

## **Cold Storage Options: Costs and Implementation Issues**

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Cold storage has long been recommended for the preservation of unstable film and color photographic media. This article discusses the relative costs of various cold storage options and some associated operational issues. Due to space limitations in this article, important issues related to the safe implementation of cold storage, such as specific detailed protocols for vapor-proof packaging, handling, and maintenance, are not discussed.

The benefits of cold storage are that it:

- Extends the useful life of unstable materials.
- Buys time for materials that are already deteriorated until duplication or digitization can be performed on an as-needed or systematic basis.
- Decreases casual use and browsing of collections, and associated wear and tear, due to the inconvenience of accessing cold materials.
- *Reduces or even eliminates the need to replace poor-quality enclosures that are physically intact, a considerable material and labor cost for large collections.*  
Enclosures degrade more slowly at cold temperatures, thus decreasing or eliminating harmful off gassing and associated reactions caused by substandard housing materials.

### **Cold Storage Options**

This article discusses the relative costs of various cold storage options:

- Walk-in cold vault or storage room, with relative humidity (RH) control.
- Walk-in cold vault or storage room without RH control.
  - Using vapor-proof packaging to wrap containers or items (to maintain RH) stored on open shelving.
  - Using sealed, microclimate storage cabinets to maintain RH.
- Free-standing, frost-free freezer units using vapor-proof packaging to wrap materials.
- Leased commercial storage space from a reputable company.

### **Factors Affecting the Selection of an Appropriate Cold Storage Option**

The type(s) of cold storage that an institution might select depends on many factors, including the costs to implement, maintain, provide security, and protect from fire or other hazards. Institutions must weigh the advantages of one option over the other based on the

- Urgency of need and the time it will take to implement cold storage.
- Appropriate space, the impact of its location on- or off-site, and the need for any modification prior to use for cold storage.
- Budgets or grants for freezers, or for vault construction and furniture purchases.
- Experienced staff to specify, contract, and oversee a vault construction.
- In-house staff, contract labor, or volunteers for vapor-proof packaging, if used, and funds for those supplies.
- Experienced in-house staff or HVAC service contracts for routine vault maintenance and associated costs.

- Ability to monitor certain types of equipment and respond correctly and promptly to malfunctions before collections are endangered.
- Long-term energy costs.
- Ongoing budgets for long- or short-term leasing, including the shipping/handling fees associated with high-use materials.

### **Determining Space Needs for Cold Storage**

It is useful to calculate the storage needs based on the space the collection currently occupies if standard shelves or cabinets of the same type will be re-used or purchased for a new vault. Where this is unknown or not easily calculated, a helpful starting point is a conversion table for various formats. The U.S. National Archives conversion tables for films and prints are an example (<http://www.archives.gov/records-mgmt/publications/audio-visual-records-inventory-form-instructions.html>):

#### **Est. # Photographic Media/Cubic Foot (CF)**

<b>Photographs</b>	<b>Items/CF</b>	<b>Motion Pictures</b>	<b>Items/CF</b>
4x5-inch negatives	2184	35mm reels (1000')	6
35mm slides	8640	16mm reels (1200')	11
6-frame 35mm strips	2300	16mm reels (800')	15
8x10-inch prints	2350	16mm reels (400')	32
4x5-inch prints	9400		

Each collection presents various formats, housings, and containers that influence its total space requirements. The actual number of items that will fit into one cubic foot (CF) may vary depending on the types of enclosures and containers, thickness and format of the photographs, distortions, mounts, etc. Likewise, the actual *usable* capacity of a cold storage unit can vary from 30-70% due its internal dimensions and shelving configurations. In practice, a 20-CF household freezer may only have an actual usable space of 15 CF because approximately 5 CF are occupied by shallow door shelves/bins.

Practical experience demonstrates that approximately 250 negatives that are housed in seamed paper envelopes will fit within a standard 12-inch "shoebox," four of which can be stacked in one CF for a total of 1000 negatives/CF. However, constraints of freezer design and shelf configuration allow only 40 standard shoeboxes to be shelved in an unmodified 20-CF household freezer, not the expected 80 boxes. This halves the *effective* capacity within the freezer to 10 CF, or only 500 negatives/CF. The actual capacity of a 20-CF freezer would then be 10,000 4x5-inch negatives, not the estimated 20,000 based on total freezer volume or the 43,680 predicted by the conversion table!

### **Estimated Costs of Various Cold Storage Options and Associated Issues**

For the purpose of this article, the cold storage options were limited to leasing commercial space, two vault sizes and climates, and a 20.3-CF household auto-defrost freezer. To simplify the cost calculations for packaging, shelving, and total cubic feet of records' storage, only one collection sample type was used to calculate these estimates: this one-cubic foot sample consisted of four standard 5"H x 6"W x 12" D shoeboxes. It was assumed that each box holds 250 negatives in paper envelopes (1000 negatives/CF). Additional assumptions included:

- 40 boxes (10CF, 10,000 negatives) could fit in one standard, unmodified 20.3 CF freezer.
- 70 boxes (17.5 CF, 17,500 negatives) could fit in one open 7-shelf unit or sealed cabinet.

All costs listed should provide an idea of *relative* expense among various options. Costs have been calculated per CF to provide easier comparison between options. Prices will vary among vendors and regions, and do *not* include every possible cost involved. Costs are constantly changing depending on materials, energy, delivery (freight) charges, and labor; these estimates were obtained during the summer/fall 2007. Because quotes were based on the generic, hypothetical options requested, vendors emphasized that their estimates were *approximate only* due to the variable and unknown factors.

### ***Leased Commercial Space***

The leasing rates of a commercial cold storage facility were provided by one vendor with a track record for well-maintained vaults and reliable shipping and handling (Table 1). Because of the variability and efficiency of shelving among formats, large-volume leasing was quoted at a maximum rate. Actual costs for collections with uniform containers or compact containers may be lower. Handling fees will vary with geographic region and usage rates as items are requested, while the variety of formats may influence any fees for the initial shelving and bar coding. Leasing rates for 20-360 CF range from \$69-96/CF/year depending on storage climate and quantity. Large-volume leasing rates for 1000-2000CF were estimated to be less than \$25/CF/year.

Although cost effective at the CF level, leasing is expensive over time due to the recurring cost and additional fees for handling and shipping. However, leasing space may be cost effective for large collections that lack space, upfront resources for vault construction, ongoing resources for annual energy and maintenance costs, and/or experienced staff to operate a vault. Leasing can also be useful as a temporary solution to preserve rapidly deteriorating materials until an institution can implement permanent cold storage. Overnight shipping from distant sites delays access, although not significantly more than some standard institutional handling protocols used to warm materials prior to use.

### ***Vaults***

A firm that has installed several institutional vaults in the Washington, D.C. metro area supplied pricing for several vault sizes (8'x12'x8.5'H, 16'x24'x8.5'H, 6'x6'x8.5'H vestibule) at 35°F and 25°F, with and without 35% RH control (Table 3). Operational costs for energy and maintenance are listed in Table 2. Very low-temperature (0-10°F) vaults were not estimated due to their cost, energy demands, and substantial user discomfort factor.

The equipment specifications included standard 4-inch thick foam-insulated metal-skinned panels for walls, ceiling, and floor; air-chilled coolers, compressors, condensers, desiccant wheels for RH-controlled vaults, backup units for RH-controlled vaults, light

fixtures, delivery, and installation. Fire suppression systems and remote environmental monitoring alarm systems were not included in the specifications. Gaseous air filtration also was not estimated, although this might be desirable when packaging is not used for collections, such as acetate film, that might emit contaminating gasses. For the purpose of determining cooling loads, it was assumed that the vault would be placed in an area with office-type conditions, rather than outdoors or in a more variable sheltered space such as a loading dock or covered garage, and that the space did not require modification, had ready access to utilities and that exterior mechanical systems could be located within a 75-foot run line. These and other factors could affect the estimates and overall costs. Therefore, these estimates must be considered *minimum approximate costs*.

Depending on their climate conditions, cost estimates for 8x12 vaults range from ~\$22,500-39,000 while 16x24 vault costs range from ~\$61,000-85,000. A 6x6 vestibule (35°F /35% RH) costs \$31,500. *In actuality, an acclimation vestibule serving either a 35°F or 25°F vault adjacent to ambient office conditions would be set at ~50-55°F /35% RH and would cost slightly less than quoted.* Cost estimates for annual equipment maintenance range from \$500-1000/year when performed in-house (estimated by the vault vendor) and up to \$4000/year for an annual service contract that provides bi-monthly inspections and routine maintenance (as reported by a facility manager for a government institution).

Vaults are more cost effective in larger sizes. Taller vaults with high-tiered shelving may provide even lower cost/CF with only a small increase in initial cost.

- Mobile shelving adds significantly to the cost compared to fixed shelving, but lowers the average cost/CF by nearly doubling the capacity. Fully shelved high-density storage also increases thermal load and may decrease energy requirements accordingly because the HVAC system is not cooling and conditioning empty space.
- Very low-temperature vaults are more expensive than equivalent warmer vaults. However, a 35°F vault without RH-control (~\$22,400) costs only slightly less to install than a similar 25°F vault (~\$23,400). Institutions with contemporary, composite, mixed-media collections, or less-vulnerable media may opt for warmer vaults (45-60°F), which will still significantly improve the life expectancy of some collection materials.
- Humidity control at 35% RH adds significantly to the initial cost of a vault—about 40% more (~\$15,000) for 8x12 vaults and 20-30% more (~\$13-21,000) for 16x24 vaults (depending on temperature). It increases equipment complexity, maintenance requirements, and doubles ongoing energy costs. These systems often include recommended backup equipment, which also increase expense.
  - At \$0.10/KWH, it costs \$700-1000 more per year to operate an 8x12 RH-controlled vault at 35°F and 25°F, respectively, than a similar vault lacking RH control. For a 16x24 vault, it costs ~\$1300-1700 more per year to operate either a 35°F or 25°F RH-controlled vault. Over time, these energy costs will inflate.
- Annual operational costs for energy *and* maintenance are substantial. For an 8x12 vault with a low-cost maintenance contract (\$1000/year), operational costs range from ~\$1900-3200/year depending on the vault climate; for a 16x24 vault the cost range is ~\$3600-5600/year. Using a high-cost maintenance contract, operational costs

for an 8x12 vault are ~\$4900-6200/year depending on vault climate. For a 16x24 vault the cost range is ~\$6200-8500/year.

- One advantage of RH-controlled vaults is that item-level access of collections is possible because the containers are not encumbered with vapor-proof packaging. Sealed cabinetry may also permit item-level access. However, *careful handling is required at low temperatures and during initial warm up due to cold-induced brittleness and potential localized condensation from warm fingers*. Some level of moisture protection from leaks or mechanical failure is still desirable in RH-controlled vaults.
- A temperature/RH-controlled vestibule is a very expensive feature because it requires precise RH/temperature control of set points specific to the vault and ambient use conditions in order to function as an acclimation chamber or allow for a more comfortable inspection of collections. It is not required for safe warming of materials and requires a two-step procedure that doubles the total warming time and delays access.
  - If the vestibule is used for acclimation or inspection, users *must* monitor the vestibule and ambient climates to ensure that all are within their allowable ranges. Otherwise, moisture condensation could occur on unprotected items being removed from the colder condition (vault to vestibule or vestibule to ambient).
  - A simple and low-cost way to avoid condensation on items is to place the materials in a sealed plastic bag or insulated container before removal from the vault, then allow the contents to slowly warm to the ambient conditions, perhaps overnight.

### ***Free-Standing Freezer Units***

A Sears Kenmore auto-defrost 20.3 CF Household Freezer (~ \$700) was the baseline unit used for this study, along with the Onset HOBO data logger (\$300) with auto-dialer and remote alarm (Table 4). Alarm hook-up to a facility-wide monitoring system, where available, costs 2 -3 times more than an auto-dialer (~\$1000/unit). Household models tend to be reliable (when rated by consumer groups) and readily available, replaced, and serviced. The unit is 32"W x 28-1/2"D x 70"H, with shelf dimensions 26"W x 17" D, and temperature range from 0-25°F. Large-quantity discounts were not factored into the estimates. Commercial (restaurant and scientific) freezer units are other freezer options and are available in 40- and 70-CF capacities. They were not selected for this study due to several factors including noise, heat, smaller doors (in a few models), some reported reliability issues, and expense (3-6 times more per unit and 2-4 times more per CF). However, they can be useful in some circumstances where a larger interior capacity and/or dimensions are required.

Freezers can be a cost-effective option for small collections. Institutions with limited resources can acquire freezers and the necessary packaging for rapidly deteriorating portions of the collection as funds allow. This approach may ensure the preservation of the most vulnerable items, such as deteriorating films, until they can be duplicated or cold vaults constructed. Freezers also can be used to complement vaults where only a small proportion of the collection require very cold temperatures and the remaining less-vulnerable collections of mixed media or composite works are safe in RH-controlled cool

vaults (45-60 °F). Vapor-proof packaging of materials stored in freezers is discussed in the section on microclimate protection (see below).

- The *nominal* capacity of 18 freezers is 360 CF, which is similar to that of an 8x12 vault outfitted with open shelving. The total cost of 18 freezers with vapor-proof packaging (~\$24,000) is approximately one half that of an 8x12 RH-controlled vault outfitted with new open shelving (~\$49-53,000), and one half that of an 8x12 vault without RH control outfitted with new shelving and packaging (~\$42-48,000).
- The *actual* capacity of 18 freezers is 180 CF (720 boxes). The actual capacity of a shelved 8x12 vault is 245 CF (980 boxes) for fixed shelving or 315 CF (1260 boxes) for mobile open shelving; 25 or 32 freezers would be required to match the 8x12 shelved vault capacity and would require a space larger than 16x24 (and cost ~\$34-43,000). The capacity of 18 freezers is similar to that of an 8x12 vault lacking RH control, outfitted with sealed cabinets (630 boxes for fixed and 840 boxes for mobile configurations). However, the cost of 18 freezers with packaging is about half that of an 8x12 vault with new sealed cabinets (~\$42-53,000).
- The use of 20-CF freezers becomes increasingly costly and impractical above approximately 18-25 units, because of the space requirements, packaging costs, and energy expense.
- Freezers featuring flat door panels provide more useful storage space. Bulky door panels with bins can be replaced with flat sheets of polystyrene (this low-cost modification may void the warranty). This modification was developed by Constance McCabe of the U.S. National Gallery of Art so that 14"x17" x-radiographs films could be shelved horizontally in household freezers, thereby increasing capacity by one-third.
- Freezer units are not energy efficient in very large multiples. The amount of energy required to run multiple freezers may exceed that of a vault when more than 18 units are used. Extra room cooling may also be needed to compensate for the heat generated if many units are operating in a confined space, although this issue is moot if units are dispersed throughout a facility to more conveniently serve different departments.
- Freezers have a negligible annual routine maintenance cost, unlike vaults.
- Freezers offer a reliable and low-maintenance option: if one unit malfunctions, only the materials within the problem unit are affected.

### ***Microclimate Protection: Vapor-proof Packaging and Sealed Cabinetry***

Materials stored in freezer units and vaults without RH control require protection from RH extremes and condensation if the containers are not airtight, as is the case with well-sealed plastic and metal film cans. This can also be accomplished with either vapor-proof packaging (bagging) of boxes or the use of sealed cabinetry in vaults. To maintain a stable microclimate in a gasket-sealed cabinet, Henry Wilhelm and Mark McCormick-Goodhart recommend using conditioned silica gel or desiccated paperboard inside as a humidity buffer [1]. They also modify the vault so that the fans are timed to operate with the compressor cycle resulting in a consistent ~60% RH within the freezer vault—thus minimizing the RH differential that the buffering material must counteract.

For a direct cost comparison between packaging and sealed cabinetry, materials and labor for vapor-proof enclosures *and* new standard open shelving were estimated along with sealed-cabinet costs. However, *neither the labor costs to prepare the buffering material nor the cost of the silica gel or desiccated paperboard was estimated for the cabinet method.*

The vapor-proof package is based on a design used by the author, incorporating a low-cost, heavyweight (6 or 8 mil) re-sealable polyethylene outer bag and an inner flush-cut bag of translucent polyethylene/polyester laminate with a metallic deposit, both sized for the standard 4x5 "shoebox." Both bags can be re-used indefinitely until damaged. Also included was clear acrylic 2-inch-wide tape to seal over the flush-cut bag and one RH indicator card per package. These packaging materials are available in bulk from Uline and other vendors. The cost of this packaging (~\$1.90/box) is about midway between using two poly bags alone or a polyethylene outer bag with an inner metal foil-laminate plastic bag (such as used at the National Gallery of Art). Due to the durability and high-quality seams of these bags, the cost of desiccated paperboard inserts between bags was not estimated due to the greater expense and labor. Shipping costs were not included, but discounts were calculated for larger CF quantities (greater discounts may reduce costs further). Labor for packaging was based on two different levels of packaging productivity and federal hourly rates (GS5 and GS7, Washington, DC region, Tables 4). Using these low- and high-labor rates of \$120.00/day and \$200.00/day, total packaging costs ranged from ~\$5.50/box to ~\$8.75/box, respectively.

### ***Shelving and Cabinetry***

Furniture estimates were provided by suppliers of museum-quality shelving and cabinetry, and included fixed and mobile units delivered and installed. (Tables 3 and 5) The costs for silicone gasket-sealed cabinets were based on units 39.5"W x 17.5"D x 84"H (Table 4) with seven 12"H shelves. A larger cabinet, 58"W x 32"D, would offer an advantage for oversize items (at a base cost of approximately one third more). Discounts for larger cabinet orders were quoted along with reduced freight charges. *The cost of a mobile cabinet installation was not quoted by the vendor and was approximated by the author.* Standard open shelving estimates were based on units 36"W x 12"D x 84"H with seven 12"H shelves. The vendor provided cost estimate *ranges* for delivery and installation for both fixed and mobile configurations. For the purposes of this article, the estimated ranges for shelving were averaged to simplify the cost calculations.

The use of any existing shelving or cabinetry is the least expensive option, but does incur labor costs for disassembly and re-installation that were not estimated into the vault costs. Two layouts, for both fixed and mobile shelving, were estimated based on the number of boxes that could be shelved. For simplicity, the tables show the different layouts as approximately 360CF, 1000CF and 2000CF.

### ***Vapor-Proof Packaging***

Vapor-proof packaging can be cost effective, compared to installing RH control for a vault, for small collections where staffing or funding for associated initial labor is available.

- Determining the cost benefit of packaging vs. RH-control or sealed cabinetry can be complicated. Labor costs and availability dramatically influence whether packaging is a feasible option for medium size collections. Using the two labor rates listed, the total costs for packaging range from ~\$22-35/CF. The amount of time it may take to package boxes at 7.5CF/day (30 boxes/day) can range from 13 days for 400 boxes, 33 days for 980 boxes, 42 and 117 days, respectively, for 1260 and 3500 boxes. Higher productivity would reduce this time and the associated labor cost of packaging. Volunteer labor is even more cost effective when available as an option.
- At \$8.57/box (\$34.28/CF), the total packaging cost increases significantly as the number of boxes increases. For an 8x12 vault, 980 to 1260 boxes can be shelved using fixed and mobile configurations with a packaging cost of ~\$8400 to ~\$11,000, respectively. For an 8x12 vault, packaging costs less than the cost of RH control (~\$15,000). For a 16x24 vault, 3500 to 6300 boxes can be shelved using fixed and mobile configurations with a packaging cost of ~\$30,000 to ~\$54,000, respectively. The cost of packaging these quantities is approximately 2-4 times greater than the initial cost to install RH control (\$13-21,000 depending on temperature).
- If new open shelving is factored into this cost (for a direct comparison to sealed cabinetry), the packaging is ~2 times more expensive (~\$19-25,000) than RH control for an 8x12 and 2.5-6 times more expensive (\$54-132,000) for a 16x24 vault.
- The use of packaging is an ongoing labor cost when collections are accessed frequently—boxes must be re-bagged prior to being placed back in cold storage after each use. In addition, packaging prevents item-level access, and the entire container must be removed and warmed up to retrieve an item. If the item being accessed will be used for more than a few days, the box should be re-bagged and returned to cold storage in order to minimize “time-out-of-storage.” The process is repeated when the item is returned to the box. Because “time-out-of-storage” should be minimized for all materials stored in cold conditions, access copies should be made for high-use items.
- Packaging can provide additional disaster protection to collections.

### ***Sealed Cabinetry***

Sealed cabinetry can be cost effective for a 35°F 8x12 vault, especially if the comparable packaging cost includes the expense of new standard open shelving.

- The cost of 9-12 new sealed cabinets (~\$19-30,000) for an 8x12 vault lacking RH control is comparable to a similar number (14-18) of new open shelving units with packaged containers (~\$19-25,000). The cost of the sealed cabinets is 2-3 times that of packaging alone (~\$9000 for 1100 boxes) and 1.5-2 times more than installing RH control (~\$15,000). Because sealed cabinetry offers less storage efficiency than open shelving (an average of 735 boxes for cabinets vs. 1100 boxes shelved) the cost/CF of cabinetry is double that of packaging and shelving (~\$143/CF vs. \$78/CF).
- The cost of 55 mobile sealed cabinets (~\$132,000) for a 16x24 vault lacking RH control is ~2.5 times the cost of installing a similar number (50) of new fixed open shelving units with packaged containers (~\$54,000). The cost of this cabinetry is 4.5 times that of packaging alone (~\$30,000), and ~7-10 times more than RH-control (\$13-21,000).

- When a 16x24 vault is fully outfitted with mobile cabinetry (55 units) or mobile open shelving (90 units), the cost of sealed cabinetry (~\$132,000) is similar to the cost of mobile open shelving with packaging (~\$132,000). However, the cost/CF is \$137/CF for mobile sealed cabinetry vs. \$84/CF for mobile open shelving with packaging because of the much greater storage efficiency of the open shelving (1575 CF, 6300 boxes) vs. that of the cabinetry (963 CF, 3850 boxes).
- The use of sealed cabinetry may permit item-level access to materials (within the cabinet) in vaults lacking RH control. However, frequent access to a cabinet can deplete the moisture buffering material, requiring its regeneration more often (an additional labor expense). As mentioned previously, items must be handled carefully when they are cold due to cold-induced brittleness.
- The use of sealed cabinetry may be feasible and cost effective where institutions already have these cabinets available for use in a new vault or a large budget for new furniture. Additional factors to consider are the resources to purchase the moisture buffering material, and the expertise and staff to condition (and periodically re-condition) the buffering material as needed to ensure that the correct RH is maintained within the cabinet. *Because the cabinet estimates in this article do not include either the labor or the cost of the buffering material, the actual costs of using sealed cabinetry are higher than listed.*
- Lockable, sealed cabinets can provide additional security and disaster protection to collections.

### ***Energy Costs Savings for Vaults Using Microclimate Protection Instead of RH Control***

There are substantial annual savings in energy costs earned by not using RH control in a vault. For an 8x12 vault the cost savings may average \$850/year (\$700/year at 35°F and \$1000/year at 25°F). For a 16x24 vault the savings increase to an average of \$1500/year (\$1300 at 35°F and \$1700/year at 25°F). With concerns about increasing energy costs and environmental impact, institutions may consider this an advantage to weigh against the costs and inconvenience of either packaging or sealed cabinetry. It is also advantageous to specify the most energy-efficient equipment for the vault.

- The initial cost of packaging alone (~\$9,000 average) is about 40% less than installing RH-control for an 8x12 vault (\$15,000). Therefore, packaging immediately begins to “pay” for itself in terms of the reduced costs for energy. It would take ~10 years for the initial cost of packaging to equal the cumulative savings in energy costs. For a 16x24 vault, it could take an average 20 years and 36 years for the initial cost of packaging 875 CF and 1575 CF respectively to equal the cumulative savings in energy costs.
- For an 8x12 vault outfitted with 9 fixed and 12 mobile sealed cabinets, it would take 22 and 35 years respectively for the initial cost of the cabinets to equal the cumulative annual savings in energy. For a 16x24 vault outfitted with 30 fixed and 55 mobile cabinets, it would take 42 and 88 years, respectively, for the initial cost of the cabinets to equal the cumulative annual savings in energy costs. Evaluating the energy cost effectiveness of sealed cabinetry is complicated by the fact that cabinetry functions both as the method of moisture protection and as furniture that would be required for shelving the collections anyway. The cost of the “shelving function” can be subtracted by using open shelving as a comparable base cost, leaving a lower cost

that is the “microclimate function” of the cabinet. For example, for an 8x12 vault, it would take 11 and 18 years respectively for only the cost of the “microclimate function” of the sealed cabinets to equal the cumulative annual savings in energy costs. For a 16x24 vault, it would take 27 and 53 years respectively for the cost of the “microclimate function” alone to equal the cumulative annual savings in energy costs.

### ***Security, Monitoring, Maintenance, and Failure***

An important part of any cold-storage program requires implementation of security and monitoring of equipment for proper operation [2]. It is also critical that the unit be linked to a central station monitoring system for the building or have an auto-dialer alarm hookup to an emergency phone number and/or include out-of-range auto-shutoff features for the relevant mechanical equipment. Both freezers and vaults have audible alarms, but remote monitoring is ideal especially where there is no staffing during off hours. Remote monitoring was not included in the cost estimates for freezers and vaults given the unknown variables of each installation.

The least problematic failure of a cold unit is a power outage or total breakdown in the equipment causing shut off and gradual warming to ambient conditions. As long as the cold unit is kept closed and any vapor-sealed packages remain intact, there is generally low risk to the contents. However, should a compressor or chiller fail in a manner that it does not result in total shut down (usually a relay switch malfunction), the unit may heat up inside. Failure of RH-controls can result in RH spikes up to 100%, causing the vault walls and ceilings to weep, and paper boxes to swell with moisture. For this reason some institutions add extra RH protection by using tightly-sealed boxes or plastic sheeting over shelving units and oversized materials.

### **Conclusions**

No single cold storage option is appropriate for all circumstances because institutions have different staffing and operational and capitol budgets that can influence the funding of upfront costs vs. financial commitment to ongoing expenses. Prices will vary among vendors and regions, and there are often additional costs not considered here. Cold storage, especially the use of vaults, requires a commitment to active oversight and maintenance that varies considerably with the chosen storage options.

Institutions must carefully weigh the advantages of one cold storage option over the other based on their circumstances and collection needs. The type(s) of cold storage an institution might select depends on many criteria, as listed in the beginning of this article. These factors fall into three general categories:

- Financial--Initial and ongoing budgets to fund all aspects of cold storage.
- Staffing--Current or supplementary personnel required during planning, implementation and thereafter.
- Facilities— Availability or appropriateness of the space for the collection’s size, format, and media stability or for cold storage apparatus.

A cost analysis during initial planning helps to clarify the issues unique to each institution, in addition to estimating all the associated expenses for the various options being considered and their sustainability over time. At this initial planning stage staff can

discuss in detail the feasibility of each option based on resources and expertise, estimate the costs of the option(s) that seem most practical for their collection, and determine which option(s) can be implemented over time with current resources. Because the cost of cold storage can be daunting, institutions may choose a phased approach, breaking the project into manageable elements to be performed over years, or utilize a combination of several options as either short- or long-term solutions. In many circumstances where the collection size warrants a vault, a multi-phase approach may be the most practical due to the extensive planning, budgeting, and space preparation required for vault installation.

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Storage Volume	20CF	200CF	360 CF	1000 CF	2000 CF
Total # 4x5 negatives; (# boxes)	20,000 (80 boxes)	200,000 (800 boxes)	360,000 (1440 boxes)	1,000,000 (4,000 boxes)	2,000,000 (8,000 boxes)
<b>25F/30% rental costs</b>					
Annual Cost/CF/Year Excl. handling/shipping fees	\$96/CF	\$90/CF	\$90/CF	<\$25/CF	<\$25/CF
Total annual 25°F cost, excl. fees	\$1920	\$18,000	\$32,400	<\$25,000	<\$50,000
<b>35F/30% rental costs</b>					
Annual Cost/CF/Year Excl. handling/shipping fees	\$75/CF	\$69/CF	\$69/CF	<\$25/CF	<\$25/CF
Total annual 35°F cost, excl. fees	\$1500	\$13,800	\$24,840	<\$25,000	<\$50,000
The leasing rates of a commercial cold storage facility were provided by one vendor with a track record for well-maintained vaults and reliable shipping and handling (Table 1). Because of the variability and efficiency of shelving among formats, large-volume leasing was quoted at a maximum rate. Actual costs for collections with uniform containers or compact containers may be lower. Handling fees will vary with geographic region and usage rates as items are requested, while the variety of formats may influence any fees for the initial shelving/bar coding. Storage volume is based on 4x5 Negatives in boxes (250 items/box) 1000 negatives/CF					

Vault CF* Shelved Vol.	~360 CF	~360 CF	~360 CF	~360 CF	~1000 CF ~2000 CF	~1000 CF ~2000 CF	~1000 CF ~2000 CF	~1000 CF ~2000 CF
Vault 8.5' H Dimensions and Climate	8x12 35°F 35% RH	8x12 35°F No RH control	8x12 25°F/ 35% RH	8x12 25°F No RH control	16x24 35°F/ 35% RH	16x24 35°F No RH control	16x24 25°F 35% RH	16x24 25°F No RH control
Energy Costs @\$0.10/KWH	\$1608/y	\$912/y	\$2160/y	\$1116/y	\$4368/y	\$2604/y	\$4560/y	\$3204/y
Maintenance Low Estimate	\$1000/y	\$1000/y	\$1000/y	\$1000/y	\$1000/y	\$1000/y	\$1000/y	\$1000/y
<b>Total Cost/y w/ LOW Estimate</b>	<b>\$2608/y</b>	<b>\$1912/y</b>	<b>\$3160/y</b>	<b>\$2116/y</b>	<b>\$5368/y</b>	<b>\$3604/y</b>	<b>\$5560/y</b>	<b>\$4204/y</b>
<b>Total Actual Cost/CF/y w/ LOW Estimate</b>	<b>\$ 3/CF-V \$8/CF-S \$12/CF-C</b>	<b>\$2/CF-V \$6/CF-S \$9/CF-C</b>	<b>\$ 4/CF-V \$10/CF-S \$15/CF-C</b>	<b>\$3/CF-V \$7/CF-S \$10/CF</b>	<b>\$2/CF-V \$3/CF-S \$6/CF-C</b>	<b>\$1/CF-V \$2/CF-S \$4/CF-C</b>	<b>\$2/CF-V \$4/CF-S \$6/CF-C</b>	<b>\$1/CF-V \$3/CF-S \$4/CF-C</b>
Maintenance High Estimate	\$4000/y	\$4000/y	\$4000/y	\$4000/y	\$4000/y	\$4000/y	\$4000/y	\$4000/y
<b>Total Cost/y w/ HIGH Estimate</b>	<b>\$5608/y</b>	<b>\$4912/y</b>	<b>\$6160/y</b>	<b>\$5116/y</b>	<b>\$8368/y</b>	<b>\$6204/y</b>	<b>\$8560/y</b>	<b>\$7204/y</b>
<b>Total Actual Cost/CF/y w/ HIGH Estimate</b>	<b>\$ 7/CF-V \$18/CF-S \$27/CF-C</b>	<b>\$ 6/CF-V \$16/CF-S \$23/CF-C</b>	<b>\$ 8/CF-V \$20/CF-S \$29/CF-C</b>	<b>\$ 6/CF-V \$16/CF-S \$24/CF-C</b>	<b>\$3/CF-V \$5/CF-S \$9/CF-C</b>	<b>\$2/CF-V \$4/CF-S \$7/CF-C</b>	<b>\$3/CF-V \$5/CF-S \$9/CF-C</b>	<b>\$2/CF-V \$5/CF-S \$7/CF-C</b>
V-vault vol. S-shelved vol. C-cabinet vol. y-year Costs/CF are rounded up or down to nearest \$	<b>The estimates in this table include only the costs of energy and maintenance to operate a vault over the course of a year. Both low (\$1000/year) and high (\$4000/year) annual routine maintenance estimates are provided.</b> *For an 8x12 vault the total vault volume is 816 CF, with a <i>nominal</i> capacity of 360 CF for mobile open shelving and ~250 CF for mobile sealed cabinets. For a 16x24 vault the total vault volume is 3264 CF, with a <i>nominal</i> ~1900 CF for mobile open shelving and ~1100 CF for mobile sealed cabinets. The <i>actual</i> storage capacity as shelved is 17.5 CF/furniture storage unit using the standard 4x5x12-in. box. The actual capacity of an 8x12 vault is ~315 CF with mobile open shelving and ~210 CF with mobile sealed cabinets. The actual capacity of a 16x24 vault is ~ 1575 CF for mobile open shelving and 963 CF for mobile sealed cabinets. Cost/CF were calculated using the higher capacity afforded by mobile configurations. Fixed configurations for shelving and cabinets provide less usable storage capacity and would raise the cost/CF by several dollars.							

<b>Table 3 Cold Storage Costs of Cold Vaults, with Open Standard Shelving and Packaging or Sealed Cabinetry [4x5 Negatives in Boxes (250 items/box) with Shelving 10 boxes (2.5CF)/Shelf, 70 boxes (17.5CF)/Unit]</b>									
<b>Vault CF Shelved Vol.</b>	<b>126</b>	<b>~360</b>	<b>~360</b>	<b>~360</b>	<b>~360</b>	<b>~1000 F ~2000 M</b>	<b>~1000 F ~2000 M</b>	<b>~1000 F ~2000 M</b>	<b>~1000 F ~2000 M</b>
Vault 8.5 Ft H F-Fixed M-Mobile Furniture	6x6 Vesti- bule 50°F 35% RH	8x12 35°F 35% RH	8x12 35°F No RH control	8x12 25°F 35%RH	8x12 25°F No RH control	16x24 35°F 35%RH	16x24 35°F No RH control	16x24 25°F 35%RH	16x24 25°F No RH control
<b>Vault Cost</b>	<b>\$31,500</b>	<b>\$36,830</b>	<b>\$22,430</b>	<b>\$38,810</b>	<b>\$23,420</b>	<b>\$73,590</b>	<b>\$60,945</b>	<b>\$84,600</b>	<b>\$63,500</b>
SF Vault	36	96	96	96	96	384	384	384	384
CF Vault <i>Nominal Vol.</i>	306	816	816	816	816	3264	3264	3264	3264
% CF Shelved	50%	44-50%	44-50%	44-50%	44-50%	30-40% F ~60% M	30-40% F ~60% M	30-40% F ~60% M	30-40% F ~60% M
Cost/CF Vault <i>Nominal Vol.</i>	\$250	\$102	\$62	\$108	\$65	\$74 F \$37 M	\$61 F \$30 M	\$85 F \$43 M	\$64 F \$32 M
<b>Actual CF (Usable Vol.) of Shelved Vault (# Boxes)</b>	<b>105 F Fixed + Double -Slider Units</b>	<b>245 F (980) 315 M (1260)</b>	<b>245 F (980) 315 M (1260)</b>	<b>245 F (980) 315 M (1260)</b>	<b>245 F (980) 315 M (1260)</b>	<b>875 F (3500) 1575 M (6300)</b>	<b>875 F (3500) 1575 M (6300)</b>	<b>875 F (3500) 1575 M (6300)</b>	<b>875 F (3500) 1575 M (6300)</b>
Cost of Open Shelving	~\$1450 6 units	\$9100-12,000 (\$10,500 Ave.) 14 units-F \$12,500-16,000 (\$14,00 Ave.) 16-19 units-M				\$17,000-32,000 (\$24,000 Ave.) 44-55 units-F \$69,000-87,000 (\$78,000 Ave.) 85-92 units-M			
<b>Cost/CF Vault w/ <u>New</u> Shelving Actual Vol.</b>	<b>\$314 F</b>	<b>\$193 F \$161 M</b>	<b>\$134 F \$116 M</b>	<b>\$201 F \$168 M</b>	<b>\$138 F \$119 M</b>	<b>\$112 F \$96 M</b>	<b>\$97 F \$88 M</b>	<b>\$124 F \$103 M</b>	<b>\$100 F \$ 90 M</b>
Cost/CF Packaging \$25/hr; 30/day <b>(Cost/box)</b>	RH Control	Packages not required	\$34.30 <b>(\$8.57)</b>	Packages not required	\$34.30 <b>(\$8.57)</b>	Packages not required	\$34.30 <b>(\$8.57)</b>	Packages not required	\$34.30 <b>(\$8.57)</b>
Cost/CF of Packages w/ New Shelving Fixed/Mobile <b>(Cost/box)</b>	RH Control	Packages not required	\$77-F <b>(\$19)</b> \$78-M <b>(\$20)</b>	Packages not required	\$77-F <b>(\$19)</b> \$78-M <b>(\$20)</b>	Packages not required	\$62-F <b>(\$15)</b> \$84-M <b>(\$21)</b>	Packages not required	\$62-F <b>(\$15)</b> \$84-M <b>(\$21)</b>
<b>Tot. Cost/CF Incl. Vault w/ <u>New</u> Shelving &amp; Packages</b>	RH Control	Packages not required	<b>\$169 F \$150 M</b>	Packages not required	<b>\$173 F \$153 M</b>	Packages not required	<b>\$134 F \$124 M</b>	Packages not required	<b>\$134 F \$124 M</b>
<b>Actual CF of Sealed Cabinets (# Boxes)</b>	35 F	158 F (630) 210 M (840)	158 F (630) 210 M (840)	158 F (630) 210 M (840)	158 F (630) 210 M (840)	525 F (2100) 963 M (3850)	525 F (2100) 963 M (3850)	525 F (2100) 963 M (3850)	525 F (2100) 963 M (3850)
Cabinet Costs	~\$4400 2 units	\$18,900 (9 units-F) \$30,000 (14 units-M) w/estimated mobile installation cost				\$63,000 (30 units-F) \$132,000 (55 units-M) w/ estimated mobile installation cost			
Cost/CF w/Cabinets <b>(Cost/box)</b>	\$126	Sealed cabinets not required	\$119 F <b>(\$30)</b> \$143 M <b>(\$36)</b>	Sealed cabinets not required	\$119 F <b>(\$30)</b> \$143 M <b>(\$36)</b>	Sealed cabinets not required	\$114 F <b>(\$29)</b> \$137 M <b>(\$34)</b>	Sealed cabinets not required	\$114 F <b>(\$29)</b> \$137 M <b>(\$34)</b>
<b>Tot. Cost/CF Incl. Vault w/ <u>New</u> Sealed Cabinetry</b>	<b>\$1026</b>	Sealed cabinets not required	<b>\$262 F \$250 M</b>	Sealed cabinets not required	<b>\$268 F \$254 M</b>	Sealed cabinets not required	<b>\$230 F \$200 M</b>	Sealed cabinets not required	<b>\$235 F \$203 M</b>
BTUH (Est. KWH/yr)	8627 (10200)	16831 (16080)	10980 (9120)	17328 (21600)	11596 (11160)	38916 (43680)	27558 (26040)	44719 (45600)	42187 (32040)
Annual Costs for Energy @ \$0.10/KWH	\$1020/y	\$1608/y	\$912/y	\$2160/y	\$1116/y	\$4368/y	\$2604/y	\$4560/y	\$3204/y

<b>Table 4 Cold Storage Costs using 20CF Household Freezers (0-25°F) with Vapor-Proof Packaging [4x5 Negatives in Boxes (250 items/box) with 40 boxes (10 CF Materials)/Unit]</b>					
<b>CF Freezer Storage</b>	<b>20 CF</b>	<b>200 CF</b>	<b>360 CF</b>	<b>1000 CF</b>	<b>2000 CF</b>
<b>Cost of Freezers</b>	<b>\$1000</b>	<b>\$10,000</b>	<b>\$18,000</b>	<b>\$50,000</b>	<b>\$100,000</b>
# Freezers	1 unit	10 units	18 units	50 units	100 units
SF Floor Space @16 SF/unit w/spacing and aisle in front = 8SF + 8SF 8/8x12 room, 28/16x24 room	16 SF 3LF	160 SF 30LF 8x12 room	288 SF 54 LF 16x24	800 SF 150 LF 16x24-2 rooms	1600 SF 300 LF 16x24-4 rooms
<b>CF Actual (Unmodified Interior)</b>	<b>10 CF</b>	<b>100 CF</b>	<b>180 CF</b>	<b>500 CF</b>	<b>1000 CF</b>
<b>Total 4x5 negatives</b>	<b>10,000</b>	<b>100,000</b>	<b>180,000</b>	<b>500,000</b>	<b>1,000,000</b>
<b># Boxes</b>	<b>40 boxes</b>	<b>400 boxes</b>	<b>720 boxes</b>	<b>2000 boxes</b>	<b>4000 boxes</b>
Cost/CF <i>Nominal Vol.</i>	\$50/CF	\$50/CF	\$50/CF	\$50/CF	\$50/CF
<b>Cost/CF Actual Vol. w/ boxes</b>	<b>\$100/CF</b>	<b>\$100/CF</b>	<b>\$100/CF</b>	<b>\$100/CF</b>	<b>\$100/CF</b>
<b>Cost of Packaging Materials</b>	<b>\$89</b>	<b>\$892</b>	<b>\$1368</b>	<b>\$3800</b>	<b>\$7600</b>
4 boxes/CF \$7.60/CF (\$1.90/box): \$1.70/2 bags /box & Sealing Tape and RH Indicators @ \$0.20/box	<b>\$2.23/box</b>	<b>\$2.23/box</b>	<b>\$1.90/box</b>	<b>\$1.90/box</b>	<b>\$1.90/box</b>
Low-Labor Costs for Packaging GS5 \$15/hr, no benefits = \$120/day; 5 boxes/hr, 35 boxes/day; \$3.43/box	\$137 (~1.1 day)	\$1370 (~11 days)	\$2469 (~21 days)	\$6,860 (~57 days)	\$13,720 (~114 days)
<b>Packaging Costs Materials/Labor Lower-Cost Contract Labor Estimate</b>	<b>\$226</b> <b>\$5.66/box</b> <b>\$22.64/CF</b>	<b>\$2262</b> <b>\$5.66/box</b> <b>\$22.64/CF</b>	<b>\$3837</b> <b>\$5.33/box</b> <b>\$21.32/CF</b>	<b>\$10,660</b> <b>\$5.33/box</b> <b>\$21.32/CF</b>	<b>\$21,320</b> <b>\$5.33/box</b> <b>\$21.32/CF</b>
<b>Total Freezer/Packaging Costs Low-Cost Labor/20 CF units Actual Cost/Usable Volume</b>	<b>\$1226</b> <b>\$61/CF</b> <b>\$122/CF</b>	<b>\$12,262</b> <b>\$61/CF</b> <b>\$122/CF</b>	<b>\$21,837</b> <b>\$61/CF</b> <b>\$122/CF</b>	<b>\$60,660</b> <b>\$61/CF</b> <b>\$122/CF</b>	<b>\$121,320</b> <b>\$61/CF</b> <b>\$122/CF</b>
High-Labor for Packaging GS 7 \$25/hr incl/benefits=\$200/day; 5 boxes/hr, 30 boxes/day; \$6.67/box	\$267 (~1.3 day)	\$2667 (~13 days)	\$4800 (~24 days)	\$13,400 (~67 days)	\$26,800 (~133 days)
<b>Packaging Costs Materials/Labor High-Cost Staff Labor Estimate</b>	<b>\$356</b> <b>\$8.90/box</b> <b>\$35.60/CF</b>	<b>\$3560</b> <b>\$8.90/box</b> <b>\$35.60/CF</b>	<b>\$6170</b> <b>\$8.57</b> <b>\$34.28/CF</b>	<b>\$17,140</b> <b>\$8.57</b> <b>\$34.28/CF</b>	<b>\$34,267</b> <b>\$8.57</b> <b>\$34.28/CF</b>
<b>Total Freezer/Packaging Costs High-Cost Labor/20CF unit Actual Cost/Usable Volume</b>	<b>\$1356</b> <b>\$68/CF</b> <b>\$136/CF</b>	<b>\$13,560</b> <b>\$68/CF</b> <b>\$136/CF</b>	<b>\$24,170</b> <b>\$68/CF</b> <b>\$136/CF</b>	<b>\$57,140</b> <b>\$68/CF</b> <b>\$136/CF</b>	<b>\$134,267</b> <b>\$68/CF</b> <b>\$136/CF</b>
Annual Costs for @\$0.10/KWH 600KWH/y/unit=60.00/Unit; Energy Cost/CF/y freezer volume Cost/CF/y actual freezer volume <b>Maintenance costs are negligible</b>	\$60/y \$3/CF/y \$6/CF/y	\$600/y \$3/CF/y \$6/CF/y actual	\$1080/y \$3/CF/y \$6/CF/y actual	\$3000/y \$3/CF/y \$6/CF/y actual	\$6000/y \$3/CF/y \$6/CF/y actual
A Sears Kenmore auto-defrost 20.3 CF Household Freezer (~ \$700) was the baseline unit used for this study, along with the Onset HOB0 data logger with auto-dialer and remote alarm (\$300). Alarm hook-up to a facility-wide monitoring system, where available, costs 2 -3 times more than an auto-dialer (~\$1000.00/unit). Household models tend to be reliable (when rated by consumer groups) and readily available, replaced, and serviced. Large-quantity discounts were not factored into the estimates. Commercial (restaurant and scientific) freezer units are other freezer options and are available in 40 and 70 CF capacities. They were not selected for this study due to several factors including noise, heat, smaller doors, expense, and some reported reliability issues.					
The vapor-proof package is based on a design used by the author, incorporating a low-cost, heavyweight (6 or 8 mil) re-sealable polyethylene outer bag and an inner flush-cut bag of translucent polyethylene/polyester laminate with a metallic deposit, both sized for the standard 4x5 "shoebox." Both bags can be re-used indefinitely until damaged. Also included was clear acrylic 2-inch-wide tape to seal over the flush-cut bag and one RH indicator card per package. These packaging materials are available in bulk from Uline and other vendors. The cost of this packaging is about midway between using two poly bags alone or a polyethylene outer bag with an inner metal foil-laminate plastic bag (such as used at the National Gallery of Art). Due to the durability and high-quality seams of these bags, desiccated paperboard inserts between bags was not estimated due to the greater expense and labor. Shipping costs were not included, but discounts were calculated for larger CF quantities (greater discounts may reduce costs further). Labor for packaging was based on two different levels of packaging productivity and federal hourly rates (GS 5 and 7, Washington, DC region).					

<b>Table 5 Costs of 25°F Cold Vault No RH-Control: Open Standard Shelving and Packaging vs. Sealed Cabinetry [4x5 Negatives in 4x5x12-in. Boxes, 10 boxes (2.5CF)/Shelf, 70 boxes (17.5CF)/7-shelf Unit]</b>				
CF Vault Volume as Shelved	~360 CF	~360 CF	~1000 CF	~2000 CF
Vault Size	8'x12'x8.5H Fixed Shelving	8'x12'x8.5H Mobile Shelving	16'x24'x8.5'H Fixed Shelving	16'x24'x8.5'H Mobile Shelving
Cost of 25°F Vault w/o RH control	<b>\$23,420</b>	<b>\$23,420</b>	<b>\$63,500</b>	<b>\$63,500</b>
Nominal Vault Volume (If Shelved)	~360 CF	~360 CF	~1000 CF	~2000 CF
# Negatives	360,000	360,000	1,000,000	2,000,000
# Boxes	1440 boxes	1440 boxes	4,000 boxes	8,000 boxes
Cost/CF Nominal Volume of Vault	\$65/CF	\$65/CF	\$64/CF	\$32/CF
<b>Actual Vault Vol. Open Shelving</b>	<b>245 CF actual</b>	<b>315 CF actual</b>	<b>875 CF actual</b>	<b>1575 CF actual</b>
# negatives	<b>245,000</b>	<b>315,000</b>	<b>875,000</b>	<b>1,575,000</b>
#boxes	<b>980 boxes</b>	<b>1260 boxes</b>	<b>3500 boxes</b>	<b>6300 boxes</b>
<b>Cost/CF Actual Vol. of Vault</b>	<b>\$96/CF</b>	<b>\$74/CF</b>	<b>\$73/CF</b>	<b>\$40/CF</b>
Costs of Materials 4 boxes/CF \$7.60/CF (\$1.90/box): \$1.70/2 bags /box & Sealing Tape and RH Indicators @ \$0.20/box	\$1862 \$7.60/CF	\$2394 \$7.60/CF	\$6650 \$7.60/CF	\$11,970 \$7.60/CF
High-Cost Labor for Packaging, GS 7 \$25/hr = \$200/day; 30 boxes/day; \$6.67/box; ~\$27/CF (#days to package)	\$6537 (33 days) ~\$27/CF	\$8404 (42 days) ~\$27/CF	\$23,345 (117 days) ~\$27/CF	\$42,021 (210 days) ~\$27/CF
<b>Packaging Costs Materials/Labor</b>	<b>\$8,399</b>	<b>\$10,798</b>	<b>\$29,995</b>	<b>\$53,991</b>
<b>Cost/box</b>	<b>\$8.57/box</b>	<b>\$8.57/box</b>	<b>\$8.57/box</b>	<b>\$8.57/box</b>
<b>Cost/CF</b>	<b>\$34.30/CF</b>	<b>\$34.30/CF</b>	<b>\$34.30/CF</b>	<b>\$34.30/CF</b>
Cost of New Open Shelving Units	\$9100-12,000 <b>(\$10,500 ave.)</b> 14 units	\$12,500-16,000 <b>(\$14,000 ave.)</b> 16-19 units (18 ave.)	\$17,000-32,000 <b>(\$24,000 ave.)</b> 44-55 units (50 ave.)	\$69,000-87,000 <b>(\$78,000 ave.)</b> 85-92 units (90 ave.)
<b>Cost of Packaging w/ New Shelving</b>	<b>\$18,899</b>	<b>\$24,798</b>	<b>\$53,995</b>	<b>\$131,991</b>
<b>Cost/CF</b>	<b>\$77/CF</b>	<b>\$78/CF</b>	<b>\$62/CF</b>	<b>\$84/CF</b>
<b>Cost/box</b>	<b>\$19.28/box</b>	<b>\$19.68/box</b>	<b>\$15.43/box</b>	<b>\$20.95/box</b>
Total Vault & Packaging Cost <i>w/Re-use of existing shelving</i>	\$31,819 \$130/CF \$32.47/box	\$34,218 \$109/CF \$27.16/box	\$93,495 \$107/CF \$26.71/box	\$117,491 \$75/CF \$18.65
<b>Total Vault &amp; Packaging Cost w/ New Shelving Actual Cost</b>	<b>\$42,310</b>	<b>\$48,218</b>	<b>\$117,495</b>	<b>\$195,491</b>
<b>Cost/CF; Cost/box</b>	<b>\$173/CF</b> <b>\$43.17/box</b>	<b>\$153/CF</b> <b>\$38.27/box</b>	<b>\$134/CF</b> <b>\$33.57/box</b>	<b>\$124/CF</b> <b>\$31.03/box</b>
Nominal Cabinet Volume 27.3 CF/Unit	245 CF	328 CF	819 CF	1501 CF
# Negatives	245,000	328,000	819,000	1,501,000
# Boxes	980 boxes	1312 boxes	3276 boxes	6004 boxes
Nominal Cost/CF of Sealed Cabinets	\$77/CF	\$91/CF	\$73/CF	\$88/CF
<b>Actual Cabinet Vol. 17.5CF/Unit</b>	<b>158 CF actual</b>	<b>~210 CF actual</b>	<b>~525CF actual</b>	<b>~963CF actual</b>
# negatives	<b>157,500</b>	<b>210,000</b>	<b>525,000</b>	<b>962,500</b>
# boxes	<b>630 boxes</b>	<b>840 boxes</b>	<b>2100 boxes</b>	<b>3850 boxes</b>
<b>Cost/CF Actual Volume Cabinets</b>	<b>\$119/CF</b>	<b>\$143/CF</b>	<b>\$114/CF</b>	<b>\$137/CF</b>
<b>Cost of Sealed Cabinets</b> ~\$1600.00/unit + freight & installation; (Cost of Mobile Rails Estimated)	<b>\$18,900</b> 9 units@\$2100 ea	<b>~\$30,000</b> 12 units@\$2100 ea + ~\$5000 rails est.	<b>\$60,000</b> 30 units@\$2000 ea	<b>\$132,000</b> 55 units@\$1900 ea + ~\$27,500 rails est.
<b>Cost/box</b>	\$30.00/box	\$35.71/box	\$28.57/box	\$34.29/box
<b>Total Vault &amp; New Cabinets Cost</b>	<b>\$42,320</b>	<b>\$53,420</b>	<b>\$123,500</b>	<b>\$195,500</b>
<b>Cost/CF Actual Volume</b>	<b>\$269/CF</b>	<b>\$254/CF</b>	<b>\$235/CF</b>	<b>\$203/CF</b>
<b>Cost/box</b>	<b>\$67.25/box</b>	<b>\$63.50/box</b>	<b>\$58.75/box</b>	<b>\$50.75/box</b>
Annual Energy and Maintenance Cost Using low (\$1000/y) and high (\$4000/y) maintenance estimates	\$2116/y low est. \$5116/y high est.	\$2116/y low est. \$5116/y high est.	\$4204/y low est. \$7204/y high est.	\$4204/y low est. \$7204/y high est.
Equipment specifications included standard 4-inch thick foam-insulated metal-skinned panels for walls, ceiling, and floor; air-chilled coolers, compressors, condensers, desiccant wheels for RH-controlled vaults, backup units for RH-controlled vaults, light fixtures, delivery, and installation. Fire suppression systems and gaseous air filtration were not estimated. Filtration is desirable when packaging is not used for collections, such as acetate film, that might emit contaminating gasses. For the purpose of determining cooling loads, it was assumed that the vault would be placed in an area with office-type conditions, and that the space did not require modification, had ready access to utilities and that exterior mechanical systems could be located within a 75-foot run line. These and other factors could affect the estimates and overall costs and must be considered <i>minimum approximate costs</i> . <b>Annual routine energy/maintenance costs are listed.</b>				
Furniture estimates were provided by suppliers of museum-quality shelving and cabinetry, and included fixed and mobile units delivered and installed. The costs for silicone gasket-sealed cabinets were based on units 39.5"W x 17.5"D x 84"H (Table 4) with seven 12"H shelves. Standard open shelving estimates were based on units 36"W x 12"D x 84"H with seven 12"H shelves. Re-use of any existing shelving or cabinetry is the least expensive option, but does incur labor costs for disassembly and re-installation that were not estimated into the vault costs. Two layouts, for both fixed and mobile shelving, were estimated based on the number of boxes that could be shelved. <b>The installation cost for mobile cabinets was approximated. The cost of buffer materials and labor to condition was NOT estimated.</b>				

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