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TRENDS IN MASS STORAGE TECHNOLOGY AND POSSIBLE IMPACTS ON
HIGH ENERGY PHYSICS EXPERIMENTS

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ABSTRACT

The reasons for the widespread use of magnetic tapes to record data from high energy physics experiments are analysed. Problems due to the sequential nature of the medium and to the large amount of human intervention required are discussed. It is suggested that a high capacity removable disk might resolve these problems.

An analysis of track-to-track spacing in magnetic recording shows that multi-track tape is unlikely to be of major interest.

A discussion of helical recording shows that the proposed Ampex Super High Bit Rate Recorder might allow for extremely high data rates at future general-purpose facilities.

A review of optical disk recording shows that it has great potential for physics data recording. Several areas needing careful attention to product design are indicated.

Holographic tape storage is briefly reviewed.

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1. USE OF MAGNETIC TAPE FOR DATA RECORDING IN HIGH ENERGY PHYSICS EXPERIMENTS

It is still possible to find experiments at high energy particle accelerators where no data is recorded on magnetic tape, but such experiments are now rather rare. Even five years ago a significant number of bubble chamber experiments were recorded solely on film, but it is now standard to use external particle detectors in conjunction with bubble chambers, and these detectors record to magnetic tape. Streamer chambers frequently digitise the optical image in real-time and record to magnetic tape. Some experiments with particularly simple pattern recognition problems and well thought-out on-line processing capabilities can proceed directly to the accumulation of the experimental distributions, thus avoiding the data recording phase completely. However, we can summarise by saying that over 90% of all present experiments at high energy accelerators record at least a part of their data on magnetic tape.

The scale of use of magnetic tapes can be glimpsed from some CERN statistics. At the present time the CERN Computer Centre stores some 100,000 tapes which can be accessed at a few minutes' notice, and a further 100,000 tapes which can be accessed at a few days' notice. Because of the policy that much of the data recorded at CERN is analysed outside we could reasonably expect that there are at least as many tapes in European physics institutes as there are at CERN. During the period July 1979 until June 1980, which was a period of very heavy data taking prior to a major shutdown of the CERN accelerators in order to prepare for proton-antiproton collider physics, the CERN stores issued some 37,000 magnetic tapes, and one major production experiment alone recorded some 10,000 tapes during this time.

With the exception of those people who record data, frequently pictorial, from aircraft, satellites or spacecraft, high energy physics is probably one of the most intensive users of magnetic tape recording in the world.

2. SOME FIGURES CONCERNING CAPACITY

2.1 1600 BITS PER INCH

If we ignore the inter-record gaps the capacity of a 2400 foot reel of magnetic tape recorded at the 'classic' density of 1600 bits per inch (bpi) is 46 million bytes (Mbytes). To try to relate this capacity to a more human scale we can estimate the size of the largest dictionaries that are commonly found in households (say Petit Larousse for French and Chambers Twentieth Century Dictionary for English) at about 10 Mbytes.

However, it is unrealistic to ignore the half-inch gap which is needed between each record on magnetic tape in order that the tape may stop if required. If we assume, and this is an assumption and not a requirement, that each record on tape has the same length, then a little calculation gives the following formula:-

$$\text{Effective Capacity} = \frac{\text{Record Length}}{\text{Record Length} + 800} \times 46 \text{ Mbytes}$$

To take two reasonable examples we would obtain a capacity of about 35 Mbytes by filling the tape to 75% of its theoretical capacity with records of 2400 bytes in length, or we would obtain a capacity of about 41 Mbytes by filling the tape to 90% of its theoretical capacity with records of 7200 bytes in length.

2.2 6250 BITS PER INCH

The calculation is very similar to the 1600 bpi case. However, the inter-record gap is slightly shorter, 3/10" in place of 1/2".

The theoretical capacity of a 2400 foot reel, ignoring inter-record gaps, is 180Mbytes. The appropriate formula taking gaps into account is:

$$\text{Effective Capacity} = \frac{\text{Record Length}}{\text{Record Length} + 1875} \times 180 \text{ Mbytes}$$

This leads to 75% utilisation (135 Mbytes) for 5625 byte records and 90% utilisation (162 Mbytes) for 17 Kbyte records.

Although it is possible to obtain fairly high tape utilisation on 6250 bpi tapes we must be careful about making the records too long. 16Kbytes is about the largest value which can be conveniently read on a wide variety of mainframes.

2.3 COMPARISON WITH MAGNETIC DISKS

We are used to the idea that the magnetic disks attached to 16-bit minicomputers, used for example in the field of data acquisition from high energy physics experiments, have a capacity of some 5 or 10 Mbytes, significantly less than the capacity of a magnetic tape reel recorded at 1600 bpi. The medium-size disk units frequently attached to more modern 32-bit scientific minicomputers have a typical capacity of some 75 Mbytes, still well below the capacity of a magnetic tape reel recorded at 6250 bpi.

However, many mainframe computers possess strings of disks having capacities such as the 317 Mbytes of the IBM 3350. This is 2 to 2.5 times the capacity of a reasonably full 6250 bpi reel. The latest IBM disk offering, the 3380, can be purchased in configurations where 2400 Mbytes are available in a single 'box', though there are several 'drives' in the conventional sense. The capacity of a 3380 accordingly approaches 15 times that of a 6250 bpi tape.

3. SOME FIGURES CONCERNING DATA RATES

Although the amount of data that can be held on a magnetic tape plays an important role in determining how difficult it will be to manage the data from an experiment, it is also necessary to be sure that data can be written to tape quickly enough during the precious periods when a particle beam is available for the experiment and all of the detectors are working correctly. To compare the data rates of 1600 bpi and 6250 bpi a reasonable figure of 14 Kbytes for record size has been chosen. It is also assumed that the unit can be driven at full speed, which is a reasonable assumption using modern data acquisition software.

1600 bpi (95% full with 14Kbyte blocks)		
Unit Speed (ips)	Effective Transfer Rate (Kbytes/sec)	Tapes Filled per Hour
45	68	5
75	114	9
125	190	16
6250 bpi (88% full with 14Kbyte blocks)		
Unit Speed (ips)	Effective Transfer Rate (Kbytes/sec)	Tapes Filled per Hour
75	410	9
125	690	16
200*	1100	25
*Note that 200 ips units are only available on mainframes at the present time.		

TABLE 1

We can see that magnetic tape recording therefore offers a wide choice of data rates, from a few tens of kilobytes per second on the standard 45 ips 1600 bpi drives, up to a very respectable performance of about 700 kilobytes per

second at the top end of the minicomputer market. However, the tapes will fill approximately each 4 minutes if you wish to exploit a 125 ips drive fully.

The requirement for high data rate is perhaps fortunately somewhat self-limiting. The recorded data must be analysed subsequently and that requires significant computer power. For example, if it takes 20 μ sec of central processor time on a mainframe to analyse each byte of recorded data (and 20 μ sec is a very conservative value), then each day of data taking will require a day of mainframe processing if the data rate is 50 Kbytes/sec. When the rate rises to 500 Kbytes/sec each day's data taking will produce a need for ten days of mainframe processing.

On the other hand, when an experiment starts the situation is fairly hectic, with problems of accelerators, beamlines, power supplies, computers and detectors seeming to combine to minimise effective data taking. At these moments everyone is happy if data can be taken as quickly as possible while all systems are working at the same moment.

4. THE REASONS FOR THE DOMINANT POSITION OF MAGNETIC TAPE RECORDING

1. A major factor is that the data rates from present-day high energy physics experiments match well with the rate at which data can be recorded on magnetic tape. It is only when the average data rate falls below say 10 Kbytes/second that it will be worthwhile to consider a cheaper recording device. On the other hand, anyone who has wanted to record at speeds in the several hundred Kbyte/second range had needed to think very carefully about how he could possibly analyse the data he was taking.
2. It is the normal case that a physics experiment is performed by a collaboration of physicists (typically 5-100) from several different institutes (typically 3-10). These institutes will, more often than not, be in different countries. It must be possible to distribute the raw data among the various institutes that will carry out the analysis. This requires well-defined standards for the recording medium and for the recording techniques. These standards exist for magnetic tape recording on half-inch tape at 1600 bpi and 6250 bpi and units that conform to the standards are widely available.
3. As part of this distribution process it is possible, if required, to copy the data involved at a reasonable cost.
4. The recording medium is cheap (about 25 Sfr. for a 2400 foot tape reel) and can be reused if necessary.
5. It is possible to archive the data on a magnetic tape for a period of several years. Physicists often like to do this because beam time at particle accelerators is a rare commodity, worth some 50 KSfr/day, and it is reasonable for them to archive the raw data tapes, probably costing less than 5KSfr/day, as the most tangible record available of their exact running conditions. However, the shelf-life of archived magnetic tapes is variable. If the storage environment is not well controlled, especially from the point of view of humidity, it can be difficult to re-read the data after as little as one or two years. If the tape is never mounted on a unit and wound and rewound a slow leakage of the magnetic information takes place through the substrate to the radially neighbouring bits of tape. Provided these points are attended to a shelf-life of ten years is entirely feasible, which is normally adequate for the completion of the data analysis from the experiment.
6. The capacity of a single reel, about 40 Mbytes for 1600 bpi and 150 Mbytes for 6250 bpi, is adequate for most purposes. As we shall see below, it is a bit borderline for some modern experiments.
7. Finally, magnetic tape units are normal peripherals which are offered by computer manufacturers on almost all mini- and mainframe computers. There is no trouble in having these units maintained and operating system software that meets most of the physicists' requirements is available.

5. THE FEATURES OF MAGNETIC TAPE RECORDING THAT ARE NOT IDEAL

1. One of the obvious problems with magnetic tape recording is that human intervention is required for each loading and unloading operation. In computer centres this normally leads to the use of computer operators to fetch magnetic tapes from rack storage, mount them onto the units, dismount them, and subsequently replace them in the racks. Physics experiments run 24 hours/day, 7 days/week and a physicist on shift, who has a complex job to perform and is frequently responsible for the operation of potentially hazardous detectors, may find himself needing to load and unload tapes every five minutes. We see that the capacity that can be stored on a single magnetic tape is very much on the limit.
2. Another practical problem arises since magnetic tapes are not normally 'managed' by computer operating systems in the way that disk packs are managed. We expect to be able to know the symbolic name of any data stored on disk, such as MYDISK:EXP123.MUON#RUN3, and to be presented with this data when we need it. Most operating systems do not 'catalogue' their magnetic tapes, and even if they did, since there is no 'de facto' standard for cataloguing, one would not be able to track the status of data on magnetic tapes that are physically moved from one machine to another.

The normal solution is for each experiment to set up a manual bookkeeping scheme so that questions such as 'Where is the data for this event?' and 'What is on this tape?' can be answered. Since this sort of book-keeping in the fast moving environment of physics computing is notoriously unreliable, attempts are being made to use database management tools to improve the situation.

3. Besides these rather obvious inconveniences of manual intervention, there is a rather more subtle problem. Magnetic tape recording is sequential and this fact effectively constrains the subsequent data analysis to be sequentially oriented as well. The improvements in detectors, accelerators, ideas, recording methods, etc. that have taken place over the past years in high energy physics can be used in two general directions. One way is to use the larger number of events that can be studied to improve the understanding of common interaction modes. The other approach is to filter the larger number of events in order to start to see adequate numbers of rare event types. If this second approach is being adopted then the 5-15 minutes which is the average access time at a well-run computer centre to the data of a randomly selected event stored on magnetic tape prevents many interesting approaches to the analysis of such special events. To restate the point; the convenient way to process raw data recorded on magnetic tape is sequentially, using computer programs that do the same thing to all events. This leads to batch processing oriented environment where it is difficult to quickly see what is happening to the data processing of a few events which are regarded as especially interesting.

6. IDEAL IMPROVEMENTS

Ideally we would like, for high energy physics data recording, an approach that retains all of the benefits of magnetic tape, but which did not require human intervention except at very infrequent intervals, and which had random access possibilities.

This seems to imply a removable disk which has a very high capacity (and is cheap, widely available, can be archived, etc., etc.).

7. TRACK SPACING AS A LIMIT

7.1 GENERAL

Since at this point we start to look at bit sizes for the first time, I include a word of warning. Manufacturers seem to become increasingly reluctant to let the real technical specifications of their devices stray into foreign hands. It is often necessary to make deductions and intermediate calculations in order to compare data from several different device types. One point that frequently gives trouble is the distinction between 'user' bits and 'raw' bits. 6250 bits per inch magnetic tape in fact records 9042 magnetic flux reversals per inch. These 'raw' bits include a large amount of redundant information used to detect and correct errors, and the final 'user' bit density is the well-known value.

Confusion can also arise because of the different radii at which density is recorded on disk. The normal technique is for maximum densities to be used on the more central tracks, and for lower densities to be used to store the identical amount of information on tracks furthest away from the centre.

I have tried to make my comparisons by always referring to 'user' rather than 'raw' bits, for either density or data rates and to refer to density on the innermost tracks of a disk.

7.2 WINCHESTER DISK TECHNOLOGY

In 1980 IBM introduced several new disk products, among them the 3370, for attachment to 4300 series processors and the 3375 and 3380 for attachment to 303X and higher System 370 processors. All of these disks exploit a new recording head produced by thin film techniques. In this paper all references are to the 3370 simply because there is an interesting publication available which gives much detailed technical background. [Entry 6 in the Bibliography]

In the 3370 each bit occupies an area of about $80 \mu\text{m}^2$. This corresponds to roughly a spacing of $1.5 \mu\text{m}$ along the track (equivalent to some 17000 bpi) and a spacing between tracks of some $50 \mu\text{m}$. To give some idea of scale this $50 \mu\text{m}$ separation is about the diameter of a human hair.

In order to achieve such a small separation between adjacent tracks, Winchester disk technology uses:-

1. Thin film techniques, such as the etching and photo-deposition used to produce integrated circuits, to fabricate a head having a $1 \mu\text{m}$ magnetic gap incorporated at the end of an aerodynamic slider having a length of some $100 \mu\text{m}$.
2. A head 'flying' in an aerodynamically stable equilibrium some $0.5 \mu\text{m}$ from the surface of the disk. This is in some senses equivalent to flying a DC-9 at a height of 50 cm above a calm lake.
3. Elaborate techniques to keep dust particles larger than $0.3 \mu\text{m}$ out of the so-called 'head-disk assembly'. Larger particles are obviously capable of causing severe disturbance to the 'flying' head, and ultimately of causing a head crash. In order that the elaborate air filters can be guaranteed a pure starting environment, Winchester technology deals with magnetic disks that are non-removable (in the classic sense of a device that can be removed by a computer operator).
4. Disks that are mechanically rather flat. An indirect reference in [6] indicates that smooth vertical motion in the range $25\text{-}100 \mu\text{m}$ ('several thousandths of an inch') can be tolerated while the head maintains its $0.5 \mu\text{m}$ offset. However, local flatness has to be better than $0.4 \mu\text{m}$ for obvious reasons, and this can be checked using a piezo-electric 'head' as part of the manufacturing process.

7.3 6250 BPI MAGNETIC TAPE

On this medium each bit of information occupies some $4000 \mu\text{m}^2$, corresponding to a spacing along the track of about $2.8 \mu\text{m}$ (roughly 9,000 'raw' bits per inch) and a track-to-track separation of $1400 \mu\text{m}$.

We notice that the major difference from a Winchester disk is that the tracks are some 25 times further apart on the tape. An obvious question that arises concerns the possibility to reduce the track spacing on conventional magnetic tapes. Some thought shows that this approach has many problems.

1. As the track come closer together the problems of thermal and humidity effects play an increasingly important part.
2. A new standard definition, for 128 track magnetic tape for example, will be needed before the idea is useful for interchange among a large number of physicists. Many manufacturers will need to be persuaded that they should provide interfaces and support for such new devices.
3. The head assembly (assemblies) might be very difficult to assemble and align accurately.
4. Multi-track tapes need a fairly complex set of analogue electronics per track. It would need some 200 heads, compared to nine at present, to achieve $50 \mu\text{m}$ track-to-track spacing.
5. Because of the tighter tolerances required the problem of compatibility between different drives and between different manufacturers' drives looks rather frightening.

8. HELICAL RECORDING

8.1 GENERAL

In contrast to the standard approach of longitudinal placement of the tracks on tape (Figure 1) various devices have made use of a helical placement (Figure 2). Basically one or two magnetic heads are placed on the outside of a stubby cylinder (the mandril) which rotates. A set of rollers brings the tape into proximity with the mandril and advances the tape slowly. It is normal for an air bearing to be maintained between the tape and the mandril.

Tapes used in helical recording are pre-formatted with control, timing and address tracks being recorded longitudinally along each edge. The technique of spinning the mandril gives a relatively high data rate through a single head. For example, a tape advanced at about 7 ips past a mandril rotating at 3600 rpm generates a head-to-tape speed of some 720 ips.

In general terms we can see that helical recording, with the use of pre-formatting, brings some of the desirable characteristics of disk storage, potentially including random-access, to magnetic tape devices. It also allows for rather better control of the track-to-track separation. The technique has been used for three devices that are of some interest in the present context.

LONGITUDINAL RECORDING

FIGURE 1

PLAN

1-2
INCHES

~ 5°
ANGLE

PRE-FORMATTED CONTROL
TIMING AND ADDRESS

HELICAL RECORDING

FIGURE 2

8.2 THE IBM 3850 MASS STORE

This device was designed for the mechanical archiving of data from normal IBM disk packs to 2 inch wide magnetic tape. Each tape holds 50 Mbytes of data and is about 60 feet long. When not being read or written the tape is held in a plastic cartridge which is stored, at a position known to the control software, in a honeycomb-like matrix. Besides permitting a very compact form of data storage the use of helical recording also allows access to smaller units of data, such as files or even cylinders.

In these two respects the 3850 represents a major step forward over several systems that limit themselves to automating the search and subsequent mount of standard magnetic tapes. Size and weight just seem to make these devices too clumsy.

Much of the power of the 3850 comes from its role as a 'back-end' storage and the very thorough integration into the normal operation of an IBM computer centre that is made possible by the provision of comprehensive software. However, these features limit its usefulness outside large IBM-based computer centres. The cost and fairly low average data rates exclude its use for data recording in the physics environment. The very good level of integration achieved also demonstrates the scale of investment that will be needed if customers try to use such a device as a 'facility' in a general-purpose high-speed network.

8.3 VIDEOTAPE RECORDERS

The principal driving force for the development of videotape recorders was the need to record television programs, either professionally or for home entertainment purposes. In one model this led to the choice already quoted of a mandril rotating at 3600 rpm and a synchronous tape advance of almost 7 ips. Combined with a bit density of some 11000 bpi this produces an aggregate data rate of about 1 Mbyte/second, which is the bandwidth required to drive a television screen.

A device of this type was interfaced to a Hewlett Packard computer at CERN and used for data recording at the ISR experiments R605 and R606. It is now being prepared for use in the UA1 experiment at the proton/antiproton collider.

In this context a videotape recorder has some positive and negative qualities:

1. You are strictly on your own for interfacing, maintenance and software questions. The computer industry does not seem to be interested.
2. Videotapes cannot be taken anywhere else, since (to date) no one else has an equivalent drive.
3. The storage capacity is very high, about 9000 Mbytes on a 7000 foot tape if you can fill it completely. This factor 50 above the theoretical capacity of a 2400 foot magnetic tape recorded at 6250 bpi comes from the extra length (a factor 3), the extra width (1 inch in place of 0.5 inch), closer tracks (a factor 6) and the combination of slightly higher density recording and fewer redundant bits for error detection/correction (a factor 1.4).
4. The data rate which can be recorded is very high if you can run in synchronism with the tape advance, some 750 Kbytes/second. This is slightly above the maximum rate that can be attained on 125 ips 6250 bpi magnetic tapes, but because of the much higher capacity a change of reel is required far less often.

8.4 THE AMPEX SUPER HIGH BIT RATE (SHBR) DIGITAL RECORDER

Ampex has discussed a product that might be available by about 1983 and that can be considered an updating of the videotape approach. It seems to be primarily aimed at the image recording market where satellites and planes require very high data recording rates. At present many rather specialised products, including multi-track magnetic tape, have been developed for the primary recording. It is rather common for the data to be completely or partially copied to 'normal' 9-track magnetic tape for subsequent processing.

The SHBR proposes to use a helical recording format but with 27 magnetic heads recording in parallel. In order to overcome the problems posed by the synchronous tape advance of classical videotape the assembly of 27 heads would be moved in a sawtooth manner transverse to the track. A movement of about 1mm permits the head assembly to cope with tape speeds varying from rest up to 90 ips.

If such a device is constructed it would have enormous capacity, of the order of 150 Gbytes or about 100 reasonably full 6250 bpi tapes, and very high data recording rates, up to about 100 Mbytes/second. Unfortunately, the cost projections were of the order of 500 KSfr, so it is hard to see it coming into generalised use for data recording at high energy physics experiments. On the other hand, it may be rather well matched to some very large general purpose detector assemblies that can be described as 'electronic bubble chambers'.

9. OPTICAL DISK RECORDERS

9.1 BACKGROUND

The fundamental technology of videodisk recording is being investigated by many companies, since they believe that it will provide a successful product for several markets where television pictures are required. Among areas thought to be of interest are self-paced or computer assisted instruction, and presentation of a variety of reference material such as repair manuals, spare-parts catalogues, etc. In addition videodisks are believed to be more interesting than videotapes for the home entertainment business in the long-term.

In parallel there is much investment in using the techniques of videodisk recording to create low-cost, high-capacity storage units which would become the 'filing cabinets' of the office of the future. In this environment there is a need for increased emphasis on error detection and correction (the eye can cope well with a few dropped bits in a television image) and a requirement for recording as well as play-back capabilities.

It is the obvious heavy investment in the field by many companies that gives rise to the hope that the eventual product(s) will be cheap and widely available. We can take 'cheap' to mean at, or below, the cost of 45 ips 1600 bpi magnetic tapes. Provided some care is taken with the initial design it should be easy to interface most of these products to several manufacturers' 16- or 32-bit minicomputers.

9.2 LASER DISK TECHNOLOGY

One of the approaches to videodisk recording is to use a laser to burn a hole about 1 μm in diameter in a thin (30 nm) layer of metal which covers a plastic or glass disk. Before the hole is formed the metallic surface reflects incident light and after formation incident light is transmitted. This forms the basis of a binary read-out system which is gated by the presence or absence of a hole.

Much work has been done using tellurium (Atomic number 52) as the basis for the coating material. It seems to have appropriate characteristics for the creation of thin surface and for hole formation with reasonable power input, although it is not without problems, as we shall see later. A 10-20 mW burst over about 50 μs is needed to form 1 μm holes in a 30 nm layer.

The original approach in this field seems to have been to use gas lasers in order to have adequate pulsed power. However, in view of their size they must be kept 'external' to the disk turntable and keeping them aligned with the tracks becomes a difficult problem. The whole approach became much more

interesting when semiconductor lasers, consisting of four layers of suitably treated gallium arsenide and gallium aluminium arsenide, were used.

In 1978 Philips announced the existence of a 40 gram head that incorporates a semiconductor laser together with feed-back systems to control the laser focus and to track along a pre-grooved optical disk. Compared to magnetic recording heads, which typically fly at 0.5 μm above the disk surface, such a head would be some 2 mm above the surface. The technique also allows the separation between adjacent tracks to be kept down to about 2 μm , at least a factor 20 better than present-day magnetic recording.

9.3 THE POTENTIAL PROBLEMS

1. Since a semiconductor laser is small, roughly 0.1mm square, it is only to be expected that a pulsed mode of operation will limit the operational lifetime because of thermal fatigue. It seems, however, that reasonable values can be achieved and in any case the operation of changing the head is relatively simple and not likely to be excessively expensive.
2. In the author's opinion the properties of tellurium may prove the biggest stumbling block, although as the power available from semiconductor lasers rises it may become possible to use other less noxious metals. In order to keep dust particles away from the holes that are the data, and to keep air away from the coating, all of the various proposals for videodisks enclose the metal surface behind barriers of various sorts. The Philips' proposal would create a miniature 'dust-free room' by making a double sided videodisk with external plastic or glass and two layers of tellurium-based material inside (see Figure 3).

The following information comes mainly from the section entitled "Selenium, Tellurium and Polonium" by K.W. Bagnall in Comprehensive Inorganic Chemistry, Volume 2, Pergamon Press, 1973. Tellurium, in common with the related elements selenium and polonium, appears to be taken up by the human kidneys, spleen and liver. The recommended maximum permissible concentration of tellurium in air is 100 $\mu\text{g}/\text{m}^3$, which is two orders of magnitude more stringent than the recommendation for hydrogen cyanide. Although the problems caused by the element itself seem to be mainly social ('foul smells'), the properties of some of the compounds are more obviously dangerous to people's health. Let us hope that these problems have all been ironed out before we start filling the world with disks each of which has been treated with 20 milligrams of tellurium based compound.

3. There are two interrelated problems concerned with the lead time to the launch of a product. The first is purely one of economics and planning. Much of the production of magnetic media is carried out independently of the production of magnetic recording devices. If anyone wishes to launch an optical disk as a computer peripheral he had better make sure that as well as being able to build the device he can also supply the (new) market for optical disk media. On the other hand there is a need to establish standards for preformatting these disks, otherwise they risk to be useless for data transfer when different computer manufacturers decide to offer disks which record using different conventions.
4. Many of the companies who are working in this field do not have a background in the mainstream of scientific computer or peripheral manufacture. It is hoped that they will investigate the requirements for successful computer interfacing, and provide a sensible set of primitive software functions in their device controllers.
5. Until these devices are adopted by computer manufacturers as standard peripherals and they worry about providing diagnostic programs and maintenance facilities, their use will probably be rather restricted in the high energy physics environment.

9.4 POSSIBLE CHARACTERISTICS OF A PRODUCTION DEVICE

Several sources indicate 1983 as the most likely year for the availability of laser disks as computer peripherals. We might expect the following characteristics of such a product:

1. A capacity of 600 Mbytes, or the equivalent of about four 6250 bpi magnetic tapes, on each side of the disk.
2. A transfer rate of some 200 Kbytes/second. Though this is less than some 6250 bpi tape units can offer, the need for high rates has to be carefully examined in each individual experiment. It is not obvious where enormous data rates can be subsequently processed.
3. The disk drive looks much like a record player and costs less than 30 KSfr. Each disk costs somewhere in the 20-100 Sfr. range.
4. Interfacing to some 16- or 32-bit scientific minicomputers is offered by a few manufacturers and/or systems houses.
5. Random access to any data on the side of the disk that is being played takes between 100 and 250 msec.

In the future there seems to be no reasons why the transfer rate cannot be increased substantially. The present limit is entirely due to questions of the life of the semi-conductor laser, and laboratory work indicates that rates of up to 700 Kbytes/second should be feasible a few years after product launch.

There also appear to be extensive possibilities for mechanical handling of these disks in 'juke box' like structures. If adequate software becomes available to manage all of this data (see Section 5, point 2 above), then real possibilities will exist for holding massive data on a scientific minicomputer.

9.5 SUMMARY

Laser disk technology looks as though it might possess all of those characteristics which made magnetic tape so acceptable for high energy physics data recording (see Section 4 above), with the notable exception of not being reusable. In the form discussed above, the disk either has 'holes' or 'no holes', and there is no way to fill the 'holes' back in and return to the original 'no holes' state. In the longer term, say perhaps ten years, some materials offer possibilities of reversible changes under the action of pulsed light. In the immediate future the question is certainly 'Does the irreversible nature of the recording matter?'. I am convinced that for future energy physics data recording it does not matter, provided that the probable media costs given in Section 9.4 are not unrealistic. Most raw data tapes from present-day experiments are used for archive storage and are not then re-used. The media

costs of laser disks looks to be no more than for present-day tapes, and therefore they should be just as cost-effective.

In addition there is the prospect of random access to the recorded data, which might offer significant benefits of greater selectivity in the subsequent analysis of events. It should become feasible to form 'offline triggers' where one or more key detectors are examined and the analysis of the other detectors is only undertaken when certain defined topologies are encountered.

Finally these developments might have a major impact on the decentralisation of computing reserves. The most effective barrier to wider decentralisation at the present time is the fact that mass data storage, including the control and back-up aspects, is personnel intensive. It is only at the major computer centres that there are sufficient staff and operating system resources to start to automate the control function. In fact at the present time the only coherent approach of which the author is aware to the automatic management of really large amounts of data is the package of Hierarchical Storage Manager software plus big disks plus 3850 Mass Store plus 303x processors plus the MVS operating system offered by IBM. Because of their size, weight and sequential nature, magnetic tapes do not appear to form a suitable basis for an automated system. However, cheap optical disks with a 'juke box' system appear to offer the chance to the manufacturers of 32-bit minicomputers to enter this field, and their entry would have an enormous impact in high energy physics.

10. THE PLESSY HOLOGRAPHIC MEMORY

In 1977 Plessy announced plans to produce a memory product using holographic recording onto 16mm film. The idea was to pass a laser beam through a 32-bit 'light shutter', which was based on lanthanum doped lead zirconate-titanate ceramics, and then to record the hologram resulting from interference with the reference beam. In a working prototype seen in Spring 1977 the hologram of 32 bits of data was recorded in a 50 μm by 400 μm area, and each hologram overlapped its neighbour by about 50%.

In principle the use of holography removes some of the requirements for an extremely consistent media since the record of each bit of data is smeared across the whole hologram. In the same way, problems due to dust should be much reduced, and less precise optics are needed than would be the case for direct imaging. On the other hand, the areal density that was being achieved, roughly 1 bit per 300 μm^2 , though significantly better than normal 6250 bpi magnetic tape, is still much worse than is available on magnetic disks, and roughly two orders of magnitude away from optical disk densities. Although the projected data rate figure was quite respectable, the performance of the prototype in this respect was not very encouraging.

The most exciting part of the original announcement was probably the claim that Plessy had perfected reversible photochromic materials and intended to use them in its optical memories. That means that a length of film coated with the appropriate material would form an extremely high capacity store that could be continually overwritten. The subsequent work seems to have concentrated on the less glamorous photographic version of the memory. After recording the holograms on film coated with fairly normal photographic emulsion, the film has to be developed and only then can it be read. In this form the device is even more restrictive than a laser disk, since there you do not have to wait to record the full set of information before being able to read any of the data.

In conclusion, what looked at one stage like an interesting idea seems to give few practical advantages, at least for high energy physics uses. However, there must be a future for reversible photochromic materials somewhere in the area of mass storage development.

11. CONCLUSIONS

It is wise to remember that an effect called 'The Persistence of the Old Technology' is a powerful force. When working semiconductor memories became available, it was predicted that they would take over from core memories extremely quickly. What happened in practice was that the companies which had money invested in core memory capacity made small extra investments to improve their competitive position, essentially learning how to thread smaller and smaller cores together. At the same time, the companies wanting to invest in semiconductor memories had to start everything from scratch. The final result

was that it took much longer than expected to complete the switch-over from core to semiconductor memories. There have also been products like thin film memories that never even made the transition to wide commercial acceptance because of similar effects.

The purpose of this preamble is to warn that much money and expertise has been invested in magnetic recording techniques for computer peripherals. At least on the disk side the prospects of better head construction, disks covered with metallic films, and vertical recording techniques still seem to offer the chance for significant improvements in areal density.

However, the prospect of random access to data and very high areal densities will make optical disk memories very interesting for the high energy physics community in the 1980s. The really important point is that it looks as though videodisks should be as cheap as simple magnetic tape units and as widely available.

It will be worthwhile for potential optical disk users to put pressure on the manufacturers of both computers and optical disks to do a good job in the area of standardisation, interfacing, diagnostics and data management software. Otherwise we will not be able to transport and/or manage the data effectively.

Multi-head helical recording, as proposed for the Ampex SHBR device, may be the most practical approach to very high rate data recording during the next 6-7 years. However, the technique looks expensive and might be overtaken by multi-head optical disks before 1990.

It is always wise to remember that making predictions about technology development is a very inexact science, or even no science at all. It is still quite possible that none of the approaches discussed in this paper will be useful for high energy physics, or that a different approach, such as magnetic bubble recording, will provide the panacea. Only time will tell.

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The following list is far from exhaustive but should allow anyone interested to start investigating the field in more detail.

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