The Long-Term Storage Can o' Worms

A Guide to ensuring your equipment can still be built and maintained in years to come.

Will you be able to build your product next year?

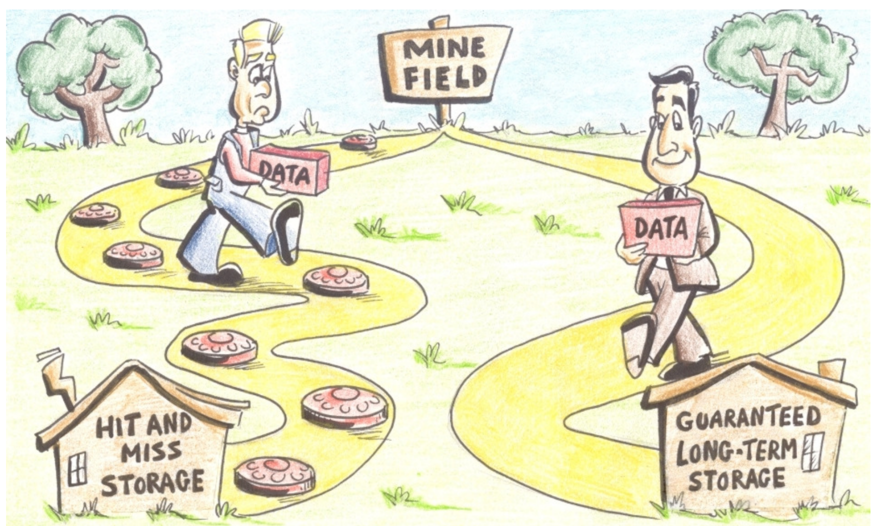
Have you protected your component supply?

Is your inventory safe?

Are you really archiving your documents and data?

Can you retrieve your archives?

If you can honestly answer 'yes' to ALL the above questions, then you've already read this booklet !



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Why do we store product?

Whilst this is an obvious question, it is one that can often produce different answers. To the manufacturing engineer, it is to keep his production line running, to the accountant it is often a just another point of lost revenue, to the real design engineer it is a source for quick “try-it-and-see” components, and to the store person it is their *raison-d’être.*

We sometimes store items as a buffer stock against our periodic or sporadic usage, smoothing out the requirement to re-purchase an item, or we may be forced to store items because, when procuring items, we are faced with a minimum order quantity (MOQ). Just try purchasing a single paper clip, sheet of paper or metal washer.

Inventory may be stored at any time during its usage cycle, from raw BOM (bill of materials) and BOF (bought out finished) through to the final end product, awaiting delivery or customer acceptance.

Part-finished items may be stored for long periods, and the final delivered product may well be a kit of unassembled or partially assembled parts for the customer to integrate or complete.

Throughout the supply chain, “users” rely upon “suppliers” to hold inventory to some degree or another. However, although purchasing/ manufacturing methodology systems, such as JIT (Just-In-Time), Kanban, Bottle-Neck management etc., have been used, someone, somewhere, holds a stock of finished or partially-finished product to maintain the production flow. These methodology systems can easily be upset when the inventory or distribution chain has a minor hiccup - often because these systems, which work well in mass-production, are employed under the wrong circumstances. Where inventory is held, for how long, and at whose cost, is a major financial and logistical factor for all manufacturers to address.

In order to minimise the financial impact of having large duplicate stores, one approach (often favoured in accounting circles) is to have a single centralised store. While this may be more satisfactory from the financial angle, if any stores are too remote from the point of usage, extra effort and time is wasted in transporting the call-off items.

In a fast-flowing assembly line, such as a car manufacturing plant, the stores are split between a centralised store, used as a intermediate-term buffer for incoming stock, and the in-line stores, which are in immediate proximity to the assembly bay or point of usage. This system works well, provided there is sufficient flow from central to local store in pace with the stock consumption.

Primarily, a store-person’s function is to satisfactorily hold, protect and monitor the inventory such that items can be released in a timely and orderly fashion, either as single items or as kits of parts. There are many anecdotes, some apocryphal, involving stores personnel, generally relating to their reluctance to release product under any circumstances … thus taking their responsibilities to comical extremes. Quotes such as “*you can’t have it, it’s the last one*”, “*I can’t open the bag just to give you one*” and “*do you know what it looks like?*” are common. Centralising office material stores, such as for paper consumables, has also led to some extremes, such as a one-mile round-trip to obtain a notebook or a ballpoint pen - hardly the most efficient use of someone’s time. Believe what you will, it has happened!

The item/inventory stores, therefore, can be seen as both as a buffer /reservoir against consumable usage, and as an insurance policy against item obsolescence.

Stores can be differentiated by their contents and purpose. Two significantly different types of store exist, the consumable item store and the archival store.

In general, the requirements of each type of store differ, but both take up valuable floor real-estate that can be seen by accountants as a wasted asset. The consumables store can be further analysed into a fast-moving consumables store, or a long-term storage point.

The fast-moving consumables store may often be computerised, with rapid mechanical storage and retrieval systems. Inventory is often then placed in preferential locations - shelf lifetimes and stock turn-around may then automatically considered.

Hedging against obsolescence?

The long-term storage of some items can be impractical or may present an unacceptable hazard. Consideration as to their consumption versus storage facilities and attendant costs is, therefore, needed. Certain items are regarded as environmentally unfriendly, toxic or flammable, and, dependant upon local legislation, may possibly require external monitoring, regulation and/or licensing.

Other items may be unsuitable for long-term storage due to an inherent time dependant degradation mechanism, often requiring careful or specialised packing to prevent deterioration. In certain instances, storage orientation and/or ambient climate may also affect the effective shelf life of specific items.

In a perfect world where items could be stored indefinitely and when purchasing COTS (Commercial Off The Shelf) items as inventory, there would be the options as to whether:

- manufacture immediately,
- manufacture later, or
- manufacture on demand.

A simple example could be the supply of 100 finished units over 10 years, on a regular supply basis using COTS components. Here, the options may be:

1. to build all 100 units immediately, whilst all the components are available,
2. to build on demand, purchasing components “just in time”,
3. to purchase all component items up-front, and then build on demand, or
4. to purchase all the “sensitive” components immediately, and use a mixture of options 2 and 3.

Option 1 presumes that all 100 finished units can be stored without degradation, but it has the advantage that the assembly and test jigs can be re-allocated once the total build is complete.

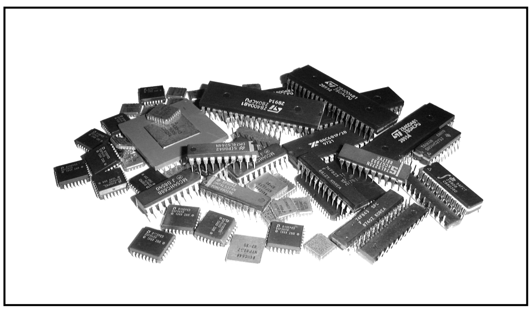
Option 2 is naturally fraught with obsolescence issues, remembering that the “C” in COTS means commercial.

Options 3 and 4 also require storage without degradation, but only of the element components, and even then only those components deemed to be at risk of obsolescence.

Options 1, 3 and 4 require the creation of an "obsolescence store", or a type of bonded warehouse where the units can be stored and the components ring-fenced specifically for this order or project.

An obsolescence store may be created intentionally, as an insurance policy against critical items becoming unavailable, either in the short, medium or long term. The "store" may also be created accidentally, by over-stocking, by the item being no longer required, or even unofficially in the proverbial "engineer's bottom drawer".

Individuals in a company may be more aware than others of the critical aspects of a component and/or impending supply problems, and may decide to take their own independent remedial action when faced with lethargy or intransigence from those who should know better. Whilst this latter approach may be applauded when it works,



it can be equally harmful in both preventing a more formalised approach to obsolescence, and the means of storage with relevant traceability paperwork is often inadequate.

Long-term storage of components should be a company-wide decision, with commitment from all relevant departments, including finance, engineering and purchasing. The choice of storing on- or off-site, multiple warehouses, or using an external agent, and exactly what is to be stored should be the concern of all departments.
Time for retrieval, physical location, control of inventory, storage methodology and damage/risk analysis should be considered during the decision phase.

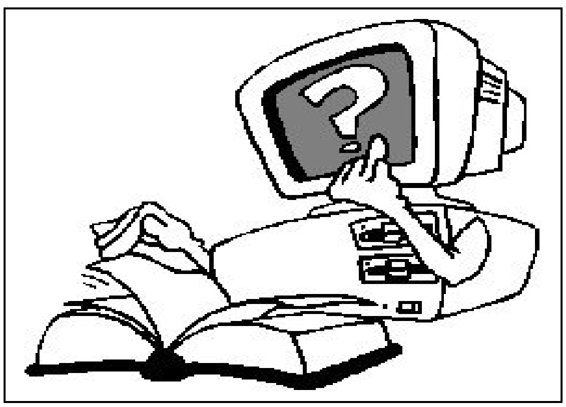
Part of this obsolescence store may be the archival store, where all the relevant documentation and know-how are stored along with the component, albeit in a separate location. This "know-how" may include the engineering notes and day-books, assembly and build data, design and procurement details, CAD & CAM files, test program files and specifications. An "application sensitivity" chart is recommended, indicating what other plant/machinery/process/materiel/sub-contract service is needed to complete the build, verification and use of the stored component.

The effectiveness of the stored component is only as good as the surrounding systems, so if the manufacturing process is altered, the effect of that change on the stored components should be considered. With electronic components, the assembly processes might well have migrated to a Pb-free solder, so the component lead finishes and assembly temperatures of existing stored items become relevant, but if the component or sub-assembly tester is scrapped … ?

The actual physical obsolescence store may, indeed, be part of the existing in-line stores with the components within the obsolescence stores being regarded as pre-allocated, and kept in quarantine against specific project or projects demand. A degree of cross-project component standardisation can also limit the overall requirement in terms of that particular selected component becoming designed-in across many projects, the only caution being to prevent one avaricious project consuming the stored component to the detriment of other projects.

In addition, standardisation of components can have positive implications when purchasing against fixed MOQs (Minimum Order Quantities), and can give leverage to the procurement departments when negotiating one-time buys. The use of programmable logic, such as PALs, PLDs and FPGAs should be considered; using the same physical device with differing programmed functionality for many projects and applications. The use of a high-level synthesis design language, such as Verilog or VHDL, can greatly simplify the upgrade path to newer or current parts. When using complex FPGAs, the programming station, whether in-circuit or stand-alone, should be considered as a candidate for archiving, along with the requisite design and programming software.

The Archival Store



The archival store is generally used to store data on whatever medium is presented. The contents are generally regarded as insurance as opposed to consumable items. The value, intrinsic to this store, is held not in the physical items present, but in the associated data content, and, unlike the consumable store, the value is very hard to quantify. Certainly, the data held is a company asset without which the company might cease to function. It is, however, often difficult to justify significant expenditure upon something, which in reality, is priceless.

The physical security of the archive store will not be mentioned further here, but should be a main consideration when planning its location and access.

Data storage

From the early 1960s onwards, media for storing data other than paper (and of course, tablets of stone), has historically inclined towards magnetic media. More recently, however, optical methods of data storage have been gaining ground.

In the past, data has been stored as readable print or script on paper, and although there have been other methods of data storage, such as punched tape, card-decks, wooden blocks or metal-tang cylinders, the preferred choice has remained the printed word, as begun by Guttenberg and Caxton.

Now, however, some printed data is effectively undecipherable without computer assistance (such as bar codes) but, in general, the data on paper is in the local language, which may be made computer-friendly by optical scanners and optical character recognition (OCR) software. Audio data has been stored on all manner of media, from the Edison wax disk and cylinders, through shellac 78s and vinyl 45s and 33s. Now, however, the compact cassette and CD hold sway, indeed, fewer Hi-Fi

systems now come with a cassette player, but almost none come with a record deck!
Microfiche film has been used extensively to compact the storage of paper documents, but has been slowly giving way to more electronic means of storage. There are modern threats to even traditional printed books, such as e-books, where the data is held on a semi-volatile electronic memory medium (disk or flash memory), and read/displayed by a suitable miniature computer. Whilst these e-books may be initially treated as gimmickry, there is a growing trend away from traditional paper text; even public lending libraries now lend CDs, DVDs and tapes.

Paper storage has always presented problems. Concerns of bulk, weight and flammability, coupled with the vulnerability to damage from water, chemical degradation and, of course, fire, have not endeared its continued use as the medium of choice. At times it would appear that there is something to be said for "tablets of stone". Old manufacturing drawings held on vellum may still be usable, whilst the old dye-line reproduction methods have long since been obsolete. But despite known issues, some forms of paper will continue to have a valuable place and be used for a long time yet.

Why does the legal profession like parchment? Because it has an incredibly long life dependent on the ink used.

Early Fax and printers, using thermal or "spark" printing technology certainly had issues with permanency and legibility. Even today many types of printer ink have known lifetimes.

However, in today's fast moving technology, old data-books that were once considered redundant and ready for discarding, can now be seen as a treasure house of information when faced with component parts replacement or obsolescence issues. Paper de-acidification technology is in regular use in relation to the preservation of many of our important historical documents. Much restorative work of paper and books is a continual 'work-in-progress' function at most large library centres, especially on books printed during the last century, where the high-chlorine content of bleached paper creates an in-built destruction mechanism.

Electronic Data storage

Careful selection of the electronic medium is required, as there are many hazards in relying on this media that are not instantly apparent. It must be remembered that data to be archived must be retrievable, otherwise the purpose of archiving is negated.

Full use of the Internet could well remove the need for single point data storage in the future, the data being stored and retrieved simultaneously on numerous different host computers and, as each computer is individually upgraded or replaced, the data is retained on other host computers. The main objection to relying upon the Internet for data storage is its currently perceived vulnerability, having both potential security issues and the danger that data may be uncontrollably replicated and corrupted with great rapidity.

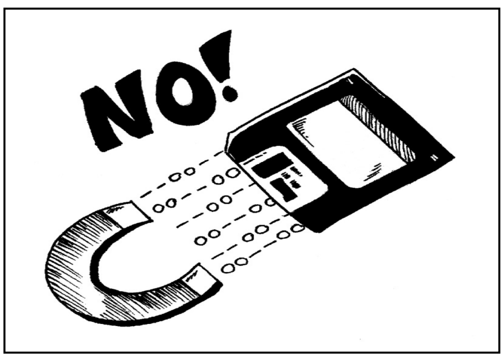
Third party "data storage"/"data warehouse" companies exist, and these are often used as a suitable secondary location backup and repository for critical or sensitive data.

All electronic media requires the use of a computer of some sort or another to retrieve the data and convert it into a human-sensible format. So we are relying on four main precepts to recover this data:

- The endurance and lifetime of the media itself.
- The presence of the specific media-reading hardware.
- The associated computer.
- The interpreting and display/application software.

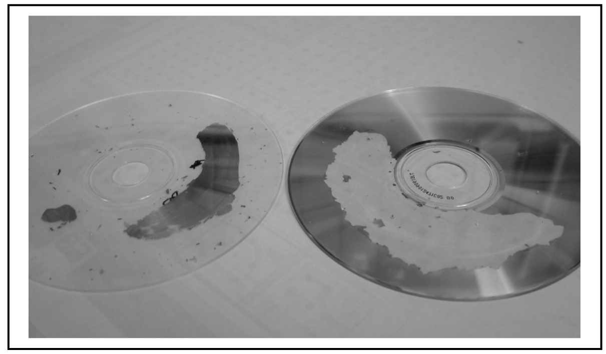
The Media

When considering magnetic media such as tapes and disks, it is well known that the long-term storage of magnetic media has its own attendant issues. Problems of oxide-shedding and magnetic "punch-through" on magnetic tape quickly render a tape unusable, often in as little as 5 years if the tape has not been carefully stored. Platter disks are generally less susceptible, but "punch-through", can still occur, and head-dust, caused by deterioration of the ferric-oxide bonding agent, can lead to irreparable damage to both the platter and read heads as soon as the platter is mounted.



Floppy disks, in their many guises, can be susceptible to mechanical and magnetic damage.

Optical media, such as the ubiquitous compact disk (CD) and the increasingly popular DVD disk, can also present problems. CD-Rs that are written by the average work PC have a distinct shelf life, and, dependant upon the storage ambience can lose data in 18 months or less, the quality of the initial CD-R or CD-RW media is paramount.



CD-R damage
Photo: Alun Jones – Austin Semiconductors

Shedding of the reflective aluminised coating and delamination can also occur, and the sensitivity to UV light and certain cleaning chemicals is well documented. There are other electronic storage mechanisms, such as holographic storage, ferro-optical disks, or bubble memory modules, which seem to have come and gone without having a major impact on the mass data storage market. The above picture shows damage to a CD-R disk that has been poorly stored. The reflective metallisation has peeled away onto the packing.

The Media Reader.

This is often the most critical item, as even if the data remains intact upon the storage media, the function of the media reader cannot be guaranteed. Data formats change, sometimes rapidly, due in part to the need for increased storage density and retrieval speed.

What was once the media of choice in the 1970s and early 1980s, the open-reel ½ in. magnetic tape, has now become a museum piece. Suitable working data readers are few and far between, although some specialist companies maintain these readers for the sole purpose of data recovery. The ½ in. magnetic tape gave way to the QIC (Quarter Inch Cartridge) tape which many older Unix systems still use and maintain. In the PC world, the plethora of data standards has meant that the days of the QIC tape are numbered.

Various cartridge-type tapes, from "audio-cassette" to DAT have been around, but it is highly likely that the appropriate data reader is non-functional and obsolete. Unusual data readers, such as the Bernoulli disk, or the Sinclair Microdrive™, became quickly marginalized, just as the old in-car 8-track was superseded by the cassette player, which is now marginalized by the Compact Disk (which is being ousted by the DVD). Floppy disks have fared somewhat better, but few companies will have 8 in. or 5¼ in. floppy drives available and operational. Even the 3½ in. floppy drive is being phased out on modern PCs.

Integral with the reader is the native format of the data and operational commands, such that many drives will not function without the appropriate software functions. Specialised driver software is, therefore, required to operate the reader.

Very old teletype readers, such as the ASR-33, used punched tape, which could, at a pinch, be deciphered into plain ASCII by human eye (I know, because I used to have to do it!), but reading magnetic tape, even by using fine magnetic powder, is not really that viable.

How many of these types of storage media can you identify. And how many could you read?
Photo: Alun Jones - Austin Semiconductors

In the author's opinion, Unix platforms have tended to be more stable in their hardware and computer data formats, using TAR or BAR generally as the archive data format onto QIC or DAT tapes, but many newer QIC readers will not accept the older 30MB and 60MB tapes, preferring the newer 150MB or 525MB tapes. On rare occasions, DAT tapes, with differing compression algorithms, may also present a problem.

The Computer

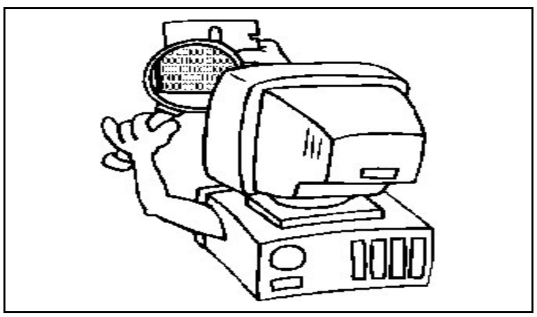
Whilst this again appears obvious, some of the early data readers, such as ½ in. magnetic tape readers used dedicated computer hardware built into the main-frame of the computer, after all, MACs and PCs didn't exist before around 1985 (remember the BBC, Atari, Amstrad, Commodore PET, Amiga, Sinclair Spectrum, ZX80/81 … if you do, you're getting on a bit !).

Other Unix or CPM boxes, often based upon the S100 buss system, had dedicated boards for magnetic tape and 8 in. floppy disk readers. Early PCs first had ISA then EISA based boards to control specific hardware … today it would be difficult to find a modern PC that supported EISA based cards. The pace of computer development, especially PC development, gives rise to potential problems with data archival in both the immediate and long-term time frames.

Once again the Unix hardware platforms, such as HP or SUN, have remained significantly more stable than their PC brethren.

The Software & Data Format

This can often be the hidden pit-fall, as even if a new computer & hardware can be "cobbled" together to extract the data from the archive media, there is no guarantee that the data will make any sense without some additional conversion software. Older data archival systems, especially those that were predominantly hardware bound, used data formats that are now quite alien to the modern PC. Data character formats, such as EBDIC and TRASCII, require significant re-translation before it becomes human- or machine-sensible again.



As an aside, it is worth noting that the Phoenician writing system known as "Linear A" is an archaic textual format that has apparently been lost forever, this could also apply to many "current" formats; we will always require a "Rosetta Stone" to "crack" the data-data translation.

Another issue arises due to the different versions of reader software; if converting a document from Word '95 or WordPerfect 3.0 to be acceptable to Word 2000 is tough - just picture the issues when converting from other operating systems, such as CPM/86, RDOS, VMS, Linux, MacOS, DRDOS, TOS, CROMIX or DOPSY.

Happily, much of this older data is either in plain ASCII text format or direct binary, so conversion is often straightforward, albeit tedious. Not all plain ASCII data need be Carriage-Return / Line-Feed (<CR/LF>) bound; when computer memory was expensive, link-list or tokenised ASCII data was also a common data format.

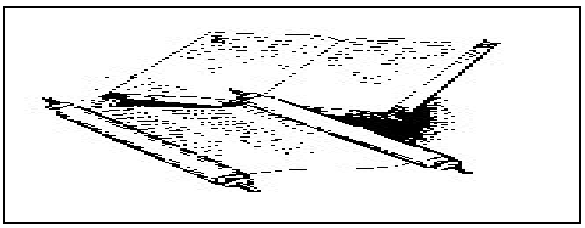
When performing data conversion, it is often easy to pick out conversion errors if the data was originally human-sensible. But if the data was originally in pure binary, intended as computer-only, then conversion errors are often hard to detect and track down.

Other data formats may be proprietary, such as the commonly used Portable Document Format (PDF) from Adobe, Word format from Microsoft or GDSII (Graphics Display System) of Calma (now part of Cadence). Whilst these formats may be well used and documented, they are none-the-less subject to "upgrades" and "revisions" beyond our immediate control.

Many companies have attempted to standardise their documents and formats, selecting AutoDesk's DXF format for all mechanical drawings, for example, but are now reliant upon backwards compatibility from the software supplier, or require to maintain legacy equipment for the eventuality of data retrieval. Periodic "upgrading" and transfer to modern media and software of the archived data may be routinely required. Standardisation on document formats, such as Word from Microsoft, can also lead to periodic revisiting, as upwards compatibility is often prone to "enhancements", a.k.a. bugs.

Data storage, initial conclusions

The only data storage media that has really been proven over extended periods of time is paper (not forgetting stone!). Although this media may well suffer and degrade with the ravages of time, the mechanism of data interpretation, translation and extraction (the human brain) is, to date, still probably the best around. Nonetheless, as previously noted, paper has its own severe limitations.



Optical Character Recognition (OCR) software is improving, and there are large book and sheet optical scanners available to convert paper print into computer-legible text.

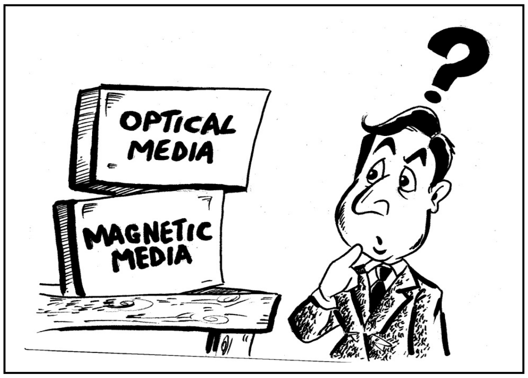
A testament to the durability of paper is provided by the 4th century AD parchment *Schedae Vaticanae* containing sections of Vergil, and this document is comparatively recent when compared with the 1st century B.C. Dead Sea Scrolls, the many Greek papyri from 4th century B.C. Egypt, or Egyptian papyri of some two millennia earlier. And we have not really yet mentioned stone, a much older medium, viz: The Rosetta Stone.

But the best and most imperishable writing material in history is certainly the Assyrian/Babylonian clay tablet, which, when fired, has the fine detail of clay coupled with the permanence of stone.

The Library of Assurbanipal or the tablets from Pylos point to a different kind of life expectancy from papyrus and paper, and all of them make our electronic-magnetic recordings seem somewhat ephemeral.

Choosing the media …

Where data is required to be computer sensible, e.g. CAD/CAM data, then the current choice generally comes down to optical or magnetic storage, and as we have seen, both have their attendant concerns. Truly critical data will be archived on differing media, and be periodically and methodically re-verified, and, where necessary, transferred onto the next generation of media. Care should be taken at system level that data recovery can be accomplished without interference to any other current system, that individual files can be accessed and recovered without overwriting or destroying other data, and the recovered data can be re-inserted or imported into a working system. This is particularly germane when archiving a "live" time-critical MIS (Manufacturing Information System) or accounting systems. In 1995, *Scientific American* reported that "responsible estimates for data storage in the order of 2 years for tape, 5 years for magnetic disk and about 10 years for CD." The general consensus seems to be that CDs and other electro-optical media will deliver data a lot further down the track than magnetic media. They are also somewhat more tolerant of dust storms, passing magnets, and coffee or strawberry jam incidents. The situation hasn't changed much since 1995, except that we are cramming more and more data onto the same disk or CD.



Technical enhancements and increasing densities of these storage technologies, coupled with improved manufacturing techniques, now offer increasingly cheaper mass data storage, but the underlying physical principles used have not changed, just shrunk, putting a finite limit on the potential life-span and corruption sensitivity of any such storage technology. Data compression may appear a boon when squeezing data onto a CD or floppy, but it also has the unfortunate side-effect of making that compressed data more vulnerable to a single bit or byte change. Error detecting and correcting algorithms are then used, but adversely affect the overall data compression ratio. Enhancements to these algorithms to recover data often serve merely as an increasingly more complex barrier to "un-encrypting" the original data should something have gone wrong. Thought should be given to whether the stored data should be compressed or encrypted, as this may prevent successful data retrieval … there is little worse than that sinking feeling when the computer reports "`CRC error - data corrupt`". So one of the "golden" rules is:

KISS … Keep It Simple, Stupid …

which, in this scenario, would imply storage only of immediately readable data (either by machine or a human being).

As the cost of storage on hard disk decreases, currently (2004) at around £0.20 to £0.50 per gigabyte, the use of multiple hard disks is potentially an attractive storage solution. Data densities increase and short-term reliability improves whilst physical size and power consumption decrease. The choice of electrical interface used to be between IDE/ATA and SCSI/SCSI2, but now Serial ATA (SATA) disks are offering SCSI performance at IDE prices.

These disks would normally used in a mirrored RAID-type scenario, with suitable computer hardware, but the lifetime of un-powered disks or disk docking systems has not been investigated here. (*Q. Can you still read your old ESDI disk, the latest and greatest in the early 1990s?*).

Control of the media's environment (temperature, humidity, electromagnetic shielding) becomes important during storage; the bottom of an engineer's drawer generally does not normally suffice, although this repository is frequently used.

Maintenance and operational knowledge of the requisite hardware and software to extract the data is as relevant as the data itself, as discussed above, and so certain military agencies, with an eye for the future, still maintain very old data readers, themselves subject to component obsolescence.

Considerations

- Select the media with a view to its own shelf life, and select the media packing material with care
- Select what data is to be stored, if everything is archived, subsequent searches and retrieval becomes more onerous.
- Select the media/reader/hardware combination for sustainability & maintainability
- Control the media environment in storage
- Maintain a regular update/retrieval/ verification programme
- Create a clear data recovery procedure, preferably one that doesn't interfere with the normal running of the day-to-day computer systems.
- Upgrade to new hardware/media once the existing system exhibits terminal decay.
- Upgrade to a new data format when appropriate
- In preference, use a data format that is common, not hardware bound, and not encrypted in a unique manner.
- Don't throw away old "paper data"/"data books" (nor those hammers and chisels …)
- Consider that your customer could be relying on you archiving your (his) data?

Remember to upgrade and "copy-forward" your vulnerable, critical and irreplaceable data long before the media deteriorates, YOU HAVE BEEN WARNED !!!

Some media formats (current and fading …)

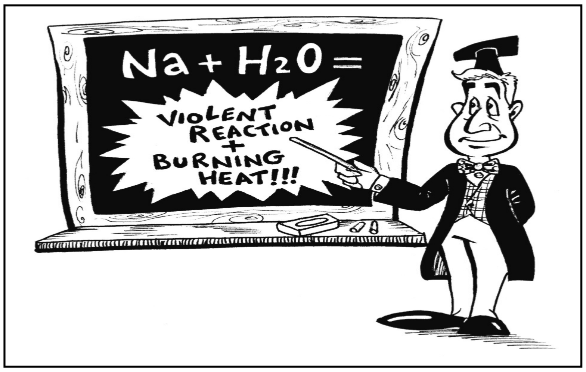
8″ floppy disks (multi-format, hard & soft sectored), 5¼″ floppy disks (low and high density), 3 ½″ & 3″ floppy disks (low and high density), 120M floppy disks, ZIP™ disks (100M & 250M), JAZ™ drives, Microdrive™ disks, Bernoulli drives, ½″ magnetic tape (9- or 8-track), ¼″ magnetic tape, compact cassette, 4mm, DLT, 3480/3490, 3570/3590, 8-track cartridge, DAT
DDS tape, QIC cartridge (30M, 60M, 125M, 625M etc.,), 8mm & Hi-8 tape, DEC disk platter, MiniCartridge™, Syquest™, Ditto™ cartridge, WORM Drive, VHS™ Video Tape (remember BetaMax™ & V2000), Pinnacle MO drives, 5¼″ MO, 3 ½″ MO, 2120 cartridge, CompacTape™, XIMAT, AIT2 tape, ADIC drives, Laser disk, Compact Disc (in it's many formats), MO MiniDisk™, DVD (-R, -RW, +R +RW, -RAM etc.,), 5-6-7-8 punched tape, card reader, Winchester or ESDI hard drives.

What can you add to this list?

Long-term storage and corrosion

Corrosion. n. *Wearing away of a substance from the surface inwards by chemical action or disease.* Normally associated with chemical action, corrosion is often the best means of rendering an item unusable, primarily by altering the surface nature and dimensions.

Various methods of anti-corrosion protection are used, and this could well takes us back to basic inorganic chemistry, … and the classroom …



"Remember, boy, phosphorous is stored under water, and sodium is stored under oil, NOT the other way round!"

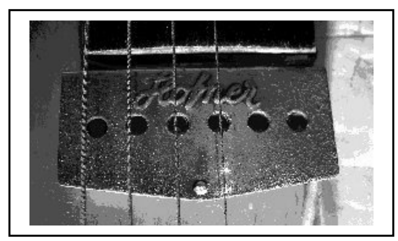
The corrosion in normal long-term storage is predominantly by oxidation, whether caused by atmospheric oxygen, airborne sulphur or chlorine ions. There are many other reactive agents which can cause corrosion of metals, especially in the presence of moisture. Special packing techniques are often employed to reduce the exposure to harmful chemicals, and the UKs MOD Def Stan 81 is an excellent source of standards and guidelines for packing methods and materials.

Further information on Def Stan 81 can be gathered on their website at http://www.dstan.mod.uk/

Apart from a few of the noble metals, all metals are found in nature as their oxides or sulphides.

Copper, Zinc, Mercury, Lead and Silver are primarily refined from their sulphides while Tin, Aluminium and Magnesium are extracted from their oxide and Iron may be extracted from both its oxide and sulphide. These primary ores represent the metals' most stable chemical state in nature, so it is unsurprising that the refined metal would willingly revert back to its native state as rust, or oxide & sulphide bloom. This reversion may be temporarily halted or suspended by various metallurgical or chemical mechanisms, but may also be aggravated by incorrect storage, manufacture or handling.

Corrosive agents can be introduced by atmospheric means, by degradation of proximity materials, or by contamination during handling. Inappropriate handling, such as leaving fingermarks, can lead to severe corrosion. Inter-metallic corrosion can be accelerated by electrogalvanic action, sometimes caused by a poor initial choice of original metals, leaving the final article with an in-built destructive mechanism.



Example of rotting guitar strings, "rust" aggravated by furniture polish.
Photo: Alun Jones

Bacterial or microbiological corrosion also occurs, predominantly on organic substances such as natural fibres and plastics. Whilst this "corrosion" is often a non-invasive surface mould growth, some of the bacterial by-products can cause real surface damage, and would still cause rejection at an inspection stage.

Other storage media

One industry sector that has needed to gain and also disseminate significant data on extended long-term storage is the nuclear power industry, which mainly needs to securely store hazardous nuclear waste material. This material is certainly not for re-use in the foreseeable future, so the requirement for corrosion resistance differs from that usually associated with other mechanical and electronic industries.

Stainless steel tanks, concrete and lead-lining and vitreous materials are amongst the most commonly used barrier materials, and geologically stable sites are sought for the storage location.

The AMARC division of the USAF, based in Davis-Monthan air base, Tucson, Arizona, makes extensive use of the nearby Sonora desert, renowned for its hot and arid conditions, to store whole aircraft and airframes for re-use and solving obsolescence issues. This aircraft "graveyard" is very extensive and a great deal of effort is put into the pre-storage preparations.

Long-term cryogenic storage has been used for sometime to store biological material with the full intention of re-use. The suitability and cost of this type of storage tends to limit its use to either the laboratory or high specialist medical organisations. Short-term low-temperature refrigeration and dry-ice storage is commonly used for transporting and storing both biological material and certain chemicals, such as low-temperature curing adhesives.

Shrink-wrapped Boeing Sea Knight CH46E helicopters !
Photo: Omega Intercept

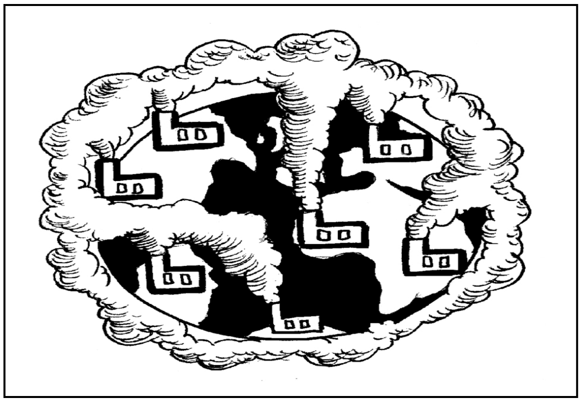
Packing Materials

It should be considered that while the original packing materials are intended for short-term protection during transit, this does not necessarily imply that they are suitable for long-term storage, so information from the supplier should be sought. "Green" or biodegradable materials, often favoured as delivery packing, can create by-products that may adversely affect the stored item, so again checking with the item supplier as to the conditions of storage and the delivered outer packing material is needed.

The use of desiccants, chemical filters or active getters for long-term storage should be carefully considered, as, with time, they may lose their effectiveness and create small particles or dust that may abrade the stored material.

Volatile Corrosion Inhibitors, (VCIs) are also available, using complex chemistry to prevent specific corrosion problems. Unfortunately, the majority of VCIs have attendant problems, mainly associated with the high toxicity of the chemicals employed, which may well be subject to environmental and health legislation in the near future, refer to *http://toxnet.nlm.nih.gov/* for further details. Waxed or oiled paper and fabric, or oil-on/oil-off methods of metal protection are common for short - to medium-term storage. The main problem here is both the cost of the oils with the oiling equipment and the "gelling" or solidifying of the protective oil, requiring periodic oil removal and subsequent re-oiling.

Our atmosphere



Along with the oxygen and nitrogen in our atmosphere, there are many, highly reactive pollutants that can affect metals. Ozone, Sulphur, Chlorine or Nitrous compounds can attack non-ferrous metals, whilst ferrous metals can be affected by both galvanic corrosion and oxidization … rust!

The common corrosive gasses are Nitrous Oxides (NOX) from combustion engines; Ozone (O_3) from electrical machinery or UV action; di-Hydrogen Sulphide (H_2S) and Sulphur Dioxide (SO_2) as effluent from oil refineries, heavy industries or decaying vegetable matter; Carbonyl Sulphide (COS) from incomplete fossil fuel combustion; Ammonia (NH_3) from decaying matter; and Hydrogen Chloride (HCl) from fossil fuels and saline water (sea-water, sweat etc.). Higher concentrations of these gasses often occur in third-world countries where environmental legislation is either lax or ignored.

One common misconception about corrosion is that it is caused by water. Water does act as an excellent carrier for these corrosive gases and reactive ions. Ions are easily dissolved in water and are then carried by humidity, water vapour and steam. Water also acts as an accelerator - increasing the reaction rate of these gases and ions with the metal surfaces. However, water in and by itself does not cause corrosion – it's what is in the water that does the damage.

Knowing this, corrosion and environmental effects should be taken into account during the design phase of any item, and specific attention should be paid to the "inert" life of the item, such as transportation and storage.

One of the more interesting observations made has been that metals used as part of a circuit, wires, PCB traces etc., are less prone to corrosion when current is flowing through them than when electrically inactive. The layman's explanation is that current flowing through the metal has the effect of temporarily chemically altering the metal, reducing its apparent "reactiveness".

This change makes the reaction with a corrosive gas more difficult (less driving force) and hence far less prevalent or likely. In storage, shipment or manufacture, the circuit and the metals are not active and become active targets for corrosive gas attack. (See papers by Rebecca Starling, General Dynamics).

Methods of protection

Isolation of the item from reactive agents is obvious, but when this cannot be avoided, selected preferential corrosion sites or separate sacrificial material can be employed. Adding a surface coating, such as metallic zinc (galvanizing), or mineral oils that are removed before use, is one common method of providing a temporary anti-corrosion barrier, but is not suitable for all materials. Where unavoidable galvanic corrosion is anticipated, employing an external electrical charge may be considered. This, of course, is the prime reason that all modern cars have a negative earth system, as it was discovered many years ago that a positive earth charging and ignition system encouraged corrosion of the mainly ferrous body-panels.

Metallic aluminium has its own self-preservation mechanism. In air, it forms its own hard oxide, Al_2O_3, which effectively protects the metal from further oxidization, but this self-protective layer can itself be attacked by chlorine, from salt water or sweat, and by the basic hydroxides, such as KOH or NaOH, which are often present in cleaning agents.

The chemical formation of a natural intermediate barrier can be useful, fluorine and hydrofluoric acid, both highly reactive "nasty's", can both be transported and kept in copper containers, where the formation of a copper fluoride barrier lining prevents further attack of the copper vessel.

Adhesives, used on tape or containers, often either polymerise or dry-out with time and/or UV exposure, losing their adhesive properties and often powdering, creating an abrasive dust that can damage sensitive mechanical and electronic parts. When unpacking, caution should be exercised to minimize disturbance of this dust, as it is bound to be harmful to either the stored item, or personnel in the vicinity (silicosis-potential). Other adhesive labels and tapes leave residues on the attached item, which will then have to be cleaned with a solvent, such as IPA or benzene (which is highly flammable and carcinogenic), so consideration to the binding method of the final and intermediate packing materials also becomes necessary. All of a sudden, string sounds almost attractive!

Use of desiccants to control the humidity, and carbon filters or getters to absorb gasses is common, but are generally subject to short or limited working lives, and so should be checked and replaced at regular intervals. Sealed foil bags can act as a moisture and gas barrier, often providing additional anti-static shielding. These bags are only as good as the seal, and "silvered" foil bags have shown a tendency to shed the inner coating under long-term storage, producing flakes of silvered coating. Dependant upon the bag material, some plastics and foams can polymerise, often aggravated by ultraviolet radiation, producing some highly reactive chemical reagents.

Specialist materials, such as Static Intercept® and Corrosion Intercept®, originally developed by Lucent Technologies' Bell Laboratories, have been engineered specifically for long-term storage and protection, fully meeting Mil Spec 81705. The Intercept material is particularly unusual and effective, in using highly active copper particles embedded in a polyethylene sheet, the copper effectively acting as a sacrificial anode. Whilst not particularly cheap, these materials have been subjected to numerous rigorous trials to ensure their long-term impermeability and ageing characteristics, and currently offer one of the best solutions to long-term immediate-proximity packing. A recent development in the Intercept range is the Reactive Intercept™ Barrier System or RIBS material. Further information and details on the Intercept material range may be obtained from Omega, the UK based sales company representing the Intercept products, refer to their website at *http://omega-intercept.com/*

As with all items destined for high reliability use, the associated "paperwork" needed for final use and item traceability will also require careful storage and protection against "corrosion".

Refer to the section on "The Archival Store" for further information.

Storage of Plastic Encapsulated Microcircuits (PEMs)

All plastic encapsulated ICs exhibit moisture absorption and chemical ingress into the plastic, sometimes to such an extent that, during rapid changes in temperature such as during soldering, the rate of out-gassing or vaporization can cause rupturing of the plastic package itself, this is known as "the popcorn effect". To overcome this, the PEMs are usually dry-packed or vacuum-packed for storage, sometimes with an attendant desiccant, and then gently baked to remove any internal gasses (dehydrate) before any high temperature processing. After final processing, a standard con-coat or a specialist conformal coating, such as Parylene™, may be applied to limit the effect of moisture on the final assembly.

If the moisture carries with it any ionic contaminants, the die metallisation may corrode. When it occurs, corrosion of the metallisation typically begins at the bond pads that are deliberately left exposed in order to permit wire bonding. High temperature and applied voltage can accelerate this mechanism.

The interconnection wire bonds themselves are also susceptible to corrosion in the presence of moisture and contaminants. Ionic contaminants hydrolyse and can react with the aluminium in the gold-aluminium intermetallic phase of the bonds. Wire bond and die metallisation corrosion failure modes can include electrical parametric shifts, excessive leakage currents, short circuits, and electrical opens.

Corrosion of a bond may not directly result in a failure, but may result in an increase in contact resistance that can cause the PEM to malfunction earlier during its working life, and this is often referred to as the "walking wounded" scenario.

Different plastic moulding compounds exhibit differing degrees of out-gassing and permeability. Each material should be independently assessed for its long-term stability, using techniques such as HAST or HTOL. In general this has not proved to be a major problem with other technologies, especially the pin-in-hole technologies with a high plastic – die volume ratio. Smaller SMT packages use differing moulding compounds, sometimes with sulphur-polymer plasticisers that have not shown great stability over long-term storage trials.

The proximity of the active die area to the outside environment is also decreasing as the chip-scale packaging ratios are approaching 1:1 (for wafer scale packaging), increasing the sensitivity to ionic contamination of the die surface area. Individual devices are often rated for their resistance to moisture ingress, or "floor life". The moisture sensitive classification level, or MSCL (ANSI/IPC-SM-786) in common use ranges from MSCL Class 1, which has an almost unlimited floor life, to Class 6, which limits the floor life to 6 hours. *Refer to EIA JESD-22-A112 and JSTD-020B at http://www.jedec.org/ for further details.*

Long-term storage for PEMs in general follows the same practice as given for die and wafer product, with the additional concern regarding the tarnishing or corrosion of the component lead finish which then affected the product's solderability. Under certain circumstances, sample devices may be destructively analysed, whilst the remaining devices would be "relifed".

Older plastic parts may be affected by incoming environmental legislation, such as the European RoHS and WEEE, requiring the original Lead-Tin finishes to be stripped and replaced with an alternative lead finish. Pure Tin finishes should also be inspected for "tin-whiskering", that, dependant upon the metal deposition process, can occur under normal storage conditions.

Considerations for long-term Storage of Die & Wafer product

Die and wafer products, often regarded as essentially only "half completed" components, in that they are lacking their final packaging and protection, are amongst the most vulnerable electronic components that we consider storing. Many of the guidelines given here are equally applicable to other items of a sensitive nature, electronic or otherwise.

Why store die and wafers?

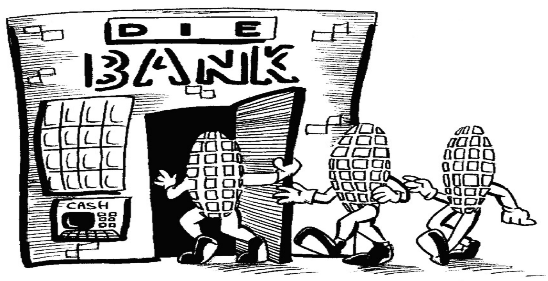
The long-term storage of semiconductor die or wafer products, often referred to as die/wafer banking, has been taking place since the late 1960s or so, initially as a direct supply to the semiconductor component hybrid industry. Die or wafer were usually stored at specialist facilities under strict environmental conditions, and supplied in small volumes to the hybrid manufacturer.

Many of the initial die-banking requirements and programs were military sponsored, both in the USA and the UK. Nowadays these facilities, often referred to as "chip houses", act as intermediaries between the semiconductor manufacturer, whose interest is mainly in high volume supply, and the hybrid industry, which is generally geared to high-reliability low-volume products.

Sometimes die banking has occurred for purely accidental reasons, such as manufacturing overflow, but, more recently, it is being used as a deliberate mitigating solution against semiconductor component obsolescence.

Whilst it may initially appear counter-intuitive to store a semiconductor device in its most vulnerable form (from both the physical and chemical contamination viewpoint) the overall benefits of storage range from the size factor, (the actual die often occupying less than one hundredth of the volume of its packaged counterpart), the ability to select different assembly package styles and options at a later date, and financial implications, as the die cost can often be only a fraction of the final assembly cost.

The hybrid and MCM industry, amongst others, require the use of bare die in any event, the die effectively being the smallest physical form factor available for that specific function.



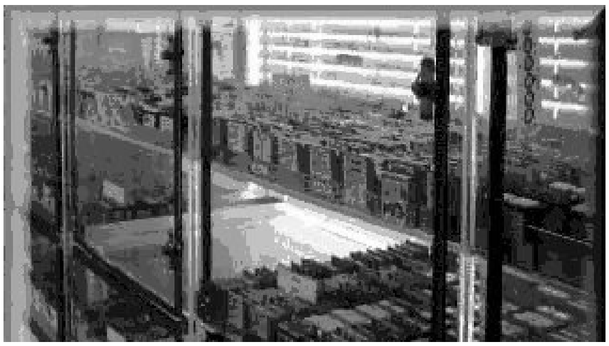
Over a long period of storage, previously packaged devices may suffer lead finish and package degradation, which, without remedial treatment and periodic re-lifing, will render the devices finally unusable. Current semiconductor date-coding practice reflects only the date of final packaging/encapsulation, irrespective of the actual age of the active die, so use of die banking facilitates a continuing low-volume supply of "new" packaged product to the end user over an extended period, which may often continue for as long as 20 to 40 years in many military and aerospace programs.

There was a distinct lack of international standards in this area, concerning information and best practice regarding die storage, and what information should be expected from the die storage facility. This is now addressed by the IEC TC47, in part 3 of **IEC 62258: Semiconductor die products – Minimum requirements for procurement and use**, published in 2004.

Organisations such as the European Commission funded ENCAST and Good-Die network *http://www.gooddie.net/* and the American Die Products Consortium *http://www.dieproduct.com/* are currently working together to produce informative data on all die and wafer related products. The Good-Die team have already produced a European Specification, **ES59008: Data requirements for semiconductor die**, which is currently published in twelve parts by the British Standards Institution (BSI) *http://www.bsi-global.com*.

This document is not meant to be alarmist, rather it is intended to raise the awareness that long term storage of modern-day and future semiconductor product requires a re-examination of the methodology and conditions of storage, and that we must now consider the secondary and tertiary effects of the storage environment. Many more questions have been raised during these initial investigations than have been addressed and answered herein.

Initial assumptions for die & wafer storage
The initial assumption is that the die or wafer is required to be stored for up to 25 years, with a zero call-off rate. After this period, the die shall then be "process-able", and the die (once processed) shall be expected to work as if it were a new device (as indicated by its assembly date code). The inherent reliability or specification of that final device shall not be compromised due to the dies' storage or storage environment.



A typical die and wafer storage bank.
Photo Alun Jones – Austin Semiconductor.

Historical storage
There is much historical and anecdotal evidence regarding the long-term storage of die and wafer products, and the author's company has been storing die/wafers for well over 30 years, with few problems, but it must be remembered that this was OLD technology product, often 10 micron to 7micron SLM/DLM or even larger geometries, that was BUILT and DESIGNED to last, often simply out of the conservatism of the existing design rules and manufacturing controls.

The fact that these older technologies have proved to be so robust is often due to them being "over-engineered", "over-tested" and "under-specified" for their final application. In many cases, these device types were military-type or military sponsored, and so the technology was COARSE, RUGGED and ROBUST, such as Bipolar, PMOS, NMOS or MG-CMOS on 4in. wafers or smaller. Modern devices, with shrinking geometries, for many reasons do not exhibit the same ruggedness found in earlier parts.
In general, the required environmental conditions, such as ESD protection and overall cleanliness for storage of this type of product were easily met, and the accompanying product related data, such as test results, wafer maps and specifications, was held on paper.

If we are now to store new die product for 25 years, then the data medium for the accompanying "paperwork" requires the same operational life, and again we have seen enough historical evidence that there are issues in this area to be addressed.
Please refer to the section "The Archival Store" for a more in-depth discussion on storing data.

Known product sensitivities, or "How to damage die product ..."

It is worthwhile digressing to discuss the ways and means of practically destroying die and wafer products, thereby ascertaining what is needed for their protection. We can crudely categorise the three main elements of destruction as being mechanical, chemical, and electrical, each discussed separately. Regular "interference", such as opening the containers for inspection, stocktaking etc., can be sufficient to cause damage, so consideration as to the total storage methodology is pertinent.

Mechanical damage.

Under this category we would lump such damage as may be caused by thermal expansion, fractures, abrasions, breakages, visual defects etc. We would also include damage caused by mechanical stress, such as the changing of electrical parameters through in-built surface strains or body-related piezo-effect stresses. Crazing or cracking of the passivation that can compromise the integrity of the seal-ring or the active area of the die, and damage to the die underside and to exposed contact areas such as bond pads should also be included. Poor probe marks are another source of damage, both from the contact area viewpoint, gouging into the sub-metal structures, and by the provision of "spare" loose contaminant material.

Mechanical damage is often initially detected by visual or optical inspection, and different application markets, such as the space industry, impose differing inspection criteria.

Protecting against mechanical damage.

So, die mechanical protection and initial placement (accuracy of the carrier geometry), are important in preparation for storage, and whilst during storage issues such as vibration and movement become relevant, the use of anti-shock and anti-vibration packing materials should be considered. Inappropriate die removal, handling and inspection may also contribute to the collection of mechanical failures. When storing wafers, the question of storage orientation may also be need to be addressed, as this may affect some MEMS type product. Pay close attention to the proximity to other materials, and the likelihood of abrasion and adhesion of foreign matter, generated by local materials, to the die or wafer surfaces … silica-gel type package desiccants are an excellent source of micro-particles (abrasives), as is silicon dust itself.

Both the ambient temperature and humidity must be well controlled. Current industry practice is for a constant temperature of between 17-25ºC, with a relative humidity (RH) of between 10% and 40%. Too high an RH can lead to condensation and moisture problems, too low an RH can lead to the build-up of electrostatic fields. The die and wafers should be protected against excessive temperature excursions, and ideally, the temperature and RH should be periodically monitored and stored for future reference. Large changes in atmospheric pressure should also be avoided where practicable, as this encourages "breathing" of the partially sealed packing container (so don't keep the die in the lift!).

Chemical damage
(*corrosion or contamination*)

Mainly caused by ionic contamination of the active area, which is generally introduced by poor pre-storage handling and cleaning. Inter-metallic growths, caused by an external reagent or promoted by a local catalyst can occur on exposed contact areas; this would be especially true where the die or wafer is stored with either bumped or interconnect structures, or has some unique cocktail of UBM (under-bump metallisation) processing. Other exotic materials used nowadays in the die process may exhibit as yet unknown sensitivities to reagents.

One of the major sources of contamination derives from the degradation of certain packing materials. The polymerising of rubber can give rise to gaseous sulphurous compounds, chlorine and ammonia from certain types of paper and cardboard, fluorine from "pink" anti-static foam, and formic and acetic acids from some plastics and silicone sealants.

Polyurethane and polyethylene foams, dependant upon the process of manufacture and blowing, can give rise to many different organic and inorganic compounds, and is subject to much current research on environmental issues. Cellulosic papers, including highly stable cotton papers, are also known to produce a range of organic acids, including formic, acetic, lactic and oxalic acid. The same acids also form in alkaline papers but are neutralised by the alkaline reserve, giving rise to other chemicals. Many of the more common plastics used as transient or temporary packing readily polymerise in UV from fluorescent lighting (UVA) or direct sunlight UVA/UVB/UVC), with the production of complex halogen-hydrocarbons, the effects of which are unknown over a long period of time. Certain electrical equipment and specifically local "ionisers", used to prevent the build-up of static charge, can produce ozone, which again is highly reactive,

Airborne contaminants, such as hydrocarbon micro-particulates and sulphur compounds, often occur in high concentration in many Third World countries, whilst contact contaminants, such as sodium, chlorine, urea and even spittle, are generally caused by poor handling and are nowadays, well documented and identifiable problems. The use of vacuum packing is seen to encourage the ingress of external contamination and, again, the addition of desiccants can cause minor particles to be present. Anti-static and/or metallized coatings commonly used on conductive plastic bags, have been observed to "flake" or rub off, again the source of "unidentified" contaminants.

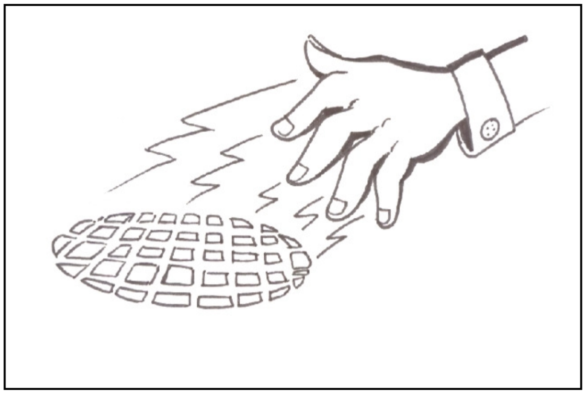
It is important to remember that chemically caused discolouration, often the product of localised oxidisation, whether benign or not, can be sufficient to reject a die on visual grounds alone.

Protecting against chemical damage

Current storage systems usually rely on a positive pressure inert gas environment, generally nitrogen but other noble gasses, such as helium and neon could equally be used if viable. It should be noted that, as with any positive pressure system using an inert gas, the local oxygen levels must, in accordance with local legislation, be regularly monitored in areas where people have access. The "cleanliness" or purity of the gas used should be regularly monitored and recorded, but deliquescence monitors, such as cobalt chloride indicators should preferably be avoided.

As with all storage issues, the proximity of known "active" reagent sources must be considered. The use of modern "bio-degradable" materials again should be avoided until further data becomes available. The long-term lifetime of certain adhesive "tacky" type packing and gel-based packing again has yet to be fully established.

Electrical damage



Electrical damage to semiconductor devices is well-understood and documented, especially from an ESD viewpoint, and catastrophic damage, such as P-N junction breakdown, or FOX-GOX breakdown / puncturing, are generally the result of poor handling procedures. Once again, inappropriate packing materials or storage methodology can be the root cause.

Continuous electrical, magnetic or nuclear radiation, even at low strengths doses can significantly alter the electrical properties of sensitive active components over an extended time.

Such parameters as a change in V_T from a trapped Q_{SS} charge, or a change in the I_{OFF}/V_{OFF} knee parameters, whilst not catastrophic, could still effectively render the final die unusable by shifting sensitive or operational parameters. Storage, even under ambient light conditions can give rise to photovoltaic energy effects/defects on sensitive analog die, especially true for reduced feature size and geometries.

Poor or incorrect electrical testing can also contribute towards damaging a part, so that it is stored with initial damage; not all electrical damage is "observable", either by visual or electronic inspection, but the final device could be amongst the "walking wounded", finally resulting in a shortened operational life.

Protecting against electrical damage

High background radiation, proximity to ES or EM field sources (? a local phone mast), local RF and microwave sources, UV. & X-ray sensitivity and ambient light should all be considered, and also the effects these have not just on the die product, but the effects caused by this "ageing" on proximity materials, such as the accelerated polymerisation of specific plastics etc.

From the point of view of the die, a cool dark, not too damp environment, well away from other electrical equipment is preferable (well away from mobile phones and microwave cookers!), with a chemically inert conductive covering, such as aluminium foil, as a final wrapping.

Preparation for storage

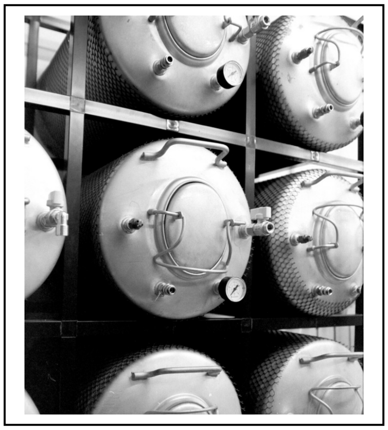
The Golden Rule for long-term storage is

GIGO: **G**arbage **in** – **G**arbage **o**ut.

Don't expect rubbish product to miraculously 'improve' during storage – it doesn't happen.

Only fully-screened and tested die or wafer products should be stored. Wafers should either be inked or stored with the wafer map in a 'future-readable' form. If die product is to be stored, then separated singulated known-good-die only should be stored. For logistical security, multi-site storage may be considered.

It should be assumed that the die or wafers have been shipped by the manufacturer or supplier in temporary / transient packing unless advised otherwise. While this packing may well be adequate and/or ideal for long-term storage, the manufacturer or supplier, unless otherwise advised, only supplies this packing to protect the devices while in transit, and not with the intention of extended long-term storage.



Long-term (30 year) storage
Photo: Charles Battersby – SemeLab plc

All operations should take place in a clean-room environment, preferably class 10,000 or better, and the final storage area for the packed product should be held in an environment of class 100,000 or better. Many reputable suppliers of die and wafer storage materials and containers produce detailed instructions, recommendations, precautions and procedures on how to use their products to achieve optimum results. These instructions should be requested and then heeded. There is a broad variety of die/wafer container types and methods, such as wafer vial, wafer cassette, sawn wafer on film & frame, tape and reel, waffle pack, Gel-Pack®, etc., which may be selected based upon the storage and call-off/periodic inspection requirement. Consideration to the mounting and chemical properties of any tape or gel, the prolonged tack and adhesion levels, any physical die movement and mechanical migration, and UV exposure sensitivities (for UV release tape) should be added to the already over-long list.

Visually inspected and cleaned product would then be mounted, re-inspected in the container mounting and finally re-packed and stored (you do remember where you stored it, don't you?) with all the accompanying "paperwork". Backups of any computer-based records should be part of a regular archival regime, but knowing how and where to retrieve the data is also an important consideration. Final packing should be clearly marked with the contents, quantity and storage date, and whether die, part wafer or whole wafer is inside, along with appropriate handling, ESD instruction labels and the requisite QA approval.

Retrieval from storage would again be under a similarly clean environment, and any pre- or post-storage processing would also be done in a controlled clean environment.

Information needed before setting up a storage plan…

… from the Semiconductor Manufacturer or Supplier

- Recommendations from manufacturer as to known issues with packing materials
- Expected lifetimes of manufacturer supplied packing materials, in particularly those regarded specifically as transient packing or temporary packing

- Known sensitivities of the specific semiconductor technology
- Any recommended pre- and post-storage processes that may enhance the storage life.
- Are there any known pre- or post-conditioning requirements? If so, follow them.

... from the Storage House.
- Suitability of the storage conditions for the product concerned.
- Die & wafer traceability, and any abnormal or adverse conditions that have been applied to die or wafers during storage.
- Qualification of the product prior to storage and then again after storage.
- Actual age of silicon die, (not shown on final date code).
- Known or other historical data on the sensitivity to external effects
- Clearly marked packages, including static sensitivity
- Storage conditions (die history), and the Min-Max conditions

... from the Packing Supplier
- Best practice methodology for using the packing
- Any known mechanical, electrical or chemical degradation. What are the known sensitivities of the supplied materials and what are the known susceptibilities to chemical reagents, radiation, etc?
- Existing reports, material details and processing
- Recommendations on storage and lifetimes.

... from the Customer
- How long do the components need to be stored? as this will affect the approach taken for storage.
- What call-off rate is expected and what periodic inspection is required? i.e. how often do the containers have to opened?
- Are there any known pre- or post- conditioning requirements?

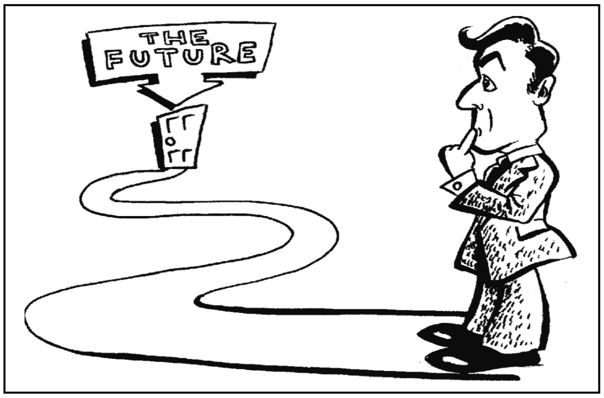
Speculation on future problems
As technology moves apace, there are more and more issues to be considered. New processing materials and properties such as copper metallisation give pause for thought …

Aluminium, due to its oxide Al_2O_3, is relatively inert, but the many oxides and sulphides of copper are all highly chemically active, and the long-term stability of dual-damascene copper vias has yet to be proven. New bump materials give rise to some novel inter-metallics, and many Pb-free solders have a high Tin content, therefore “whiskering” and conductive oxides give rise to new concerns.

Modern passivation materials, new polyimides etc., are necessarily employed, not for their longevity, but for their short-term effectiveness and cost; there is still little history on some of the more exotic semiconductor materials now available - *beware*.

Simulated long-term lifetime reliability techniques, based upon the standard Arrhenius chemical reaction rate prediction model cannot accommodate all secondary and tertiary effects that can affect semiconductor storage.
As die geometries continues to shrink, there is naturally an increased sensitivity to ES field damage, increased sensitivity to minor contamination, increased sensitivity to marginal

processing and in-built defects, and in some cases, unknown "survivability" beyond the life of a PC or cell-phone. It is now true that some products are now neither designed nor manufactured for longevity.



Again, there are uncertain issues when re-packaging and re-assembling and availability of "other" items in the build list. There is now becoming a shortage of metal TO-style canning capability, and the ubiquitous DIL package is still readily available in most of its guises, but consider the future availability of any of the current variety of new "sexy" packages, such as non-JEDEC BGAs; re-inventing those styles of packages is going to be no picnic!

The tester and related test and burn-in hardware may also subject to obsolescence, and whilst migration of test software is regularly performed, there remain the attendant costs for such an engineering exercise.

Finally, consider the total operation of storage and its possible effect on the environment and local health / safety legislation and regulations, both for now and in the future.

Unknown Issues for the future (MEMS)
And then, looking at the plethora of MS and MEMS type technologies, the storage sensitivities will be dependant upon MS type and application:

- Bio-sensors
- Chemi-sensors (Gas or liquid)
- Mechanical movement, (electrostatic, thermo-cycle or piezo-mechanical)
- Fluidic (pressure etc.,)
- Mechanical sensing, (acceleration, vibration, field/extraneous sensing, magnetic, electrostatic, optical, radiation)

Additional storage dependencies may include vertical/horizontal orientation, biological cleanroom packing, specific limits on mechanical movement, etc.

Initial conclusions on die & wafer storage

As in most cases, the application of common sense will lead the storage facility to adopt obvious and specific working practices so most of the following notes will already have been adequately addressed.

Specific training in the handling of semiconductor products, and die products in particular, coupled with a rigorous quality and process control procedure is needed throughout the handling, storage and shipping process. For further reference, read **IEC62258 Part 3: Recommendations for good practice in handling, packing and storage**, and then apply it.

- Current historical data involved OLD, RUGGED, BULLET-PROOFED technology. In many cases, this data no longer applies to MODERN, SENSITIVE devices, and the trend is not improving.

- Awareness of changes in processing technology and associated sensitivities that will affect product longevity.
- Manufacturers consider the delivery packing to be TEMPORARY only, used for short-term storage and delivery and not necessarily for extended long-term storage.
- Only store fully-tested product (remember GIGO!), and DON'T keep opening the containers to see if the die are still there.
- Ensure the die trays or wafer packs are correctly packed and identified, preventing excessive movement within the container … follow the manufacturers packing instructions.
- The control and logistics of the call-off rate needs consideration to prevent unnecessary disturbance of product in storage, store in appropriate sized containers, where practical.
- Traceability is needed throughout storage, with the selection of suitable storage media for data.
- Consider security and related logistics, e.g. is there a need for separate, off-site, storage?
- Thoroughly read and apply the good practices highlighted in**:**
  IEC62258 Part 3: Recommendations for good practice in handling, packing and storage.

Initial conclusions regarding the storage facility

- A clean room facility, class 100,000 or better, should be used, with appropriate controlled anti-static measures.
- Use of conductive or electrostatic dissipative materials is strongly advised. Some products may require clean room conditions significantly better than this minimum.
- Consider localised conditions, including security of product, and the proximity of unknown or "hazardous" materials; remove all known problem packing materials.
- Control temperature & humidity, 21ºC ± 4ºC and 30% RH ± 15% @ 1 At (STP)
- Dry Nitrogen supply, N_2,@ 99.5% purity. > .5% O_2 & Ar content, >0.01% other gasses, >1 PPM Halides, >10 PPM sulphurated gasses. Use of contaminant monitors is advised.
- Refer to the following standards:
  SEMI C3.5.93. STANDARD FOR BULK LIQUID NITROGEN (N2).
  SEMI C3.29.96. STANDARD FOR NITROGEN (N2), BULK GASEOUS
- The final shelving / containers should be suitably rigid, with some degree of anti-vibration and anti-resonance mounting. Use anti-shock & anti-vibration packing
- Limit exposure to illumination/radiation of any kind
- Confirm the orientation of storage, where applicable
- Confirm adherence to local health and safety standards

Die Banking

Typical die banking process flow.

Again, one can only re-iterate the GIGO adage, Garbage In, Garbage Out

- **Preparation for storage**
  - Procurement of wafer
  - Visual inspection
  - Electrical Test at wafer probe
  - Qualification of product for final application
  - Sawing / singulation and separation
  - Mounting into die carriers, with visual inspection

- Mounting into packing for long-term storage

- **STORAGE in controlled environment**
  - Class 100,000 in dry N_2
  - Temp. 21ºC, ±4ºC, RH = 30% ± 15% @ 1 Atm.

- **Retrieval of product**
  - Visual inspection of die from storage
  - Assembly
  - Pre-cap inspection
  - Assembly sealing
  - Gross and Fine Leak
  - Electrical and Environmental screening
  - Qualification of product for final application
  - Packing and device delivery

Commercial Implications

As alluded to previously, die/wafer storage can have specific commercial advantages for long-term projects. One of the main benefits derives from the fact that only part of the total fabrication and assembly process need be completed and funded "up-front". The wafers or die require to be initially purchased and tested prior to storage, but the actual cost of storage, by comparison, is almost negligible. At the author's company, as with other responsible suppliers, if the final assembly and test is to be processed in-house, then currently no charge is imposed for the die banking service.

Final assembly and test of the final device may then be commissioned on a device-by-device basis, the call-off and delivery rate being entirely driven by the customers requirements, whilst giving the final customer an effective insurance against component obsolescence. Changes in this back-end process can be readily accommodated, such as variances in the screening routine and differences in package types and styles. Alterations in the final assembly processes can also be easily catered for, such as the change to Pb-free tinning and solder dip.

Many OEMs have imposed restrictions on the date code for deliverables, requiring the date code to be within a specific time period of the purchase date.

Once again, as the date code solely reflects the date of final assembly, die banking assists in accommodating this commercial imposition.

Summary of Die Banking Advantages.

- Mitigation against component obsolescence, insurance for long-term projects and products.
- Relatively low funding required, final assembly and test costs only when needed
- Known quantity and quality available
- Storage costs minimal
- Call-off rate can be variable
- Package style can be changed at any stage
- Re-grades and re-selection can be performed
- Bond-out options (where applicable) can be selected batch-to-batch
- Legislation on final package lead-finish can be accommodated
- Build to order obviates date-code delivery issues and lead-finish problems

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A note from the author.
Dear reader, when I embarked upon the initial research précised in this document over 30 months ago for the GoodDie project, I had little idea of what a Pandora's box I was opening. Even as I conclude this booklet, events in the storage arena are moving apace. I am embarrassingly aware that there is much I've skipped or glossed over, so my apologies for any burning issues missed or major topics that I've omitted.

Other Websites:

ENCAST	*http://www.encast.org/*
BSI	*http://www.bsi-global.com/*
DPC	*http://www.dieproduct.com/*
DSTAN	*http://www.dstan.mod.uk/*
JEDEC	*http://www.jedec.org/*
SEMI	*http://www.semi.org/*
SBA	*http://www.semiconductor.org/*
INTELLECT	*http://www.intellectuk.org/*
IEEE	*http://www.ieee.org*

For a project that has a design brief of over 1000 years, please look at the MAITREYA Project *http://www.maitreyaproject.org/*

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Annex 1. Glossary.

- **Organizations …**

ENCAST *European Network for Challenges in Advanced Semiconductor Technologies*
COG *Component Obsolescence Group*
JEDEC *Joint Electron Device Engineering Council*
SBA *Semiconductor Business Association*
SEMI *Semiconductor Equipment and Materials International*

- **Electronic & Design terms …**

CAD *Computer Aided Design*
CAM *Computer Aided Manufacture*
GDSII *Graphics Display System, mark II*
MEMS *Micro Electro-Mechanical Systems*
MS *Micro Systems*
PAL *Programmable Array Logic*
PLD *Programmable Logic Device*
FPGA *Field Programmable Gate Array*
VHDL *VHSIC Hardware Description Language*
VHSIC *Very High Speed Integrated Circuit*

- **Production terms …**

MOQ *Minimum Order Quantity*
OEM *Original Equipment Manufacturer*
JIT *Just In Time*
BOM *Bill Of Materials*
BOF *Bought Out Finished*
PEM *Plastic Encapsulated Microcircuit*
COTS *Commercial Of The Shelf*
BGA *Ball Grid Array*
DIL *Dual In Line*
DIP *Dual Inline Package*
SMT *Surface Mount Technology*
HAST *Highly Accelerated temperature/humidity Stress Test*
HTOL *High Temperature Operating Life*
QA *Quality Approval or Quality Assurance*
KGD *Known Good Die*

- **Computer terms …**

RAID *Random Array of Inexpensive Disks*
IDE *Integrated Drive Electronics*
SCSI *Small Computer System Interface*
ESDI *Electronic System Data Interface*
OCR *Optical Character Recognition*
CD *Compact Disc*
DVD *Digital Versatile Disc*
TAR *Tape ARchive*
BAR *Blocked Archive*
QIC *Quarter Inch Cartridge*
DAT *Digital Audio Tape*
MD *MiniDisc*
ASCII *American Standard Code for Information Interchange*

- **Chemical / Physical terms …**

KOH *Potassium Hydroxide*
NaOH *Sodium Hydroxide*
RH *Relative Humidity*
VCI *Volatile Corrosion Inhibitor*
UV *Ultra Violet*
ES *Electro-Static*
EM *Electro-Magnetic*
ESD *Electro-Static Discharge or Electro-Static Damage*

- **General terms …**

GIGO *Garbage In – Garbage Out*
KISS *Keep It Simple, Stupid.*
e- *prefixed to almost any word to make it appear electronic and exciting.*

- **Notes …**

The two words "package (material)" and "packaging" as used throughout this document carry distinct and different meanings. Packaging is an encapsulation or interconnection technique, whereas packing is the material and/or action used to protect items during transportation and storage. Packing is discarded before the incorporation of the item into its end application.

Annex 2.

Table of Materials

General comments from the author on some materials that may be found in storage facilities. This list is intentionally non-exhaustive, and contains only very general comments on the material suitability for long-term storage.

Material	Notes on long-term properties
Aluminium	Excellent
Stainless Steel	Excellent
Glass	Excellent
Ceramics	Generally very good to excellent
Gold, Platinum, Diamond	Usually a girls best friend, very stable.
Copper & Silver	Poor, readily corrodes and tarnishes
Wood	Variable from excellent to poor, dependent upon wood type, treatment and environment.
Mica (mineral)	Good
Polyethylene	Good
Polyvinyl chloride	Poor, chemically unstable
Polypropylene	Good
Mylar-D (polyester)	Good
Leather	Bad, protein based, unstable
Newspaper	Bad, high chlorine content
Paper … alkaline buffered	Poor, can give off unknown gasses
Money, paper or coins	Insufficient evidence, usually vanishes.
Wool, silk, nylon fabrics	Bad, can give off sulphurous gasses
Polyurethane	Bad, chemically unstable
Styrofoam	Bad, chemically unstable
Synthetic packing materials	Generally poor, can give off unknown gasses
Starch based packing	Bad, chemically very unstable
Dow Ethafoam 220 or similar	Good
Inks or felt-tip markers	Poor, rapid degradation
Pressure sensitive tapes or adhesives	Bad, generally chemically unstable
"Bluetack"	Bad, generally chemically unstable
Foodstuffs, even canned	Bad, microbial attack
Rubber	Bad, de-vulcanises giving off sulphurous gasses
Granite	Good, but can give off Radon gas
Most electrical batteries, apart from those specifically intended for long shelf life.	Poor, most primary & secondary cells can exude corrosive electrolyte