, all transfer rates cited are native (uncompressed).

The ranking in Table 3-2 was determined by adding the actual or approximate read and write rates for each drive, setting the ranking for the fastest drive to 10, then ranking the others against the leader. For example, a drive having one-half of the total read/write transfer rate of the leader would be ranked 5. Since actual TS1170 transfer rates are not available, they were estimated by using the percentage of advertised rate from TS1160 tests and applying that to the TS1170 advertised rate.

Tape Drive Technology	Advertised Native Rate	Source of Test Results	Actual/approximate Native Write Transfer Rate	% of Advertised Rate	Actual/approximate Native Read Transfer Rate	% of Advertised Rate	Ranking
IBM LTO9	400 MB/s	EROS test	375 MB/s	93.8%	398 MB/s	99.5%	10.0
IBM TS1170	400 MB/s	Estimated	378 MB/s	94.5%	377 MB/s	94.2%	9.8

Table 3-2 Transfer rates.

3.3 Capacity

A secondary requirement is to conserve rack or pallet storage space and reduce tape handling by increasing per-media capacity. The current archive media of choice at EROS is LTO9 at 18 TB (16.37 TiB) of usable capacity per tape. The minimum capacity requirement for this study is 15 TB, with 20 TB or more desired. Both reviewed technologies exceed the 15 TB requirement based on the advertised capacity. Because much of the data archived are not compressible, all capacities are native (uncompressed).

The ratings were determined by computing each actual, or approximate, capacity score as a percentage of the highest capacity drive on a scale of 1 to 10, with the highest capacity as a 10. The source of the capacity ratings is noted in Table 3-3. Capacity yield varies by media vendor. Since actual TS1170 capacity is not available, it was estimated by using the percentage of advertised capacity from TS1160 tests and applying that to the TS1170 advertised capacity.

Tape Drive Technology	Advertised Native Capacity	Actual/estimated Native Capacity	% of Advertised Capacity	Ranking
IBM LTO9	18.0 TB (16.37 TiB)	16.37 TiB measured	100.0%	3.6
IBM TS1170	50.0 TB (45.48 TiB)	45.48 TiB estimated	100.0%	10.0

Table 3-3 Storage capacities.

3.4 Cost Analysis

Table 3-4 shows the relative media costs, and the cost per terabyte for media. Rankings were established by setting the least expensive media to 10, then rating the other against the lowest cost. Media costs per terabyte are based on advertised capacity. Prices are based on the lowest price present on the Web.

Accurate drive pricing is not readily available. The sales volume of tape drive models for use in robotic libraries is low enough that pricing is available only through a vendor quote, and quoted prices are proprietary information. Past purchases show the drive costs between the TS11 and LTO robotic-library models to be similar, with LTO being slightly lower.

Tape Drive Technology	Media $/unit[4]	Media $/TB	Ranking Media Cost/TB
IBM LTO9	$90	$5.00	10.0
IBM TS1170	$844	$16.88	3.0

Table 3-4 Media costs.

3.5 Scenarios

The media cost for three scenarios is shown in Table 3-5. Where there is market competition for media, a significant drop in media prices often occurs within six months after drive introduction. Tape drives are not included in the scenarios since pricing is not readily available, and when it was available in the past, the LTO and TS11 drive prices were similar.

Rankings are based on the 1,000-TB option and were established by setting the least expensive to 10, and then rating each of the others against the lowest cost. Advertised native capacities are used. The number of cartridges is rounded up where only a partial cartridge is required in the final cartridge to reach the stated scenario capacity.

Technology	500 TB	1000 TB	2000 TB	1000 TB Ranking
IBM LTO9	$2,500	$5,000	$10,000	10.0
IBM TS1170	$8,440	$16,880	$33,760	3.0

Table 3-5 Scenario costs (drives, media).

3.6 Vendor Analyses

When selecting an archive technology, it makes sense to look at the company and product histories. An analysis of each company and the stability of each technology is shown in Table 3-6. For this revision of the study, IBM produces both of the alternative drives, so the comparison comes down to the longevity of LTO and TS11 product lines. IBM is an established and stable company; therefore, this rating should not be viewed as a market analysis. The longevity rankings were determined by the following formula:

(company age + technology age) / 13.9 (to adjust the highest rank to 10)

[4] Cited media costs are in quantities of 20 at Tapeandmedia.com

Company	Technology	Years in Business	Technology Age in Years	Longevity Ranking
IBM	LTO	114 (1911)	25 (2000)	10.0
IBM	3592 (TS11)	114 (1911)	22 (2003)	9.8

Table 3-6 Vendor analyses.

3.7 Drive Compatibility

The level of intergeneration drive read compatibility and planned future drives are shown in Table 3-7. The column “Previous Generations Read” indicates backward-read compatibility. Backward-write compatibility is of little consequence for archiving, thus is not considered. Note that backward compatibility is prevented by drastic specification change such as tape formulation or number of channels. The column "Future Generations Mapped/Predicted" indicates the number of generations planned in the current drive family, following the current drive being evaluated. The following formula determined the ranking:

(Previous Generations Read + Future Generations Planned) x 1.667 (to adjust the highest rank to 10)

Technology	Previous Generations Read	Future Generations Mapped/Predicted	Ranking
IBM LTO9	1	5	10.0
IBM TS1170	0	1	1.7

Table 3-7 Drive compatibility.

3.8 Ranking Summary

The ranking summary provides a quick reference to the rankings.

Drive	Design Criteria	Capacity	Media Cost	Drive Compatibility	Transfer Rate	Vendor Analyses	Scenario Cost
IBM LTO9	10.0	3.6	10.0	10.0	10.0	10.0	10.0
IBM TS1170	6.6	10.0	3.0	1.7	9.8	9.8	3.0

Table 3-8 Ranking summary (blue indicates the highest ranking in category).

Section 4 Conclusions and Recommendations for USGS Offline Archiving Requirements

4.1 Weighted Decision Matrix

A weighted analysis of the drives considered is shown in Table 4-1. The criteria emphasize the importance of traits contributing to data preservation. The USGS made the final decision regarding which criteria to use and the relative weighting of the criteria. The columns with a green heading are relative ratings for each technology. The columns with a yellow heading are calculated by multiplying the relative weight by the relative rating. The following list describes each criterion:

- Design (reliability of media) — This criterion describes the ability of the media to remain readable with time. Included in this criterion is the number of passes per full-tape read or write, cartridge construction, and uncorrected BER. (Table 3-1).
- Capacity — This criterion describes the measured, or approximate, capacity per cartridge, which is typically less than the advertised capacity (Table 3-3).
- Media Cost per TB — This criterion is a rating of the relative cost per terabyte for media using the advertised capacity (Table 3-4).
- Compatibility — This criterion describes the likelihood that the drive technology will continue to evolve and the extent to which future drives will have backward read capability. This criterion gives an indication of the ability to maintain drives that can read an aging archive (Table 3-7).
- Transfer Rate — This criterion describes the aggregate read-and-write transfer rate, which is typically less than the advertised transfer rate (Table 3-2).
- Vendor Analyses — This criterion is the rating of the viability of the vendor and technology (Table 3-6).
- Scenario cost — This criterion is the rating of the cost of scenario No. 2, which comprises media cost. The advertised capacity is used (Table 3-5).

In the decision matrix spreadsheet shown in Table 4-1, not all criteria have been selected for the final analysis of this trade study. These unused criteria were provided in the spreadsheet so that users may insert the criteria weights for their specific application.

Selection Criteria	Wt	IBM LTO9	IBM TS1170	IBM LTO9	IBM TS1170
Design criteria		10.0	6.6	0.0	0.0
Capacity	20	3.6	10.0	72.0	200.0
Media cost/TB		10.0	3.0	0.0	0.0
Compatibility	15	10.0	1.7	150.0	25.5
Transfer rate	15	10.0	9.8	150.0	147.0
Vendor analyses	15	10.0	9.8	150.0	147.0
Scenario cost	35	10.0	3.0	350.0	105.0
Total Weighted Score				**872.0**	**624.5**

Table 4-1 Weighted decision matrix.

4.2 Conclusions and Notes

LTO9 achieved the highest total score in this study, though with proper handling and multiple copies, either of the technologies evaluated in this report could be deployed for offline archive use.

LTO9 has been installed and is being used as the current EROS offline archive technology, and TS1160 has been deployed as the nearline tape technology in the Spectra Logic robotic library. The TS1160 and LTO9 drives have both been tested by Information Management Services (IMS).

Using multiple tape technologies, where multiple copies of an archive exist, is an industry best practice which reduces the risk that a media or drive issue impacts all copies.

As any drive saturates the market, media costs drop, particularly for LTO since there are two cartridge manufacturers.

The BaFe tape composition of LTO will reach density limits around 48 TB per cartridge and is presumed to be followed by SrFe which would support higher density recording for several LTO generations.

Tunnel Magnetoresistance (TMR) tape head technology was implemented for LTO8. This and other changes are blurring the lines between enterprise and non-enterprise drives. Quantum has proposed that LTO is now an Enterprise drive (Quantum, 2018).

Note that technical trade studies might either recommend a new technology choice or validate continuing with the current technology choice.

4.3 Recommendations

Since TS1160 has been deployed as the nearline tape technology in the EROS TFinity ExaScale robotic tape library, and best practice is to utilize at least two different tape technologies for multiple archive copies, staying the course with LTO9 is advised.

1. The USGS should continue to utilize LTO9 as the offline storage media of choice, then test and consider adopting LTO10 when available.

2. To reduce risk, the USGS should continue the strategy of storing datasets on multiple technologies. For example, store a working copy of a dataset on nearline TS1160, store offline/onsite data on LTO9, and store offline/offsite copies on LTO9. This strategy partially mitigates the risks of one or the other technology failing or being retired prematurely. This practice has been implemented and should continue.

3. In addition to a nearline and offsite copy of a dataset, an onsite offline copy should be maintained, providing fast recovery without risking the shipping of the offsite LTO copy. This practice has been implemented and should continue.

4. The USGS periodically tests archive tapes for readability, which should continue. This testing should not be extensive enough to incur undue wear on the media or frustrate NARA, but should be frequent enough to provide an opportunity to detect deteriorating media. It is recommended to retrieve a box of media once per year from NARA so that a specific set of files can be tested. This practice has been implemented and should continue.

5. All archived files should be checksummed, with the checksum stored in the corresponding inventory record. When a file is retrieved from either the HSM or the offline media, integrity can be verified. Verification of each retrieved file may not be feasible because of CPU impacts. This practice has been implemented and should continue. Vendor verification features could be used, instead of or, in addition to file checksums.

6. All data should be migrated to new media approximately five years after writing. Although most tape technologies can reliably store data for much longer periods, after five years the transfer rates and densities that once were leading-edge will become problematic for recovery and storage, and drives will become difficult to maintain. This practice has been implemented and should continue.

7. As archive media is retired, at least 10 percent of the media should be read before disposal, to assess storage conditions and media viability. This practice has been implemented and should continue.

8. When writing archive tapes, the tapes should be verified on a second drive. This verification will help identify any drive incompatibility. This practice has been implemented and should continue.

9. Where possible, the USGS should avoid buying media brands that have proven unreliable. This is not an issue currently, as the two current manufacturers of LTO media, FujiFilm and Sony, produce quality media that is often rebranded. Though unlikely, this could become a concern if a new media manufacturer emerges.

10. The USGS should plan to update this trade study periodically. Annual updates are too frequent to observe market changes because drives are typically updated on a two- or three-year cycle. Each time this study is revisited, the highest-scoring technology may change, but this does not indicate that the USGS should change offline tape technologies frequently. Staying with a given technology for several years is beneficial, even if the technology is not continuously the leading technology. This study is a snapshot in time, and results would differ, even a few months earlier or later, because of new hardware releases. Continual consideration of new archival technologies, including public-cloud and SSD is advised.

Appendix A Supplemental Information

A.1 Vendor Sites

"Spectra Logic Advances Perpetual Archive Strategy with Enterprise-Wide LTO-10 Support" *https://spectralogic.com/press-releases/lto-10-enterprise-archive-support/* *(Spectra Logic)*

"Tape Roadmaps and Tape Library Innovation." https://youtu.be/-73u9AdsXKs (IBM)

https://www.ibm.com/products/lto-9-tape-drive (IBM)

"3592 tape drives."

https://www.ibm.com/docs/en/ts4500-tape-library/1.9.0?topic=drives-3592-tape (IBM)

"LTO Tape Drives." https://www.quantum.com/en/products/tape-storage/lto-tape-drives/ (Quantum)

"IBM Tape Library Guide for Open Systems."

https://www.redbooks.ibm.com/redbooks/pdfs/sg245946.pdf (IBM)

"Sony Develops Magnetic Tape Storage Technology with the Industry's Highest Recording Areal Density of 201 Gb/in^2."

https://www.sony.net/SonyInfo/News/Press/201708/17-070E/index.html (Sony)

"Data Storage Outlook 2023." https://spectralogic.com/white-papers/data-storage-outlook-2023/ (Spectra Logic)

"INSIC International Magnetic Tape Storage Technology Roadmap 2024"

https://www.lto.org/wp-content/uploads/2024/07/INSIC-International-Magnetic-Tape-Storage-Technology-Roadmap-2024.pdf (INSIC)

"Fujifilm develops technology to deliver the world's highest 580TB storage capacity for magnetic tapes using strontium ferrite magnetic particles." https://datastorage-na.fujifilm.com/news/strontium-ferrite/ (Fujifilm)

Ultrium LTO Home Page https://www.lto.org/ (LTO Consortium)

"LTO-9 technology and user data reliability analysis." https://www.lto.org/wp-content/uploads/2022/08/LTO-UBER-Technical-Paper-August-2022.pdf

"Making Data Archives Active" https://foliophotonics.com (Pholio Photonics)

"Low-Cost, High-Capacity Optical Data Storage: Supporting an AI Powered Future"

Optera Data Home Page https://www.opteradata.com/ (Optera)

"New 50TB Tape System a Bellweather for the Tape Industry" https://datastorage-na.fujifilm.com/new-50-tb-tape-system-a-bellwether-for-the-tape-industry/

A.2 Other

"Quantum to Help IBM Develop LTO-10."
https://www.itjungle.com/2021/10/27/quantum-to-help-ibm-develop-lto-10/
"Sony and Fujifilm Pass LTO-9 Format Interchange Compliance Testing."
https://www.backupworks.com/sony-and-fujifilm-pass-LTO-9-format-interchange-compliance-testing.aspx
"Quantum LTO-9 Media Calibration FAQ." https://www.backupworks.com/Quantum-LTO-9-media-calibration.aspx
"Holographic Versatile Disc." https://en.wikipedia.org/wiki/Holographic_Versatile_Disc
"Linear Tape-Open" https://en.wikipedia.org/wiki/Linear Tape-Open
"IBM 3592" https://en.wikipedia.org/wiki/IBM_3592
"Price Trends: Storage." https://pcpartpicker.com/trends/price/internal-hard-drive/#storage.ssdm2nvme.2000
"Fujifilm points to 400TB tape cartridge on the horizon."
https://blocksandfiles.com/2020/06/29/fujifilm-400tb-magnetic-tape-cartridge-future/
"Reversible 3D optical data storage and information encryption in photo-modulated transparent glass medium" https://www.nature.com/articles/s41377-021-00581-y
"Recap of Fujifilm Summit 2022 - Tape hot again illustrated by hyperscalers."
https://www.backupworks.com/recap-FujiFilm-summit-2022-LTO-Tape.aspx
"IBM will soon become sole gatekeepers to the realm of tape."
https://www.theregister.co.uk/2017/06/14/spectralogic_foresees_ibm_becoming_the_sole_tape_drive_supplier/
"China breakthrough promises optical discs that store hundreds of terabytes"
https://www.theregister.com/2024/02/23/optical_disc_breakthrough/
"Archive storage comes to Google Cloud: Will it give AWS and Azure the cold shoulder?"
https://www.theregister.com/2020/01/09/archive_storage_comes_to_google_cloud_how_does_it_compare_to_aws_and_azure/

"50TB IBM tape drive more than doubles LTO-9 capacity"

https://blocksandfiles.com/2023/08/23/50tb-ibm-tape/

"Digital Storage And Memory Projections For 2025"

https://www.forbes.com/sites/tomcoughlin/2024/12/06/digital-storage-and-memory-projections-for-2025-part-1/

https://www.forbes.com/sites/tomcoughlin/2024/12/11/digital-storage-and-memory-projections-for-2025-part-2/

Appendix B Acronyms

$/TB	dollars per terabyte
$/unit	dollars per unit
AWS	Amazon Web Services
BaFe	Barium Ferrite (media coating)
BER	Bit Error Rate
CD	Compact Disc
CD-ROM	Compact Disc – Read Only Memory
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
DCT	Digital Cassette Tape
DLT	Digital Linear Tape
DVD	Digital Video Disc
EO	Erasable Optical
EROS	Earth Resources Observation and Science
est	estimated
FYyy	Fiscal Year yy
GB	Gigabytes (1,024 MB, or 1,073,741,824 bytes)
Gbit	Gigabits (1,073,741,824 bits)
Gbps	Gigabits per Second
HD-DVD	High Definition-Digital Versatile Disc
HDT	High Density Tape
HPE	Hewlett-Packard Enterprise
HSM	Hierarchical Storage Management
HVD	Holographic Versatile Disc
HW	Hardware
IBM	International Business Machines

IMS	Information Management Services
KBR	KBR Inc. (not an acronym)
LTFS	Linear Tape File System
LTO	Linear Tape-Open
MB	Megabytes (1,048,576 bytes)
MB/s	Megabytes per second
MP	Metal Particle
NARA	National Archives and Records Administration
Q1, Q2, Q3, Q4	Fiscal or calendar quarter
QIC	Quarter-Inch Cartridge
RBER	Residual Bit Error Rate (post correction)
RMIT	RMIT University (formerly Royal Melbourne Institute of Technology)
SAIT	Super Advanced Intelligent Tape
sec	Second
SrFe	Strontium Ferrite (media coating)
SrM	M-type Strontium Ferrite ($SrFe_{12}O_{19}$)
SSD	Solid State Disk
TB	Terabytes (1,024 GB or 1,099,511,627,776 bytes)
TBD	To be decided/determined
TMR	Tunnel Magnetoresistance
USGS	United States Geological Survey
VSM	Versity Storage Manager

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Zhang, Q., Xia, Z., Cheng, YB. et al (2018, March 22). High-capacity optical long data memory based on enhanced Young's modulus in nanoplasmonic hybrid glass composites. Retrieved from nature.com: https://doi.org/10.1038/s41467-018-03589-y

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Williams, W. (2025, February 16). Forget about Blu-ray, Fluo-ray discs may well be the future of optical data storage with 10TB capacities for $1. Retrieved from techradar pro: https://www.techradar.com/pro/forget-about-blu-ray-fluo-ray-discs-may-well-be-the-future-of-optical-data-storage-with-10tb-capacities-for-usd1