"Safe-Core"
WAIS Divide Ice Core Transportation Proposal

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Table of Contents

List of Tables

List of Figures

Introduction

1.1 Overview

The primary logistical objective of the United States Antarctic Program's (USAP) multi-year, West Antarctic Ice Sheet Divide (WAIS Divide) ice-coring project is to safely and efficiently drill approximately 4100 one-meter long ice cores without compromising the cores' physical integrity or altering the scientific data contained within. The acquired WAIS Divide ice cores will be shipped to the United States over several years, at an anticipated rate of 1400 one-meter cores per year during the largest shipment years.

Note

All dollar figures, percentages, and other financial and technical background information noted in this report were gathered from Raytheon Polar Services Company (RPSC), the National Ice Core Laboratory (NICL), the National Science Foundation (NSF), the United States Air Force (USAF) 109th Air National Guard, the Principal Investigator and other scientists for this project, and from 2005 budgetary estimates provided by various potential equipment vendors.

It has become apparent to the knowledgeable parties involved with this project, however, that the high number of WAIS Divide cores to be shipped may overwhelm the capabilities of the existing USAP ice core transportation equipment and operations, that the cores may not be adequately protected from thermal and physical damage with the existing equipment and transportation procedures, and that injuries can occur while manually lifting and maneuvering the full ice core boxes.

Specific identified problems are as follows:

- Existing McMurdo permanent freezer will not provide sufficient ice core storage space for the WAIS program and for concurrent drilling programs during the highest-output seasons.
- Existing USAP refrigerated ISO (International Organization for Standardization) shipping containers do not offer built-in, automatic, fail-safe, redundant cooling and power systems to prevent core warming above the critical –20°C limit.
- Existing cardboard ISC ("Insulated Shipping Container") ice core transport boxes do not adequately protect the cores from physical damage or warming during numerous handling and transportation procedures.
- Existing transport procedures, box design, and back-up plans force an excessive amount of manual lifting and handling of the ice core boxes, possibly resulting in ice core damage.

- Existing ice core box weight, design, and handling methods can lead to injuries.
- New 40-lb lifting limits have been imposed by RPSC, meaning more people (from a limited labor pool) are required to lift each existing, 130-lb cardboard ice core box.

If the present ice core transport equipment and processes are left unchanged, there could be a 1.5 percent ice core damage rate. This historical value, applied to the 4100 one-meter cores, would equate to $1.23 million[*] worth of potential core damage, and/or destroyed or corrupted ice core scientific data. The "brittle" ice cores are at particular risk of this damage, while the "shallow" and "ductile" ice cores are at a lower risk of damage.

Furthermore, if the single (no backup) cooling unit on an existing 20' ISO refrigerated shipping container holding 256 ice cores fails (or is mistakenly left unplugged, as recently occurred), up to $5 million worth of cores would be at risk of warming or melting.

Also, the various grid-supplied electrical sources energizing the plug-in refrigerated ISO shipping container's electrical cooling unit are not necessarily reliable. From 1998 through 2004, the primary power plant at McMurdo Station recorded a 0.9 percent downtime rate, with the longest power outage lasting 2 hours on Feeders A, B, and C. The permanent outdoor ice core freezer near Crary Lab can maintain its setpoint temperature for only one hour after a power outage, and then warming begins (depending on the outdoor temperature, of course).

The new power plant generators presently being installed at McMurdo (over the next 2-3 years) will bring an unknown risk of electrical downtime, especially during the new system's "shakedown" and "early-failure" periods. Historical electrical supply reliability (and fail-safe backup systems) on the American Tern container vessel, at Port Hueneme, CA, and at NICL are not known at this time.

To determine the best way to prevent and circumvent these numerous existing problems and shortcomings, several in-depth discussions were undertaken with the key personnel responsible for USAP ice core movement, protection, and science, along with numerous vendors of equipment appropriate for this project. From those discussions, the critical project variables were determined, and a matrix of 144 permutations of candidate selections and solutions (ice core boxes/vaults, refrigerated ISO shipping containers, LC-130 allowable cabin loads, and ice core shipment quantities – see Section 1.7) were compiled, researched, analyzed, compared, and culled for financial, logistical, and technical viability.

[*] The $20,000 per core number is an assumed value, based on the cost of the entire WAIS Divide project divided by the number of one-meter cores to be produced. At least 5 percent of the WAIS Divide cores are expected to contain critical climate data and be "worth" $20,000, but there is no way to know which will be most valuable until after they have been analyzed in the scientists' laboratories. As well, all cores are critical to establish exact dates while layer-counting the entire length of core retrieved from the full-depth bore hole. Thus, all cores are significant, and must be handled and protected with equal care.

The research and analysis done for this report yields the following summary of proposed ice core transport improvements, termed "Safe-Core", for the WAIS Divide project:

- Use mechanized box lifting devices to prevent lifting and handling injuries during all stages of the ice core loading and transportation process.
- Use highly-insulated, shock-absorbing, durable, engineered transport boxes to safely hold and transport a high-density packing of 45 one-meter ice cores per box, in all anticipated conditions. The recommended box is termed an "HD45".
- Use space-efficient, 40-foot refrigerated ISO shipping containers with built-in, fail-safe redundant cooler units and redundant gensets (two styles of cooling systems are proposed – a recommended "nose-mount", and an alternative "window-frame") to ensure uninterrupted chilling capacity to -30°C.
- Use an improved temperature recorder device (the recommended Escort/REDi system), or improve the use of the existing HoboTemp (with alternative hard-wiring of the device), to allow fast, easy data download without corrupting the cold space around the ice cores.

The anticipated cost to purchase the recommended Safe-Core equipment upgrades noted above is $534,500, and the estimated payload vessel fees, truck rental fees, and equipment maintenance fees, over the life of the WAIS Divide project, tallies to an additional $137,284. Technical discussion of the above recommendations are detailed in Section 1.5, while the cost of the LC-130 ice core transport flights and other detailed financial information of the above recommendations (and alternative recommendations) are shown and discussed in Sections 1.6 and 1.7.

The proposed equipment upgrades will be used initially for the WAIS Divide project, with optimal delivery of the recommended equipment to McMurdo Station suggested as no later than February, 2007 (to coincide with the following WAIS Divide field season's initial high-output ice core transportation and storage schedule).

After the WAIS Divide project is completed, the Safe-Core equipment can also be deployed for many years of reliable service on other deep-field ice drilling projects, or other delicate or temperature-sensitive artifact transportation missions.

1.2 Background

The primary logistical objective of the multi-year, West Antarctic Ice Sheet Divide (WAIS Divide) ice-coring project is to safely and efficiently drill and retrieve approximately 4100 one-meter long ice cores over the course of several years, without compromising the cores' physical integrity or altering the scientific data contained within.

Extensive research, evaluation, and design efforts are being put into the drilling device and accoutrements, drilling protocol, on-site ice core processing facilities and procedures, and field camp facilities, layout, and logistics. Intensive efforts are also being put into the laboratories and interpretation methods.

However, there remains one large and critical aspect of the project that needs further definition and refinement; how to best transport the processed and packaged ice cores from the WAIS field camp to McMurdo Station, and then to the National Ice Core Laboratory (NICL) in Denver, Colorado at the end of each season. The goals are to ensure the ice cores reach NICL without damage, with confidence that they have not been warmed above the critical -20°C temperature required to preserve scientific data within the cores, and without causing injury to the ice core handling personnel during the required loading and transportation procedures.

Estimates are that at least 5 percent of the WAIS Divide ice cores will contain "critical climate data", but exactly which cores contain those data is unknown in the field. As well, the complete, intact set of one-meter long ice cores from the entire borehole are essential to allow the "critical climate data" to be precisely dated using an absolute, layer-counting methodology. Accordingly, all cores must be assumed of equal and significant scientific value during the loading, transportation, and storage process, and handled and protected accordingly.

The current cardboard ice core transportation box (termed an ISC, or Insulated Shipping Container) is theoretically designed to provide adequate thermal protection for ice cores being retrieved from the typical USAP deep field camp, several flight-hours from McMurdo Station. However, thermal calculations show that the existing ISC insulating value is only marginally adequate at accomplishing that task (Appendix A – ISC4 curve). With the WAIS Divide drill camp being even further from McMurdo than previous drill camps (such as Siple Dome), the longer LC-130 ice core transport flight will expose the cores to an uncontrolled thermal environment for longer durations than ever. Thus, the current cardboard ISC box will not provide any buffer of time even for the perfect transportation scenario; any equipment, logistical, or handling mistakes or mishaps could allow the WAIS Divide ice cores to warm above the critical -20°C temperature limit.

The use of the present cardboard ice core box on other ice core projects has previously yielded a 1.5 percent physical damage rate to the ice cores (historically, 1 percent of ice cores are damaged during transit from the field camp to NICL using current boxes and methods, and another 0.5 percent are damaged during box unloading operations at NICL's cargo dock). With the most desirable cores valued up to $20,000 per meter, this historical damage rate imposed upon the WAIS Divide project could create $1.23 million worth of damaged cores and possible compromised scientific data (assuming that the damaged ice cores were the part of the "key" 5% of all the cores).

Also, if the current 20-foot refrigerated ISO shipping container's single cooling unit failed (it has no backup/redundant cooling system) while on the multi-week vessel voyage from McMurdo Station to Port Hueneme, CA, that container's payload of 256 ice cores could potentially warm up or melt if the ship's engineer could not fix the cooler in time. (Note: The cores cannot be transferred to a backup refrigerated shipping container while on the vessel, due to space and access constraints). The loss of those ice cores could be worth up to $5 million, again, assuming the losses were "key" ice cores.

Clearly, there is significant, valuable, irreplaceable scientific information at risk if the present ice core transportation equipment and methods are not upgraded as recommended in this proposal.

Existing Procedures and Equipment

1.3 Brief Description of Existing Procedures

The following transport process, described in brief terms, has been used for past (and presently planned) USAP ice core drilling projects. (See Appendix F for an expanded, more thorough description of these current operations).

Note

Also see RPSC document LO-A0109, Shipping Retrograde Science Cargo, Revision 0, 10/28/03 (not included with this report). Note that document LO-A0109 does not describe procedures or protocols for reefer on-load to the container vessel at McMurdo, refrigerated ISO container temperature review/reporting or repair while on the vessel, some aspects of equipment off-load at Port Hueneme, and over-the-road ice core trucking procedures and backup plans from Port Hueneme to NICL. It is not known if written procedures of these operations exist within USAP, RPSC, or other agencies.

During a drilling season the following sequential operations occur:

1. Load ice cores into plastic sleeves and protective cardboard tubes at drilling camp.
2. Place four to nine tubes (depending on diameter) into a foam-lined, cardboard Insulated Shipping Container (ISC), by hand.
3. Insert a temperature recording device ("HoboTemp") into the box, and mark ISC corners with red paint.
4. Two people lift by hand and walk each 130-pound ISC from a sub-surface snow trench to a Nansen sled. (Because of a new RPSC 40-lb/person regulation, each 140-lb ISC now requires four people to move it).
5. Using a snowmobile, drive a sled with ISCs to the surface staging area.
6. Stack up to 32 boxes by hand from the sled onto an Air Force pallet (AFP).
7. Strap, thermal-quilt (if available), and cargo net the load for transportation.
8. Fork or drag the loaded AFP (up to 4,900 lbs) to the aft ramp of a "cold-deck" LC-130 Hercules aircraft.
9. Load the AFP via forklift or winch into the aircraft per Allowable Cabin Load (ACL). (Note: If aircraft does not arrive on site, reverse entire process to return ISCs to safe storage temperatures in the snow trench or tunnel)
10. Repeat this sequence for the desired number of AFPs allowed by the ACL.
11. Place HoboTemp recorder in the cargo bay of LC-130, near ice core boxes.

12. Fly cargo to McMurdo airfield (time to McMurdo varies upon drill camp location, which airfield is in operation, and flight conditions).
13. Fork AFP from LC-130 onto flatbed truck at airfield.
14. Remove HoboTemp from LC-130 cargo bay. Download data to a laptop computer for readout.
15. Drive loaded truck to McMurdo townsite. (Note: If truck breaks down enroute, unstack the boxes and restack them onto a backup truck).
16. Fork AFP off truck and drive pallet near permanent freezer outside Crary Lab.
17. Unstack individual ISCs from AFP and walk them into permanent outdoor freezer.
18. Remove HoboTemp from red-marked ISC boxes, download temperature data to a computer, and reinsert the HoboTemps into correct ISC boxes. Review data for temperature anomalies.
19. Restack ISCs on freezer shelves. (Note: If permanent outdoor freezer malfunctions, unstack boxes and restack them in a backup refrigerated shipping container until problem is resolved. Permanent outdoor freezer will hold temperature for approximately one hour after malfunction. Unknown if backup refrigerated shipping container is available at time of need).

At the end of the season when the container vessel arrives:

1. Unstack ISCs from permanent outdoor freezer and restack onto a slave pallet.
2. Fork and drive slave pallet over to 20' refrigerated ISO shipping container parked at Chalet.
3. Unstack ISCs and restack onto wooden pallets.
4. Band and stretch-wrap the palletized ISCs.
5. Fork each wooden pallet of ISCs into the 20' refrigerated ISO shipping container. (Note: If refrigerated shipping container's single cooling unit malfunctions, fork the palletized stacks out and transfer into a pre-chilled, backup refrigerated ISO shipping container).
6. Install HoboTemp in the 20' refrigerated ISO shipping container.
7. Install HoboTemp in each stack of palletized ISCs.
8. Install new 31-day temperature chart on the refrigerated shipping container's chart recorder.
9. Lift full refrigerated ISO shipping container onto flatbed truck using a container handler.
10. Drive refrigerated ISO shipping container to the ice wharf when it is time to load it on the vessel.

11. Lift refrigerated ISO shipping container onto the vessel cargo hatch area (upper deck) with ship's crane.
12. Plug refrigerated ISO container's single cooling unit (no backup redundancy) into ship's power system.
13. Ship refrigerated ISO shipping container by vessel to Port Hueneme, CA. (*If the single cooling unit fails while on the vessel, there is no way to move cores from the refrigerated shipping container; the cooling unit must be repaired on-vessel).
14. Lift refrigerated ISO shipping container off vessel and onto Port's transfer flatbed truck via the ship's crane.
15. Drive transfer flatbed truck to the Port's Freezer Warehouse.
16. Lower refrigerated ISO shipping container (with ice cores) onto ground using a container handler.
17. Plug in the refrigerated ISO shipping container to the Freezer Warehouse power cord.
18. Unload the refrigerated ISO shipping container using forks, and reload the ISC pallets into the waiting contracted refrigerated container truck. (*Contracted truck required on-site 24 hrs. in advance for cool down; required to hold –30°C for 24 hours before being loaded).
19. Install new paper chart on the refrigerated ISO shipping container.
20. Review and archive old paper chart for two years. Forward data as needed.
21. Remove HoboTemp from refrigerated ISO shipping container. Download data and compare to chart.
22. Install new paper temperature chart on the contracted refrigerated container truck.
23. Install HoboTemp in the contracted refrigerated container truck.
24. Drive contracted refrigerated container truck to NICL in Denver, CO. (Note: If contracted refrigerated container truck breaks down, unwrap ISC stacks and manually unstack and restack each box into a contracted backup refrigerated container truck).
25. Fork ISC boxes from contracted refrigerated container truck into NICL -36°C freezer.
26. Remove paper chart from the contracted refrigerated container truck.
27. Review and archive old paper chart for two years. Forward data as needed.
28. Remove HoboTemp from contracted refrigerated container truck. Download data and compare to paper chart from contracted refrigerated container truck.
29. Remove HoboTemp from each stack of ISC boxes. Download data and compare to paper chart from contracted refrigerated container truck.

30. Unstack palletized ISCs in the NICL -36°F freezer, open the ISCs, remove ice cores, and stack cores onto roller cart in desired order.
31. Remove HoboTemp from each marked ISC. Download data and review.
32. Remove individual cores from the roller cart and placed on -36°F freezer storage shelves in desired order.
33. Remove cores from -36°F freezer storage shelves in desired order, roller-cart them to the -20°F freezer Exam Room, and begin processing cores.

Overview of Problems with Existing Procedures and Equipment

Labor-intensive and injury-inducing manual ice core movements are characteristic of the present procedures, as illustrated by the frequent use of the words "stack" and "unstack" in the descriptions in Section 1.3.

The definition of "stack" and "unstack" is that two (now required to be four) people manually lift each full 50"L x 18"W x 20"H, 130-pound ISC (from ground level or from 5-feet high), then walk the ISC over uneven or slippery terrain while wearing heavy clothing, clumsy boots, and thick gloves. The lifters then place the box down again (at ground level, or 5-feet high in a stack). This is a tiring and injury-inducing task when handling dozens or hundreds of boxes, and has historically led to strained backs, arms, necks, and other ailments. High altitude drill camp locations increase the chance of incurring these injuries.

In addition, the intensive box handling efforts can lead to inadvertently dropping a box or banging it into something – especially as the work crew becomes tired. Depending on the impact, the 2"-thick, rigid-foam-lined cardboard ISCs may protect the cores, or may allow cores to become damaged, resulting in corrupted or destroyed ice core data. With each manual movement of the ice core box throughout the journey from field camp to NICL, there is a risk of the box being dropped, and potentially damaging the ice cores within.

Cardboard ISC boxes are typically reused for several years unless severely damaged. The foam/cardboard integrity, strength, and insulating value of each box is reduced over time from repeated handling and abuse, and from environmental degradation (moisture intrusion, UV degradation, etc.).

An air gap sometimes develops around the ill-fitted soft foam "plug" under the top flaps of the ISC; outside air (uncontrolled temperature) can then infiltrate directly to the core tube and cause potential core warming. Infiltration is most likely to occur when the box's top flaps are not properly and completely sealed shut with tape or banding, or when the unsealed box top is not covered by the bottom of another box while in a stack.

The minimal R13 (2 inches of polyurethane foam) thermal insulation value of the ISC box causes a particular concern whether it can properly protect the cores from warming during normal ice core transportation durations in uncontrolled temperature conditions. Even with no air infiltration, the contents of the ISC (96 pounds of ice at -20° C) are calculated to warm by 2°C in two hours and 5°C in five hours if the outside ambient air temperature is 0°C (see Appendix A – ISC4 curve). Notably, five hours is approximately the amount of time, if all goes well, that the ISC is outside a controlled temperature environment while traveling between a typical deep field camp's cold-trenches and the McMurdo freezer (via "cold-deck" LC-130, and on McMurdo's open-air cargo Delta flatbed trucks). During a typical transport trip, it is not unusual for outside ambient temperatures (near the ISC boxes) to range from -10° C to +10° C. Therefore, a core that begins at -20°C at the field camp and is located at an outer layer within a stack, could very well warm to a dangerous -15°C (or warmer) by the time it gets restacked inside a

-20°C freezer at McMurdo Station several hours later. An ice core's scientific climate data will be compromised if a core remains at -15°C for more than one hour (thus the critical, long-duration upper temperature limit is designated as –20°C), so the present ice core box design is severely pushing the thermal limits while in Antarctica.

Worse, if the ambient outside air temperature is +25° C (in California, for instance, while transferring ISCs into a spare, refrigerated reefer truck after the primary refrigerated reefer truck malfunctions on the road), these critical warm-up times are reduced to 1 hour and 2 hours respectively, cutting the safety time margin to nil (see Appendix A – ISC4 curve)

In summary, the less-than-desirable cardboard ISC box presently used by USAP for ice core transport has numerous shortcomings, including lack of sufficient insulation, air infiltration gaps, middling shock-absorption properties of the rigid foam, difficult-to-grasp slippery outer surface, and propensity to cause injuries during lifting operations. Its present use is not well designed or integrated into the overall ice core transportation process, and for the WAIS Divide project, 700 space-inefficient ISC cardboard boxes would be required.

With respect to freezer systems designed to protect the cores from warming, the current USAP refrigerated ISO shipping containers (commonly known as "reefers" or "reefer vans") do not have a built-in, backup or redundant (fail-safe) refrigeration unit; if the single refrigeration unit built into the reefer malfunctions, the cores must be removed and placed into a standby, pre-chilled backup reefer. Only then, by protocol, can the malfunctioning reefer be evaluated and repaired as needed. Also, these same reefer vans do not have a built-in or clip-on electrical generator set to power the refrigeration system should the plug-in power source be disrupted. The sole electrical supply to the reefer cooler unit is presently provided only from a plug-in power cord from an outside electrical source (such as McMurdo's Power Plant, or the shipping container vessel's on-board power generator).

If a reefer problem or electrical disruption occurs, transferring up to 64 full ISC boxes into a pre-chilled backup reefer at McMurdo can be done, but is a time consuming, labor intensive task. It requires gathering at least a dozen responsible, trained, strong people on a moment's notice to perform the manual transfer, and, once again, exposes the ice cores to possibly warmer temperatures, and the risk of being dropped.

Assuming no mid-season catastrophic event has completely destroyed or melted the ice cores, at the end of the austral season, the cores are manually transferred from the stand-alone, outdoor freezer (where the cores are first placed upon arrival from the field mcamp) to a standard, 20', single-cooler reefer van, which is then craned onto a shipping container vessel container (most recently the American Tern). Once the ice cores are onboard the vessel and underway to Port Hueneme, California, an especially critical problem with the present reefer scheme is that ice cores inside the reefer van on the container vessel cannot be unloaded into another backup reefer van on the ship if the reefer malfunctions—there is simply no space to open the reefer doors once the reefer is placed onto the vessel's cargo hatch bay location at deck level (see Appendix B). So if the reefer's single cooling system malfunctions and the interior payload space begins to warm, the only recourse is to have a ship's engineer try to fix the damaged system (with spare parts specifically for this reefer already stored on the ship) before the cores warm above -20°C. This lack of an automatic, fail-safe, redundant-cooler reefer system on the ship is likely the largest failing of the present core transport system, and places the cores at a significant risk of warming or melting during the multi-week voyage from McMurdo to Port Hueneme.

It is worth noting a few additional American Tern vessel regulations regarding reefers:

- Reefers are not placed below deck due to lack of ventilation fans and power circuits.
- Reefers are always placed on the cargo hatch deck, in specific locations.
- Reefers are only placed where there are electrical 460V plug-in circuits /cords.
- Reefers always, and only, go on the lowest (bottom) level of a particular container stack.
- A stack of up to four containers is allowed on the cargo hatch (top deck).
- The total stack of containers (1, 2, 3, or 4) can weigh up to 60,000 lbs.
- Only 8'6" tall standard ISO containers are allowed to be stacked.
- A 40' container can be placed on another 40' container.
- A 40' container can be placed on two 20' containers.
- A single 20' container can only be placed on another 20' container.
- Two 20' containers cannot be placed on a 40' container.

The final two problems with the present system have to do with the HoboTemp temperature recording device logistics, and the reefer's temperature chart recorder.

HoboTemp Recorders: Real-time access and review of an ISC's internal core-chamber temperature is not easily or readily achieved with the present HoboTemp device, which is mounted as an unwired temperature-recording drone inside any number of selected ISC boxes at the field camp. To obtain definitive, real-time or historical internal temperature data from a suspect or designated ISC, that ISC must be removed from the stack and opened. Then, the HoboTemp recorder must be removed from the interior cold space of the ISC, plugged into a laptop computer, and the data downloaded for viewing on the screen or printout. The ISC is then opened again, the HoboTemp recorder is reinstalled, and the ISC box flaps are closed.

Going through these procedures for several ISCs with suspect temperatures can take significant time and effort. As well, opening a loaded ISC allows (possibly) warmer air to enter and compromise the ice core's cold space. And, of primary concern, ice core damage may have already occurred before the interior ISC temperature history is even downloaded and reviewed, as these internal, "direct-evidence" ISC temperatures are, by protocol and practicality, downloaded and reviewed only twice during the multi-month ice core journey: Once while in the outdoor permanent freezer at McMurdo, and again at NICL, after the ISCs have arrived and have been restacked in the NICL storage room.

To overcome this sparsity of temperature data download and review of the direct, internal ISC temperatures, current protocol (RPSC document LO-A0109 - Shipping Retrograde Science Cargo – Revision 0, 10/28/03) prescribes that auxiliary, easily-retrieved HoboTemp recorders also be mounted in various locations *external* to the ISC; i.e., in the cargo bay of the LC-30 near the ISC stack (visible to the Load Master), on the side of the ISC stack while in transit on the cargo Delta truck to McMurdo, inside the reefer van near the ISC stack, etc.), with data downloaded and reviewed more frequently.

With this "indirect", external, auxiliary temperature recording arrangement, it is apparently assumed that if the measured *exterior* temperature of an ISC is below a certain limit, then the *interior* temperature of all ISCs on that shipment are also below the limit. This may usually be true, unless contact of the ISC box to a warmer, thermally-conductive outer wall of a reefer van (as has happened in the past), sun exposure on the ISC box, "non-cold" cabin air on some LC-130 "cold-deck" flights, or other unexpected warm spots on the ISC stack are not tracked by the auxiliary exterior recorder.

Overall, though a sufficient number of HoboTemps are presently in-hand at NICL for the proposed Safe-Core system for the WAIS Divide project, the present setup, installation locations, and download protocol dictates that these HoboTemp recorders be used primarily as after-the-fact archival temperature recording devices, to verify that the cores were always within the required temperature regime during transit and intermediate storage. That is fine in and of itself, but if a problem is seen to have occurred with warming ice cores, it may be too late to do anything about it once the data is finally reviewed. The existing system is sorely lacking a method for effective real-time, closed-box temperature download and instantaneous readout, to see and head off warming problems before they reach a critical level. Two methods to resolve these various concerns are discussed in Section 1.5.6.

Analog Temperature Chart Recorders: The problem with the present reefer vans's on-board chart recorder unit is that it uses an antiquated Partlow analog charting device (ink on a paper disk), so there is no capability to digitally store, download, or share the data electronically. The ink can dry out or smear, and only original paper disks (or photocopies of the disks, which can be difficult to read) are available for review, disposition, and archival purposes. Due to the existing technology in place with the USAP ice core transportation program, there is no digital data master of this temperature history – all information is paper-based.

As described in Section 1.5.6, technology is now sufficiently advanced to recommend the use of digital recording and downloading devices on the ice core reefer vans, along with a backup paper chart if desired. Partlow (and competitors) offers several units having the desired functions and features.

All the aforementioned problems and shortcomings with the existing ice core transportation logistics are addressed and solved as proposed in Section 1.4, and with the improved "Safe-Core" equipment as proposed in Sections 1.5.1 – 1.5.6.

Proposed "Safe-Core" Procedures and Equipment

1.4 Brief Description of Proposed "Safe-Core" Procedures

The envisioned Safe-Core transportation process, using the Safe-Core equipment recommended in this report, is described in brief terms below for the WAIS Divide project. (See Appendix G for a more thorough description of these proposed operations). The same proposed logistics and equipment can also be used for other, future USAP deep-field ice core drilling projects.

During a drilling season, the following sequential "Safe-Core" operations would occur:

1. With a fork loader, place an Air Force pallet (AFP) – "pre-loaded" with one to four empty HD45 boxes - onto floor rollers just inside the WAIS Divide drill camp's arch building doors. The empty HD45s must be preloaded on the AFP such that their doors will face the curved sidewalls of the arch building when the AFP is moved inside the building. Note: The AFP may be "pre-loaded" with one to four empty "high-density" ice core boxes/vaults (HD45s) before being placed on the rollers, depending on LC-130 Allowable Cabin Load (ACL) for the upcoming flight.
2. Push the AFP on the rollers until located in the desired position within the -20°C staging area near the core processing line. Remove the cargo netting and appropriate cargo straps to uncover the HD45 doors. Keep other cargo straps tightened.
3. Repeat with the placement of a second "pre-loaded" AFP inside the staging area.
4. Remove the floor roller section nearest the arch doors, and close the double doors. Both pre-loaded AFPs remain on the interior floor roller sections.
5. Open the door on one of the HD45 boxes and let the interior temperature equilibrate to –20°C.
6. Load processed ice cores into plastic sleeves and protective cardboard tubes. Insert shock absorbing cushions on each end of the ice core, outside the plastic sleeve.
7. Place up to 25 tubed ice cores on a rubber-tired rolling cart in the desired order, and roll the cart to the opened HD45 box.
8. Place the tubed ice cores (28 pounds each) into the foam-insulated, shock-absorbing HD45 box, by hand, in the desired stacking order. Up to 45 cores can be placed in each HD45 box/vault. Close the HD45 door after each loading session.
9. After each HD45 is full, insert a wireless temperature recording device ("Escort/REDi") in the designated location inside each HD45 box, and close the door. HD door will not be opened again until arrival at NICL. Attach

appropriate core data to the box, and assure that required TCN/Retro tags are affixed to each HD45.

10. Load additional HD45 boxes with 45 ice cores each, and install a wireless "Escort/REDi" recorder in each HD45 box, and tag the HD45 as needed.
11. Check that all cargo straps are tight, and cargo net the HD45s to the AFPs for transportation. Note: Empty (525-lb) or full (1785-lb) HD45 boxes can be placed on or removed from an AFP as needed using the floor-rolling, gantry-style overhead hoist and floor pallet jack. A (TBD) number of HD45 boxes can be stored along the interior (curved) side of the arch as needed for staging and emergency purposes. Additional empty HD45 boxes may need to be stored in auxiliary buildings, or (worst case) outdoors undercover. HD45 boxes cannot be stored in the arch "basement" due to space constraints.
12. Upon imminent arrival of the LC-130 ice-core pickup flight, reinstall the floor roller sections nearest the arch doors.
13. With floor rollers, roll each ice-core loaded AFP to the arch entrance door for pickup by the outdoor fork loader. (*If the loader malfunctions, use a Tucker SnoCat to skid the full AFPs out of the arch building onto the snow).
14. Fork or skid the AFPs (weighing up to 7495 pounds each with four fully-loaded HD45 boxes) over to a "cold-deck" LC-130 Hercules aircraft.
15. Load the AFPs into the "cold-deck" LC-130 via forklift or on-board winch, per Allowable Cabin Load (ACL). (Note: If aircraft does not arrive, return each AFP (with full HD45s) to the arch floor rollers and push inside the -20°C space. There is no need to unstrap or unload the HD45 boxes from the AFPs as long as they are within the -20°C area.)
16. Attach a wireless temperature recording device ("Escort/REDi") on the *outside* of the each AFP near the HD45 boxes.
17. Fly cargo to McMurdo airfield (distance and time to McMurdo varies upon flight conditions, and which airfield is in operation).
18. Fork AFPs onto flatbed truck at airfield, with Escort/REDi temperature recorders still on each AFP.
19. Download data from each uniquely identified Escort/REDi wireless device (on the AFPs, and inside each HD45) with a wireless, radio-frequency handheld reader, and review the readout screen for temperature alarms or problematic trends. (Note: All temperature data can be downloaded without opening any HD45 doors).
20. Drive loaded truck to McMurdo town site. (Note: If truck breaks down enroute, fork each loaded AFP onto a backup truck).
21. Fork each AFP off truck and place on ground-level dunnage near the two pre-chilled (-30°C) 40' refrigerated ISO shipping containers (with redundant cooling and redundant power generator backup systems). Note: the reefer vans may be either the recommended "nose-mount" style each capable of holding 16 HD45 boxes (720 ice cores), or the alternative "window-frame" style each capable of holding 18 HD45 boxes (810 ice cores).

22. Remove the two external Escort/REDi recorders from the AFPs, and place them inside one of the pre-chilled (-30°C) 40' refrigerated ISO shipping containers (reefer).
23. Fork each HD45 (with pre-installed wireless Escort/REDi recorders) directly into the -30°C reefer van. (*While at McMurdo, if the ISO reefer's primary cooler malfunctions, the built-in backup cooler (set at –25°C) will operate as needed. If the cord-supplied power is disrupted, the built-in backup genset will automatically start).
24. Download data to a laptop computer from the 40' refrigerated ISO shipping container's built-in digital temperature datalogger, and compare it to the data downloaded from the two wireless Escort/REDi temperature recorders inside the reefer.
25. Note and act on any temperature anomalies. Share and archive the digital data as needed.

At the end of the season when the shipping container vessel (American Tern) arrives:

1. Lift the full 40' refrigerated ISO shipping container onto a flatbed truck using the FatCat container handler. (Note: If container cooling is needed while unplugged, one of the built-in backup redundant gensets will automatically provide power to the cooling unit).
2. Drive the refrigerated ISO shipping container to the ice wharf upon appropriate timing for loading the shipping container vessel.
3. Disconnect (switch off) the two backup gensets on the 40' refrigerated ISO container. (Note: Gensets are not allowed to operate on the shipping container vessel, and must be disabled for the voyage).
4. Hoist the refrigerated ISO shipping container onto the vessel cargo hatch area (upper deck, first layer) with the ship's crane.
5. Plug the 40' refrigerated ISO container cooling unit (dual redundancy) into ship's power system, using one cord plug.
6. Ship the 40' refrigerated ISO shipping container by vessel to Port Hueneme, CA. (Note: If primary -30°C cooling unit fails while on the vessel, the built-in backup cooling unit will automatically start as needed to maintain a -25°C setpoint. Primary cooling unit will be interlocked "Off" at that time to prevent concurrent operation.)
7. Lift 40' refrigerated ISO shipping container off vessel and onto the Port's 40' flatbed truck via the ship or Port crane.
8. Re-enable (switch on) the 40' refrigerated ISO container's two on-board gensets, to automatically provide power to the cooling units as needed while the refrigerated ISO shipping container is unplugged.
9. Drive 40' transfer flatbed truck to the Port's Freezer Warehouse.

10. Lower the 40' refrigerated ISO shipping container onto ground using a container handler.
11. Plug in the 40' refrigerated ISO shipping container to the Port's Freezer Warehouse power cord. Operating genset will cease operation, and the redundant genset systems will then remain on automatic standby.
12. Download data from the refrigerated shipping container's built-in digital temperature recorder, and compare it to the downloaded temperature data from the wireless Escort/REDi temperature recorders inside the reefer and each HD45 box/vault. There should be no alarm signals or significant warming trends from within the 40' ISO shipping container or the numerous HD45 boxes.
13. Share and archive the digital temperature data as needed.
14. Upon arrival of the contracted 40' air-ride flatbed truck, lift the 40' refrigerated ISO shipping container from the ground onto the air-ride flatbed truck using a container handler.
15. Drive contracted air-ride flatbed truck to NICL in Denver, CO. (Note: If truck breaks down, rent a pre-arranged container handler, and transfer the 40' ISO shipping container onto a pre-arranged, contracted backup air-ride flatbed truck). (Note: If primary cooling unit or genset malfunctions, backup cooler or genset will automatically kick in).
16. At NICL, download all data from the 40' refrigerated ISO shipping container's built-in digital temperature recorder, and compare it to the data from the wireless "Escort/REDi" temperature recorders inside the reefer and all HD45 boxes. Share and archive the digital data as needed.
17. Fork all HD45 boxes from the 40' refrigerated ISO shipping container into the -36°C NICL freezer, with the HD45s arranged for proper ice core sequencing.
18. Fork each full HD45 (in desired order) into -20°C Exam Room and allow to acclimate for 2-3 days. Open HD45 doors to speed the acclimation process, if needed.
19. Remove the Escort/REDi recorder from each HD45 when desired. Review temperature data.
20. Remove cores from each HD45 (in desired order), and begin processing.

Note

A more detailed description of these proposed "Safe-Core" activities can be found in Appendix G. and details of proposed "Safe-Core" equipment can be found in Section 1.5.

1.5 Details of Proposed Safe-Core Equipment

As briefly described and put into use by the Safe-Core transportation scenario envisioned in Section 1.4 (and detailed in Appendix G), four changes are recommended to achieve major improvements over the current ice core transport system (previously described in Section 1.3, and detailed in Appendix F). The proposed Safe-Core improvements consist of:

1. Ice core box and box handling/lifting/transfer systems that are well-designed, well-integrated, and minimize or eliminate the risk of injuries by using mechanized lifting and rolling equipment throughout the entire process from the drilling camp to NICL.
2. A core box that will withstand extreme environments and physical abuse, protect the valuable contents from shock and vibration damage, and maintain an acceptable interior temperature (no warmer than -20°C) for extended periods in warmer environments.
3. A space-efficient, fail-safe, refrigerated ISO shipping container with built-in, auto-redundancy coolers and gensets to obviate the need to move cores to a backup reefer.
4. A digital temperature monitoring and recording system that allows instantaneous downloading of data without removal of the logging device from the cold space (i.e., not requiring cold-space doors to be opened).

The unique ice core transportation devices meeting these requirements are described in Sections 1.5.1—1.5.6, with additional information provided in Appendix E.

1.5.1 Mechanized Lifting and Rolling Equipment

All of the mechanized equipment needed to lift and maneuver the proposed HD45 boxes and loaded AFPs already exist at the locations required, or are on order specifically for the WAIS Divide project (see Appendix C). All are of sufficient load capacity and have the appropriate dimensions and features to efficiently and safely handle the proposed Safe-Core transport equipment when fully loaded with ice cores.

The primary and backup devices needed to lift and maneuver the cores from the field camp to the NICL freezer include the camp's basement elevator, roller carts, floor-rolling overhead hoist, pallet jacks, 463L Air Force pallets, various Caterpillar fork loaders (988, 966, 953C, 950, IT28, FC40 (@ NICL), Tucker SnoCats with forks, M4K fork trucks, Delta cargo and military Volvo 40' flatbed trucks, FatCat container handler, ship crane, and Grove and Mantis cranes (as backup to the FatCat).

Note

It is critical that any future changes proposed to these existing box and reefer van lifting and trucking devices also address the impact to this proposed WAIS Divide Safe-Core ice core transportation plan. See Appendix C.

1.5.2 High Density HD45 Ice Core Box

A new ice core transport box/vault is proposed to replace the current, unsatisfactory ISC cardboard box (Fig 0).

Figure 0. ISC4 Boxes (Stacked) Existing Design

The proposed, improved ice core box/vault (Figs. 1A-1D) is deemed a “high-density” box, or HD45, because each box will hold up to 45 one-meter long ice cores in a densely-packed, horizontal configuration.

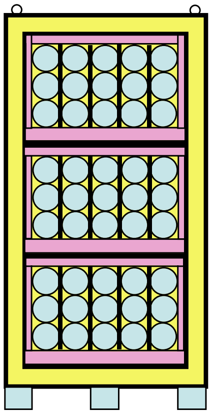

Figure 1A. HD45 Layout

Figure 1B. HD45 Door/Latch

Figure 1C. HD45 Interior

Figure 1D. HD45

Note

An optional "half-height" HD20 box capable of holding 20 ice cores is described in Appendix E (Sections 1.9.4-1.9.6). Though the stackable "half-height" HD20 box is an interesting concept, compared to the HD45 box the HD20 is less desirable for the Antarctic program because of financial, thermal, and logistical issues, also described in Appendix E (Sections 1.9.4-1.9.6).

The recommended HD45 ice core box/vault size, configuration, and weight are designed to efficiently integrate with all aspects of the WAIS Divide ice core transportation process and other Safe-Core equipment recommended in this report.

The optimal HD45 dimensions (outside) were determined to be approximately 49"L x 40"W x 74"H (dimensions will be verified accurate before final manufacture), with a full (gross) weight of no more than 1800 pounds.

The proposed HD45 design integrates efficiently with the various transportation cubic volume allowances, vehicle payload capacities, and storage areas used during the various transport, storage, and transfer stages as the ice cores' travel from the drilling camp to NICL. Also, the consolidated packing of so many (45) one-meter cores into one box minimizes the number of boxes used in the process, and the number of times the boxes must be handled and maneuvered during transport. As well, the "high-density" ice-core packing configuration in each HD45 box increases the interior thermal mass relative to the outside area of the box, which helps slow the increase in ice core temperature. Another benefit of the large, HD45 format is that its movement always requires (by deliberate design) the use of mechanized handling equipment; this will minimize the risk of personal injury, and reduce the chance of dropping the core box (as often happens when manually lifting and handling smaller, lighter boxes).

Several options of HD45 ice core box or vault design and construction methods were reviewed and evaluated, including styles fabricated with skins of wood, metal, plastic, and honey-comb panels, and units molded from various plastics. Because of the large overall size of the box, and the heavy payload inside (1,260 pounds of ice and tubes), the HD45 construction must be very robust to withstand the daily rigors of Antarctic field-camp abuse, lifting with mechanized equipment, possible drops and impacts, and 25,000 miles of round-trip yearly travel for several years.

The preferred HD45 box (Figs. 1B-1D) is an engineered and manufactured unit presently used by U.S. military, FEMA, and others requiring the most durable, thermally-stable, transportable storage box for temperature-sensitive payload in extreme-environment, rough-handling conditions. At approximately $3600 each, the HD45 box design includes a high-strength, one-piece, double-wall, rotationally-molded polymer shell injected with 4" of void-free polyurethane foam (R25 value), a secure, front-accessed door latching system, and a double-pin door hinge for full interior access. Interior shock-absorbing padding made from temperature-insensitive rubberized fiber protect the cores from impact and vibration damage, and perforated shelves separate the cores into three bays to minimize crushing loads on the core tubes, yet still allow cold air to circulate and equilibrate within the box. The molded HD45 weighs 525 pounds when empty, and 1785 pounds when loaded with 45 cardboard-tubed ice cores.

A custom mold and post-mold fixture must be manufactured to accommodate the one-meter long ice cores, but that one-time tooling fee is factored into the $3600 per-piece price (if manufactured in bulk). The recommended manufacturer of the molded transport box shown in Fig 1 is Dometic Electrolux of Luxembourg, with a Virginia-based distributorship and warehouse.

With the Dometic HD45 box, the double-walled, foam-filled HD45 is made by rotational molding, and has 1/8"-3/16" thick walls inside and out. The wall material is a specially-formulated, UV-resistant, linear low-density polyethylene plastic, designed for severe-duty use in extreme cold and high temperatures (-52° C to +52° C). The HD45 can be molded in any color; lighter colors (white, yellow, etc) will absorb less solar energy and better protect the cores from temperature rise when in the sun. Being made of molded, one-piece plastic, the recommended HD45 can be hosed down and disinfected as needed, inside and out.

Because of Dometic's highly-engineered molded box design (Fig. 1B-1D), carefully-selected quality materials, and precision manufacturing process, environmental stress cracking of the unit has not been an issue with current box owners such as the U.S. Army and the Federal Emergency Management Agency (FEMA) – even after long-term (and often abusive) field use in extreme conditions. As an added safety feature for USAP usage, metal bumper strips can be installed around the fork entrance areas to further protect those areas from accidental punctures from fork tines or other objects.

The 4-inch thick internal cavities between the outer and inner walls of the cabinet and door are filled with injected polyurethane foam* (with a non ozone-depleting foaming agent) in such a manner as to prevent any voids or uninsulated areas when completed. There are no exposed areas of polyurethane foam, so moisture absorption into the foam is not an issue. The single-piece molded HD45 box has no thermal bridges (highly-conductive heat paths) between the interior and exterior walls, and the foam will provide an insulation value of R-25 (ft2*^{0}f*hr/btu). Dometic has several methods available to verify that the foam is indeed void-free and without thermal leak paths, including the use of an infrared camera (thermography).

Note

When the proposed HD45 box is placed in a 0°C environment, thermal calculations predict that a full load of -20°C ice cores will rise in temperature only 2°C after 12 hours, and will rise a total of 5°C after 30 hours (see Appendix A – HD45 curve). When the HD45 is immersed in a +25°C environment, these warm up times decrease to 6 hours and 14 hours, respectively. And when the HD45 is placed in a +50°C environment, the warm up times will be 4 hours and 8 hours, respectively.

* Insulation is a primary concern to ensure the cores remain at the desired temperature as long as possible (see Appendix A). Various choices of insulation are available, with injected-foam polyurethane appearing as the best choice due to the seamless, joint-free final product, an R6.5/inch insulation value, and its ability to create a sandwiched "structural insulated panel" (SIP) which strengthens the box walls. With appropriate inner and outer box skins and covered edges, there is no exposed foam to absorb moisture, thus providing a stable insulating value over many years.
Other insulation contenders that have been eliminated from consideration at this time include; 1). Extruded and/or expanded rigid-board polyurethane, polystyrene, and polyisocyanurate (due to the likelihood of gaps forming at the joints after several years of intense use, and due to lower r-values for most of them). 2). Vacuum insulated panels- VIPs (due to their delicate, easily-punctured barrier covers, and because of their known tendency to have a declining R-value over several months and years as the vacuum slowly dissipates through the barrier covers). 3). Other soft, flexible foams (mostly due to insufficient R-values compared to foamed polyurethane).

The HD45 has a large, front-mounted, lever-actuated, door closure system with triplex door seals (to prevent air infiltration). A unique and robust dual-pin door hinge (3/8"-diameter rods) allows the door to be fully opened even when packed tight against neighboring HD45s on each side, thus allowing access to the full width of the interior cavities.

The HD45 interior is separated into three sections (Fig. 1A) to prevent lower cardboard ice core tubes from being crushed by heavy upper loads. Core tubes will be slid horizontally into their respective chamber, and each chamber has stiff, vertical plates separating each column of tubes to prevent them from rolling sideways while loading. The vertical plates and each floor plate are perforated to allow cold air to flow and equilibrate within the HD45. Tubes are placed directly on top of each other in a tube-on-tube fashion, which has been found to be most user-friendly manner to insert and withdraw them. Each of the three chambers can hold five tubes across and three tubes high in a high-density arrangement, for a total of 45 tubes per HD45 (thus the nomenclature).

Temperature-insensitive rubberized fiber cushions line each of the chamber sections to absorb transport shock and vibration. The rubberized fiber provides uniform and unchanging compression and rebound performance from +52° C to -52° C (unlike most foam-based materials), and the material has an open-cell structure to facilitate airflow between chambers. The cushions are removable for replacement, or to allow unhindered hosedown and drying of the HD45's interior chambers. Rubberized fiber is used extensively by the military to protect sensitive equipment in extreme environments, and has a long life span.

The HD45 has replaceable wooden blocks bolted to the bottom to prevent damage to the delicate aluminum floor of the Air Force pallet (AFP), to allow unfettered four-way pallet jacking, and to allow cold air to flow underneath while in the refrigerated ISO shipping container. Also, four heavy-duty lifting eyes are located on the top of the container to allow overhead hoisting of the HD45. Each lifting eye is structurally connected right into the floor of the HD45 box to ensure safe lifting when fully loaded with ice cores (1785-lb gross HD45 weight, with ice).

On the door there are three recessed areas for metal plates (under Lexan see-thru protection plates). These plates can be used to attach labels such as the outbound Transport Cargo Number (TCN), retrograde TCN, core sequence numbers, or other info. Pockets or recesses can be designed inside or outside the HD45 to securely mount the existing HoboTemp temperature recording module, or the recommended wireless Escort/REDi temperature recorders (described in Section 1.5.6.1).

A tiny air-equalization hole or valve (to be determined) connects between the inner cavities and the exterior of the box to allow pressure equalization—an important feature for cores that will travel from the 5,700-foot camp, to a 10,000-foot-equivalent flight pressure level, down to sea-level at McMurdo Station and Port Hueneme, up to 11,000 feet for the truck ride through Colorado's Eisenhower Tunnel on Interstate 70, and then down to Denver/NICL at 5,500 feet. The equalization hole will pass an insignificant amount of air - just enough to allow slow air pressure rebalancing as needed.

As previously mentioned, the HD45 can also be fabricated using other methods and materials (plywood, metal, etc.) by other vendors, instead of the recommended Dometic molded-plastic design. However, various vendor estimates show the cost of alternative designs and construction methods to be only slightly less (and sometimes more), and the weight significantly more. A heavier, fabricated HD45 box would necessarily displace some cores from shipment, to stay within the allowable and most efficient equipment lifting and payload limits.

Also, strength, durability and thermal performance of an alternative fabricated box may be inferior compared to the recommended, one-piece molded unit, on a pound-for-pound basis, due to the numerous joints, bolts, seams, and possible thermal bridges. On the plus side, a fabricated wood, metal, or plastic sheet-stock construction method is slightly (usually) less expensive, and would allow for fast and inexpensive modifications mid-project due to the lack of an expensive mold (though other box fixtures and jigs are still required for the fabricated box design).

In summary, the features and performance of the recommended molded-plastic HD45 offers a well-rounded combination of consolidated ice mass, R25 polyurethane injected-foam insulation, seamless construction, an easy-open air-tight door seal, and full, efficient integration with the rest of the proposed Safe-Core transportation system. The proposed HD45 will provide the required protection against ice core warm-up damage and physical damage under the anticipated conditions – and is far superior to that of any box presently used to transport USAP ice cores. Also, the HD45 can be used and adapted for other ice core projects, sea specimens, microbiological samples, and other undetermined USAP uses as desired.

Compared to the existing ISC cardboard ice core box, here is a summary of the pros and cons of the HD45 as proposed for the WAIS Divide project:

1.5.3 HD45 Pros:

- Consolidates the cores into a minimum number of boxes (31) that must be loaded seasonally. A total of only 62 HD45 boxes are needed for the project (31 northbound with cores, 31 southbound with empty tubes).
- Endures years of impacts without undue damage to box.
- Isolates cores from transport impact with interior shock/vibration-absorbing cushions.
- Provides the best temperature protection for the cores compared to other box designs and insulation values (see Appendix A).
- Requires the use of mechanized devices to lift and move the boxes. This will significantly reduce the risk of personal injuries resulting from attempts to lift or move them unaided.
- Integrates pallet blocks and lifting rings into the box design.
- Is compatible with all lifting and transport devices (hoists, fork loaders, floor rollers, pallet jacks, etc.) that will be used to transport it in the USAP system, from field camp to NICL.
- Can be either loaded with cores and then hoisted/forked onto an AFP, or hoisted/forked empty onto an AFP and then loaded with cores.
- HD45s can be easily and quickly placed or removed on an AFP as the LC-130's camp departure ACL (Acceptable Cabin Load) allows.
- Durable door, triplex seal, and robust latches remain tight during the journey, but can be quickly opened to insert or remove temperature monitoring devices, as needed.
- Requires only 31 temperature monitoring devices for a season, with one in each box.
- Any HD45 door on a full AFP load can be fully opened without having to move other HD45s for clearance.
- Maximizes the use of space inside the recommended 40' refrigerated ISO shipping container.
- The HD45 box is designed to fully and efficiently integrate with virtually all aspects of the WAIS Divide ice core transportation project. (Note: One door at NICL may need to be widened to accommodate the 40"-wide HD45, with the door purchase and modification labor estimated to cost up to $20,000. Other NICL core-handling and staging alternatives are currently being explored to avoid widening the NICL door).

1.5.4 HD45 Cons:

- Not possible to lift an empty or full HD45 by hand if planned mechanized methods and various backup methods fail.
- Must spend $224,000 up front to design, manufacture, and acquire sixty-two plastic-molded HD45 boxes.

1.5.5 Refrigerated ISO Shipping Container With Redundant Systems

A refrigerated ISO shipping container (commonly known as a "reefer" or "reefer van") is proposed which will have two factory-installed cooling units; one as primary, and the second unit as the automatic fail-safe, or redundant, cooler. Also, a primary electrical power generator set, and an automatic backup genset, will be mounted on each reefer. Interlocks and safety systems will prevent errant operation of the redundant systems.

The redundant-system reefer can be configured in two styles using different ThermoKing refrigeration and genset components: The recommended style is termed the "nose-mount" reefer (described in Section 1.5.5.1) because of how the cooling/genset units protrude from the front of the ISO shipping container, like a nose. An alternative reefer design is termed the "window-frame" system, and is also described in Section 1.5.5.2.

Note

Future upgrades to the McMurdo road system, building placement, and open space must be carefully planned to provide for plug-in parking near appropriate electrical transformers, and for safe clearance and passageway of either style of 40-foot shipping containers. (For instance, if a new building is constructed above Dorm 110 and Dorm 111, a jog in the road will be necessary, and a military Volvo 40-foot flatbed truck with a full ice core reefer must be able to negotiate through this reconstructed roadway area without hindrance or danger.

1.5.5.1 "Nose-Mount" System (recommended)

The proposed nose-mount reefer design (Figure 2), has two high-capacity, "nose-mount" cooling units on one end (one primary cooler, one fail-safe redundancy cooler), an integral fuel-driven power generator within each cooler unit, a shared fuel tank (or optional independent fuel tanks) with secondary containment, an integrated power and cooling unit control and safety system, digital temperature recording and alarm system (with options), standard swing-away doors on the far end of the reefer, and an external spare parts box.

Figure 2. Nose mount reefer (redundant coolers with integral gensets)

Although unique and not widely known, fifteen units of this redundant-system, nose-mount reefer van design are owned by a large chemical company (Arkema Group). Arkema Group uses this redundant-system reefer for world-wide, transoceanic and over-road transport of highly temperature-sensitive, hazardous organic peroxides, and their units have been operating successfully for several years. For Arkema's extremely unstable organic peroxide cargo, temperatures are held to -30°C +/- 2.5°C in a wide range of outdoor temperature and weather conditions, for months on end.

Using off-the-shelf, high quality, energy-efficient cooling systems and gensets from ThermoKing, the nose-mount reefer system (Fig. 2) provides pre-engineered, integrated, and field-proven automatic redundancy, and should provide unsurpassed performance, reliability, and ease of use for many years in the USAP environment.

Each 40' nose-mount reefer has a usable interior length of 33'6", and can hold up to sixteen HD45 ice core boxes (720 one-meter ice cores). When used to store the recommended HD45 boxes, a total of four, 40' nose-mount refrigerated ISO shipping containers will be needed for the WAIS Divide project (two reefer vans at McMurdo filled with up to 1440 ice cores, and two reefer vans southbound on the vessel - loaded with empty HD45 boxes). This number of reefer vans thus accommodates the assumed maximum ice core transportation rate of 1400 one-meter cores per season. At a cost of $75,000 per reefer, this recommended fleet of four nose-mount reefers requires a one-time investment of $300,000.

The reefer shown is Fig. 2 is a currently manufactured by RCS Group (Texas). USAP's redundant-system nose-mount reefers will only need final specifications detailed before purchase, manufacture, and acceptance testing. A fleet of four nose-mount 40' reefers is required for the WAIS Divide project, and quotes to build the USAP nose-mount reefers have been obtained from RCS Group (Texas), and Sonics (British Columbia, Canada). To be conservative, the highest quoted price was used in the financial analysis detailed in Section 1.6.

Delving deeper into the details of the nose-mount reefer pictured in Fig. 2, the system incorporates two ThermoKing TS-500-50 refrigerator units (Figure 3A), both mounted on one end of the reefer box within a skeletal framework. Each refrigerator unit is outfitted with ultra-efficient and reliable scroll compressors (Fig 3B), which are highly recommended in the industry to protect precious frozen cargo. Each individual cooling unit can maintain a set point temperature of -30° C +/- 2.5° C throughout the maximum range of outdoor ambient temperatures expected during the WAIS Divide reefer operation (-40° C to +50° C operational, -52° C to +52° C storage).

Figure 3A. Nose mount refrigerator unit

Figure 3B. Scroll compressor

Temperatures inside the reefer van and throughout the ThermoKing cooling unit are monitored and controlled via state-of-the-art digital temperature microprocessors, which also incorporate several levels of alarm reporting. The same systems allow instantaneous download of historical and real-time temperature data, from numerous sensors, for on-site or remote review. An analog, ink-on-paper disk recorder can also be specified to chart the interior cargo-space temperature (as a backup register to the reefer's digital interior temperature history). Also, several discrete locations within the reefer can be monitored with independent sensors to ensure there are no warm spots (such as near a door, the ceiling, or other potential warmer areas). An alarm signal can be triggered if any of these locations rise above a preset limit for a pre-determined amount of time.

There is one electrical plug-in on one end of the nose-mount reefer because the factory has pre-wired that plug to feed both of the cooler units. Due to limits of the American Tern's electrical circuit ampacity, only one cooler is allowed to run at a time, and this criteria can be met by adjusting the primary cooling unit's set point to -30°C, and the backup cooling unit's set point to -25°C. Also, to prevent both cooling units from operating concurrently despite the offset temperature setpoints, an integral power control and interlock system will be installed.

To accommodate the varied electrical voltages at McMurdo, on the American Tern vessel, at Port Hueneme, and at the NICL, a dual voltage (220-240V/440-480V, 3-phase, 60 Hz) transformer will be built into the reefer power system. In case of transformer malfunction, it is recommended that a spare transformer be stored in the spare parts box attached on the outside of the reefer.

A ThermoKing generator set is factory-integrated within each ThermoKing TS-500-50 cooling unit to provide continuous reefer power. This is especially important if the cord-supplied electrical source should falter, if the power cord should become damaged, or during times of reefer transport or parking without available plug-in cord power. The appropriate genset starts up automatically to power whichever cooling unit (primary, or backup) was operating at the time. Reefer gensets are not allowed to operate on the American Tern, so both gensets can be disconnected via a master control switch (without affecting cooling unit operation) just before onloading the reefer to the vessel at McMurdo Station. The gensets can then be reconnected (switched on) after reefer offload at Port Hueneme.

The gensets draw their fuel from a shared JP-5 or diesel fuel tank mounted on the reefer, with the tank sized for 3 days (or more, by design) of continuous operation. Alternatively, two independent fuel tanks can be installed, if desired. The fuel tank is durably built for over-road and sea-going travel, and has secondary containment. The gensets typically are operated with standard diesel fuel; more research is needed to find if operating JP-5 fuel will cause longevity or reliability issues, or if the factory warranty will still be valid.

Note

Whatever fuel is chosen, JP-5 and diesel fuel should not be mixed in the tank due to potential gelling problems in cold temperatures. If a fuel changeover is desired, the tanks and engines must be completely drained of the other fuel, and the gensets then run to clear out residual fuel in all components.

Because of the open-framed design on the front of the reefer, there is room for an external, lockable spare parts box to be mounted integral with the reefer, thus avoiding the typical problem of missing, misplaced, mismatched, damaged, or "borrowed" spares.

The reefer floor is a special T-slot design that not only allows airflow return under the cargo, but also provides where-needed cargo strapping attachment locations to cinch the HD45s directly to the robust floor platform. This is a much safer method of securing the cargo and allowing full airflow over the entire load of cargo, compared to using airbags between the cargo and outer wall. (Airbags can disrupt the required air distribution flow and can lead to warm areas and "short-cycling" of the airflow through the reefer. Both are detrimental to preserving ice core temperatures).

The T-slot floors are designed to allow standard pallet jack wheels (with a pallet jack tine load of up to 3,500 pounds) to roll and maneuver without hindrance or damage to the floor or pallet jack wheels.

The entire nose-mount reefer is made to ISO shipping container standards. The underside carriage of the reefer has a "gooseneck tunnel" on each end to allow either flatbed or chassis bed trucking, and the reefer van has a standard ISO twist-lock attachment connector in each corner post. The ISO reefer can be hoisted by a standard 40' spreader bar, or fork-lifted using fork pockets built into the bottom side-frames. Reefer box construction is standard sea-going duty (coated aluminum outside skin, stainless steel inside, 4-inch thick polyurethane foam throughout, ultra-seal door gaskets). As with all types of refrigerated shipping containers, annual system and component maintenance is required to ensure proper and reliable operation, and to prolong the life of the reefer investment.

The nose-mount reefer has a set of traditional, swing-open end doors that can fold back tight against the outer side walls. This nose-mount reefer design fits the traditional form factor and loading/locking methods of a standard 40' ISO reefer in terms of cooler and door placement. Therefore, handling, parking and loading at McMurdo, reefer placement and repair on the vessel, trucking over the road, and parking at the NICL loading dock can all be easily achieved.

Usable internal dimensions of the 40-foot reefer are 84"H x 86"W x 33'6"L, and the rear door opening is 91"D x 91"W. As mentioned previously, up to sixteen HD45 ice core boxes can fit inside, equaling 720 one-meter ice cores per reefer van.

The tare (empty) weight of the reefer is 12,000 pounds, the payload of a full reefer (sixteen HD45 boxes with a total of 720 ice cores) weighs 32,130, and the gross weight of the full reefer is 44,130 pounds. These values are within all limits of the various USAP lifting and trucking capacities (see Appendix C), and also meet U.S. Department of Transportation (DOT) road-weight limits for states that the ice cores will travel through on their way to NICL (using a semi-truck and 40' air-ride flatbed mounted with a full 40' reefer van).

To enhance the shock and vibration protection afforded by the rubberized fiber cushions in the HD45 (see Section 1.5.2), the proposed 40' nose-mount refrigerated ISO shipping container should travel via a contracted/rented air-ride flatbed or chassis truck while being transported from Port Hueneme to NICL.

Note

It is critical that any future changes proposed to reefer lifting and trucking devices first be reviewed to address the impact to this proposed WAIS Divide ice core transportation plan.

1.5.5.2 "Window-Frame" System (alternative)

The alternative type of 40' refrigerated ISO shipping container that may be feasible for the WAIS Divide project is termed the "window-frame" style, so known because the sea-duty ThermoKing "Magnum" cooling unit fits flush into one end of the reefer (like a window frame fits flush in a wall) as seen in the bottom of Fig. 4.

Figure 4. Window-Frame Reefer with single cooling unit (bottom of picture) and clip-on genset (top of picture). Redundant systems not shown.

Note

The window-frame reefer would have the same sea-duty interior and exterior materials, temperature monitoring and control systems, gooseneck tunnels, thermal insulation rating, and door gasketing as the nose-mount reefer described in Section 1.5.5.1, but there might not be room for an external spare parts box.

For refrigeration redundancy, the window-frame reefer would have a second "Magnum" cooling unit mounted on the other end of the cargo box (where a door is normally installed). The ThermoKing Magnum primary and backup window-frame cooling units are integral to the cargo body end walls.

For primary power and backup redundancy, two removable ThermoKing "clip-on" power generator sets (models not specified) would be hung above each cooling unit, one on each end of the reefer, as seen in the top of Fig. 4.

Because both ends of the window-frame reefer have coolers and gensets, swing-open double-wide doors would be installed on one sidewall of the reefer. This door placement does not allow optimal loading and unloading logistics, but is the most feasible location on this type of reefer.

Note

An optional method of having a rear door on a window-frame reefer was explored with several reefer manufacturers. The conceptual design is to have the entire 3000-lb+ end-wall cooling unit/genset panel on a very robust hinge, and have it swing open as one big door. Two vendors are willing to design and manufacture such a reefer, and are confident that the reefer frame and walls could handle the door-opening forces without twisting or distorting.

However, they have concerns that the opened 3000-lb panel may catch the wind and possible result in damage to the door stop-chain or rod. Worse, they fear that the reefer (total tare weight of 11,000 pounds) could flip onto its side if the wind caught the 3000-lb door. Also, someone might get hurt by any errant movement of the heavy door. Given these potential damage and safety concerns, this door design was not explored further.

As with the nose-mount reefer, the window-frame reefer's backup cooling and power systems would be designed to control and automatically take over operations as needed, with appropriate interlocks to prevent undesirable or dangerous operation.

Due to space constraints on the shipping container vessel (American Tern), the clip-on gensets would need to be removed before the reefer is craned onto the vessel's cargo hatch area. (At that time, power is supplied to the reefer van via the ship's power cord for the duration of the voyage, as with the nose-mount reefer design). The detached gensets could be stored at McMurdo for the winter, with a second set of purchased or rented clip-on gensets pre-stored at Port Hueneme for installation onto the reefer at offload, to power the reefer until it arrives at NICL. Alternatively, the clip-on gensets can be removed from the reefer at McMurdo and placed in crates for storage onboard the vessel, then reattached to the reefer upon ship offload at Port Hueneme. The dismounted pair of gensets should not be stored within the ice core reefer itself, however, due to fumes from the fuel tanks possibly seeping into the HD45 boxes and contaminating the ice cores, and in case the gensets are still warm when unclipped from the reefer van.

This dual-system window-frame reefer van design allows a usable interior length of 36'6" (3' longer than the nose-mount reefer), and can hold eighteen HD45 boxes (810 ice cores). This is two boxes (90 ice cores) more than can be stored in the nose-mount style of reefer.

As with the nose-frame reefer, a total fleet of four window-frame reefers would be required (two reefers loaded with cores at any given time) to transport up to 1620 cores. This is more capacity than needed for storing and transporting the WAIS Divide project's desired 1400-1500 one-meter ice cores per (maximum) year; the extra interior space can help accommodate a small "surge" of ice cores from other drilling projects.

Three reputable, quality shipping container manufacturers supplied estimated, budgetary pricing for a proposed fleet of four ISO-qualified, window-frame reefers: RCS Group (Texas), Sonics (British Columbia, Canada), and SeaBox (New Jersey). The highest estimated price came in at $47,000 per unit; to be conservative, that is the cost used in this report.

The less expensive window-frame cooling units and gensets makes this alternative reefer design individually less expensive than the recommended nose-mount reefer system ($47,000 vs. $75,000), and results in a fleet-of-four cost difference of $112,000 ($188,000 versus $300,000).

It is again important to note that the window-frame reefer just described is only conceptual at this time. Though a *single-system* window-frame reefer is common, the *redundant-system* window-frame reefer has not yet been designed, engineered, manufactured, or tested by any of the key shipping container vendors contacted for this project – even the three vendors who quoted on it.

All vendors stated that the redundant-system project will require significantly more time and effort to design, build, and validate than a standard (single-system) reefer van. Even the vendor (RCS Group) who has already built the fifteen redundant-system nose-mount reefers for Arkema had the same concern about the new, redundant-system window-frame reefer. From all vendors, the stated reasons for this were the additional research, engineering, first-time setup and manufacturing issues, system modification, and performance testing required. It was noted that it is always faster and easier to build something that has already been done, versus manufacturing a new design.

If the Safe-Core system equipment is to be delivered to McMurdo by February, 2007, there may be some risk of acquiring the window-frame type of reefer van in time.

In summary, when the window-frame reefer is compared to the nose-mount reefer, some negative aspects are apparent with the window-frame system:

- Compared to the recommended nose-mount reefer described in Section 1.5.5.1, the window-frame reefer's side door access may result in possible loading and unloading inefficiencies at McMurdo and NICL, and possible parking and access issues at McMurdo.
- The required removal of the two clip-on backup generator sets from the window-frame reefer in preparation for vessel onload (with reinstallation at Port Huememe) presents a logistical inefficiency, and may result in damage to the clip-on gensets at either location.
- Research for this report has determined that the window-frame reefer with a dual-system configuration has not been designed, engineered, manufactured, tested, validated, or placed into field-service conditions before, by any of the numerous reefer vendors contacted. None of the vendors contacted for this project were aware of other suppliers in the industry who had ever made this redundant-system window-frame reefer. Increased time to engineer, build, and test this reefer design may become a factor.
- There is risk of not having the window-frame reefers on board the American Tern in the Fall of 2006, due to the above issues of this alternative, dual-system window-frame reefer van.

The window-frame reefer system's primary benefits to the USAP for this project is a capital equipment savings of

$112,000 for the four-unit window-frame fleet purchase (compared to a four-unit fleet of nose-mount reefers), and the two additional HD45 ice core boxes that can be placed inside each window-frame reefer (a total of 18 HD45 boxes per unit). This additional storage space can help accommodate a small "surge" of ice cores from other ice core drilling projects.

Despite the financial and storage advantages, the several disadvantages listed above may make the window-frame reefer a less desirable choice for the WAIS Divide project, compared to the recommended nose-mount reefer described in Section 1.5.5.1. Further discussion of the advantages and disadvantages of the two reefer options may be needed between RPSC and USAP.

Note

For the sake of completeness, a third method of reefer cooling system redundancy was explored (liquid nitrogen expanded inside a piping system within the reefer, with the gas then ejected outdoors), but it was deemed too complex and an unnecessary expense given the high level of protection provided by the very reliable, redundant-system nose-mount reefer described in Section 1.5.5.1.

1.5.6 Portable Temperature Recorders

A temperature monitoring device, and improved temperature downloading hardware and/or protocol, is recommended to eliminate the need to open an ice core box or reefer door during the entire journey from the field camp to NICL in Denver. This will help preserve the thermal protection envelope afforded by the proposed Safe-Core equipment (HD45 box and dual-system refrigerated ISO shipping container), and minimize the amount of work (and potential errors) involved with installing and retrieving recording devices numerous times in order to download and review the temperature data. Two new methods to achieve this goal are described below.

1.5.6.1 Escort/REDi (recommended)

The recommended method is to use the new Escort/REDi wireless recording and reading device, distributed by Global Cold Chain Solutions in New Zealand, and Escort Dataloggers, LLC in Washington. This novel and very appropriate system is used extensively in Australia and New Zealand in the chilled/frozen food transport industry, and for pharmaceutical and chemical shipments.

The Escort's small temperature recorder (Figure 5A) is placed inside the HD45 box or refrigerated ISO shipping container, and the attached temperature probe is located where desired. When temperature information is needed, the user walks nearby the HD45 while holding the REDi hand-held radio-frequency reader (Figure 5B) and presses the download button. Sending a radio-frequency signal through the HD45 walls, the Escort recorder information is automatically sent to the REDi reader (Figure 5C) without requiring any doors to be opened, nor requiring the use of cumbersome laptop computers or download cables at the ice core box

Figure 5A. **Figure 5B.** **Figure 5C.**

The user-selectable radio-frequency technology of the Escort/REDi system can transmit signals through most materials (such as wood, glass, or the plastic on the proposed HD45), but cannot "see" through metallic materials such as the reefer walls. For reefer use, the Escort/REDi system is specifically designed to send the data through the "signal-transparent" rubber door gaskets on the reefer. If needed to improve signal strength, a small, water-proof, signal-transparent window (fiberglass, plastic, wood) can be designed into the end or side of the reefer. The wireless transmittal range of the recorder device is from 16-70 meters, depending on obstructions.

After downloading to the REDi reader, the temperature and alarm data can be viewed on-the-spot via REDi's small LCD screen, or the data can be downloaded to a computer for further review and electronic sharing. The same procedure can be used to read the internal HD45 temperature even while loaded inside a closed refrigerated ISO shipping container (with the signal passing through the HD45 walls, and out the reefer's door gasket or "signal window").

Each Escort recorder placed in each HD45 would be assigned a unique ID code, so all HD45 temperature data within a reefer can be captured (and retained in individual files) at one time. It may be useful to have a REDi hand-held reader at each of the critical download and review locations.

Cost of the recommended wireless Escort/REDi system is $10,500, as follows:

$200 per Escort recorder x 35 = $7,000 (1 in each of the 31 HD45 boxes, plus 2 in each of the 2 reefers)
$700 per REDi reader x 5 = $3,500 (WAIS Divide camp, McMurdo, vessel, Port Hueneme, and NICL)

Total = $10,500

The Escort temperature recorder and REDi hand-held reader both have a battery life of at least 2 years, and are rated well within the temperature range of this project. To avoid having to purchase one Escort recorder for each of the 62 recommended HD45 boxes in the project, the small Escort recorders can be returned to McMurdo during WinFly and put into service in each of the 31 HD45 boxes used that season. The 31 empty HD45 boxes on the southbound vessel would not contain temperature recorders.

1.5.6.2 HoboTemp (Alternative)

The alternative method to record and download data is to place the existing Onset "HoboTemp" temperature recorder (Figure 6A) on the outside to the HD45 box, and add a new feature; i.e., a remote-mount temperature sensor inside the HD45 box. The plug end of the sensor wire (Figure 6B) would be permanently routed through the HD45 walls and insulation to the outside, and connected into the HoboTemp's 2-prong thermocouple jack. The thermocouple wires and connections are fragile, so a permanent installation is recommended, rather than removing and reusing the components in other HD45 boxes.

Data downloading takes place (with HD45 door remaining closed) by either wiring a laptop computer to the HoboTemp on the outside of the HD45 box and performing the download, or by removing the HoboTemp from the outside of the box, taking it inside to a computer for the download, then returning the HoboTemp to its mounting location on the outside of the HD45. The HoboTemp recorder does not have a temperature display screen on the device—the temperature history is only known after downloading and viewing on the laptop or office computer. There is no wireless (radio-frequency or infrared) download option available for the HoboTemp.

Figure 6A. Onset HoboTemp **Figure 6B. Thermocouple wire and plug**

The HoboTemp devices are already owned by NICL and USAP, which is appealing, and only the additional thermocouple wiring and connectors are needed to improve the logistics of using the HoboTemp within the ice core boxes. Estimated cost to purchase and install permanent thermocouples and plugs in each of the 62 recommended HD45 boxes is $6,200. This alternative, hard-wired solution doesn't resolve the lack of a readout screen right on the device (for instant review of temperature data), or the requirement of needing a laptop computer right by the side of the ice core box (possibly outdoors in foul weather) during data download.

Looking at the two proposed temperature recording solutions with the long view in mind, the Escort/REDi system appears to be a easier, more integrated, more robust solution, with the additional benefit of being able to download and instantly read the present and historical interior temperature of each closed HD45 with a weatherproof hand-held reader, even if the HD45s are already loaded in a closed reefer van.

Financial Review of Proposed Safe-Core System

1.6 Financial Summary

After researching, analyzing, and comparing numerous new and existing devices and methods to safely and efficiently package and transport the WAIS Divide one-meter long ice cores from the field camp to NICL, a culled list of prospective candidates was developed, which are summarized in Table 1. (See Section 1.7 for details on the financial comparison and culling process).

A "do nothing" alternative is not shown, as it would not resolve any of the numerous issues and challenges previously described.

Table 1. Comparison of WAIS Divide Ice Core Equipment and Transportation Costs

(Based on shipping 1400[i] cores in the maximum years, and 4100 cores total for the project)

	HD45 w/ Nose-Mount **"Recommended Upgrade"**	HD45 w/ Window-Frame Alternative Upgrade	ISC4 w/ Window-Frame Minimum Upgrade
Ice Core Boxes[ii]	$224,000 *(62)*	$224,000 *(62)*	$70,000 *(700)*
Refrig. ISO Container[iii]	$300,000 *(4)*	$188,000 *(4)*	$282,000 *(6)*
Wireless Data Loggers	$10,500 *(35)*	$10,500 *(35)*	$13,500 *(50*
Sub-Total Equipment	**$534,500**	**$422,500**	**$365,500**
Vessel (Payload)	$95,284	$95,284	$75,768
Trucking/Maintenance	$42,000	$49,000	$70,000
Sub-Total Shipping/Maint.	**$137,284**	**$144,284**	**$145,768**
Sub-Total Without Flights	**$671,784**	**$566,784**	**$511,268**
LC-130 Flights[iv]	$341,667 *(15.2)*	$341,667 *(15.2)*	$480,469 *(21.4)*
Total Project Cost	**$1,013,451**	**$908,451**	**$991,737**
Number of flights for project	*15.2*	*15.2*	*21.4*
Number of flights per max. season	*5.2*	*5.2*	*7.3*
Number of 1-m cores per season	*1395*	*1395*	*1400*
Number of boxes at camp	*31*	*31*	*350*
Number of reefers at McMurdo	*2*	*2*	*3*

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[i] Does not factor "surge" ice core capacity costs if drilling exceeds expectations, or for concurrent drilling projects that also require ice core storage and shipment.

[ii] ISC4 = Insulated Shipping Container holding 4 cores. Empty = 40 lbs. Full (tubes and ice) = 140 lbs.
HD45 = High Density box holding 45 cores. Empty = 525 lbs. Full (tubes and ice) = 1785 lbs.

[iii] Assumes the use of a fleet of four custom 40' refrigerated ISO shipping containers (reefer) having redundant cooling units and redundant electrical generator units ($75,000 per nose-mount reefer, or $47,000 per window-frame reefer). Single-unit, non-failsafe cooling and genset systems are not evaluated.

[iv] Assumes operational cost of $45,000 per LC-130 round trip flight between McMurdo and WAIS Divide. Assumes that 50 percent of the flights to/from the WAIS camp are solely dedicated for transport of ice cores. Assumes an LC-130 Allowable Cabin Load of 10,000 pounds when departing the camp.

Additional notes for Table 1:
- Quantities for various pieces of equipment and for LC-130 flights are shown in parentheses.
- All required mechanized lifting and movement equipment already owned by the NSF.
- Parking site preparation for the refrigerated shipping containers required at McMurdo. Location and cost TBD.
- Electrical transformers and/or power cords to be outfitted or installed at McMurdo to provide plug-in power for each refrigerated shipping container. Cost TBD.
- Local Area Network (LAN) temperature alarm-system wiring to be installed from parked refrigerated shipping containers to the Power Plant central alarm board. Cost TBD.

Table 1 shows that the "Recommended Upgrade" system requires a one-time capital investment of $534,500 (for 62 highly-insulated, shock-absorbing HD45 ice core boxes, 4 fail-safe nose-mount refrigerated ISO shipping containers, and 35 wireless digital temperature recorders). Multi-year fees for vessel payload, U.S. trucking, and equipment maintenance adds $137,284, summing to a total project cost of $671,784 (without LC-130 flights factored in). Adding the required 15.2 project flights to transport the ice cores from camp to McMurdo, the total project cost of the "Recommended Upgrade" is $1,013,451.

The various costs of this "Recommended Upgrade" system can be readily compared to the other choices shown in Table 1. Note that for all of the Upgrade options shown in Table 1, half of the total number of boxes and refrigerated ISO shipping containers would be in Antarctica at any given time (parked at McMurdo Station), and the other half would be in transit to or from NICL in Denver, on a continuously rotating schedule.

A total of 1440 one-meter ice cores can be stored in the two nose-mount reefers parked at McMurdo, if both are loaded with sixteen HD45 boxes. If needed, an additional refrigerated 40' ISO shipping container and sixteen HD45 boxes can be purchased to accommodate a "surge" of up to 720 extra ice cores (per reefer van) from the WAIS Divide project or other concurrent drilling programs.

Each HD45 box costs $3,600, and a nose-mount, redundant-system, 40' ISO shipping container (which can hold up to sixteen HD45 boxes - 720 one-meter cores) costs $75,000. The alternative window-frame 40' reefer costs $47,000 each, and can hold up to eighteen HD45 boxes (810 cores), thus allowing a bit of "surge" capacity for additional ice cores if needed.

Note

As an alternative method to accommodate a "surge" of other ice cores, a third reefer and empty HD45 boxes from NICL could be staged in Christchurch, NZ and flown to McMurdo on a C-17 aircraft early in the season, at a round-trip flight cost of $77,000. Depending on many factors, it may instead be best to purchase extra "surge capacity" equipment (as described above) rather than using the C-17 option, to avoid displacing other critical or time-sensitive USAP supplies that can only be transported via the C-17.

There is no inexpensive manner in which to improve the present ice core transportation shortcomings. The "Recommended Upgrade" option (nose-mount redundant-system reefers, HD45 boxes, Escort/REDi temperature recorders) has the best overall technical merits, but costs $105,000 more (programmatically) than the less technically desirable "alternative upgrade" (though the window-frame reefer can store an extra 90 cores per reefer, if desired).

And the “minimum upgrade” option shows that more programmatic money would be spent by continuing to use the inexpensive ISC4 boxes than with the “alternative upgrade” approach, even though less capital expenditure for new equipment is needed (because six more LC-130 flights are needed, which negates the equipment savings). It is also critical to note that continued use of the existing cardboard ISC4 boxes may prove detrimental to ice core integrity (physical and thermal) and personal health and safety.

In the end, though the “Recommended Upgrade” option is programmatically more expensive than the other options shown in Table 1, it has been highlighted as “Recommended” because it will efficiently, reliably, and safely resolve all identified concerns with the existing ice core transportation system, while significantly streamlining the existing process. The extra cost to purchase the recommended nose-mount reefers will be worth it in the long run.

Note

For more details of the recommended, more expensive nose-mount refrigerated ISO shipping container (rather than the less-expensive window-frame version), please see details in Section 1.5.5. To better understand the reasons for recommending the more expensive HD45 box (rather than the cardboard ISC4 box, or other explored options), see Sections 1.5.2-1.5.4, and also see Appendix E.

Given the above financial overview and recommendations, NSF will now need to review these proposed Safe-Core transportation options, and decide for themselves which upgrade system best fits their long-term logistical plans, while also remaining within the USAP science, equipment, and operations budgets. Further details of the financial evaluations and decisions are provided in Section 1.7 below.

1.7 Details of Financial Decision Basis

The transportation target for the WAIS Divide project is to safely ship *at least* 1400 (and up to 1500) one-meter long ice cores from the field camp to NICL each year during the most productive phases of the project. Some number of core boxes, pallets, flights, and reefers are required to achieve this goal.

To determine the optimal number of cores delivered and the best way to do so, on a programmatic level, the following matrix of variables were extensively researched and analyzed:

Boxes	Number of Cores/Season	LC-130 ACL	Reefer Vans
ISC4 (stacked)	1400	10,000 pounds	20’ Nose-mount
ISCR4 (stacked)	1500	15,000 pounds	40’ Nose-mount
HD20 (1/2 height, “stacked”)			20’ Window-frame
HD25 (1/2 height, “stacked”)			40’ Window-frame
HD30			
HD35			
HD40			
HD45			
HD50			

This comprehensive matrix of choices required the use of a large and intricate Excel spreadsheet to link, manipulate, and examine the 144 permutations of the above variables (with correlating logistical and financial details). After review and comparison, many of the combinations were obvious “non-starters”, either financially or technically, and were culled from further consideration. Examples of culled “non-starters” include:

- 20-foot “nose-mount” reefer (poor interior space efficiency)
- 20-foot “window-frame” reefer (poor interior space efficiency)
- HD25 “half-height” box (too tall for LC-130 when stacked, sub-optimal space efficiency and thermal performance)
- HD30, HD35, HD40 “medium-height” box (high cost/core, poor space efficiency)
- HD50 “full-height” box (too tall for LC-130, too heavy for optimal ACL loading)

After this initial culling, the best remaining options were again explored, refined, and further culled, resulting in the choices shown in the following charts (Fig. 11A and 11B):

Note

The itemized costs shown in Figs. 11, 12, and 13 include the following fees (rental costs are per year):

- 40' window-frame reefer purchase: $47,000 each
- 40' nose-mount reefer purchase: $75,000 each
- Trucking rental fee (40' – 48' flatbed truck): Port Hueneme to Denver: $2,000
  (estimated trucking fee - need firm quotes)
- Denver to L.A. Reefer Maintenance Facility: $2,000
  (estimated trucking fee - need firm quotes)
- L.A. to Port Hueneme: $500 (estimated trucking fee— need firm quotes)
- Clip-on genset road rental: $2,000/week total (for window-frame reefer only)
  (estimated rental fee for 4 gensets— 2 per window-frame reefer)
- Nose-mount or window-frame reefer maintenance: $1,500/year.
- Vessel shipping fee: $0.42/lb of payload inside each reefer. (Reefer tare weight is not charged).

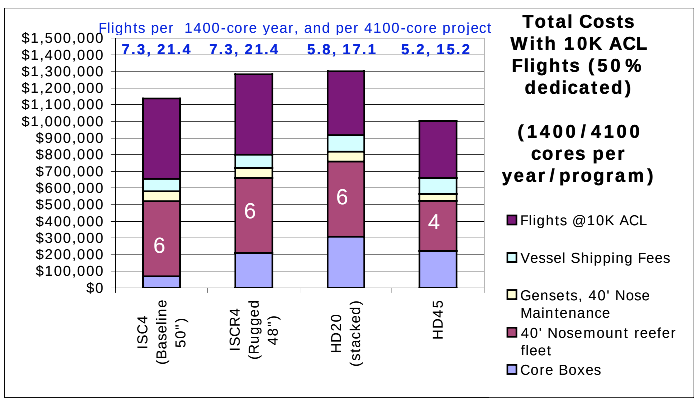


Figure 11A. 1400 cores/season

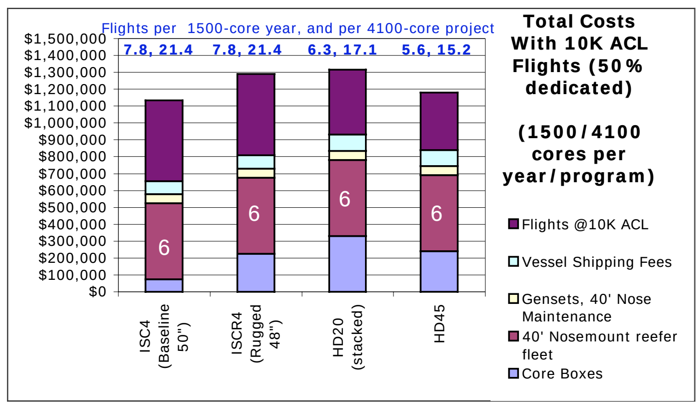


Figure 11B. 1500 cores/season

Figures 11A and 11B show that, of the choices remaining after significant culling, the HD45 core box option induces the lowest overall transport program cost compared to using other box sizes, no matter the number of cores removed per season (1400 or 1500). In fact, looking at left-hand chart (Figure 11A), the HD45 with nose-mount reefer provides a programmatic savings of almost $150,000 compared to using the present ISC4 cardboard boxes with nose-mount reefer, when all costs (including LC-130 flights) are tallied.

Figures 11A and 11B also show that moving 1400 (Fig. 11A) instead of 1500 (Fig. 11B) cores per season for the four different box sizes requires fewer *seasonal* flights, the same number of programmatic flights (see row of numbers across top of chart), and fewer of the preferred 40' nose-mount reefers for the HD45 choice (see white numbers within vertical bars). Thus, the ISC4, ISCR4, and HD20 box candidates will be removed from contention at this time, as will the 1500 core-per-season transportation rate, to help the best solution become more obvious. Nose-mount reefers versus window-frame reefers are compared next.

Figures 12A and 12B show the selection of the desirable HD45 box and 1400 cores/season rate, and compares the two different 40' reefer container styles: nose-mount and window-frame. The cost of the reefer options in these two charts includes purchase of the respective reefer fleet (a total of four reefers, regardless of style), vessel payload fees, genset rental/purchase costs, trucking services charges, and reefer maintenance costs. Note that Fig. 12A includes the cost of LC-130 ice core transportation flights for the project, whereas Fig. 12B has those flight costs removed for the sake of comparison.

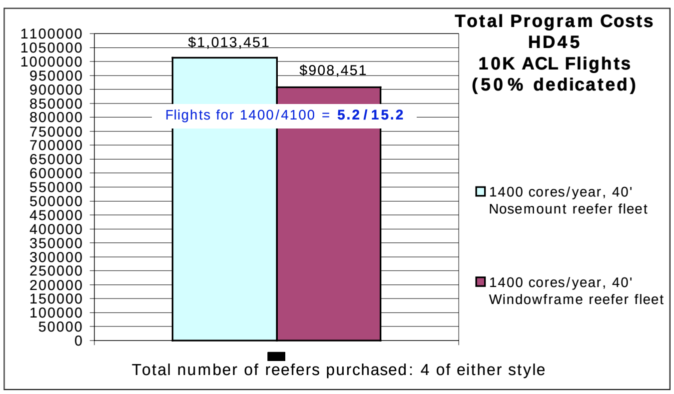


Figure 12A.

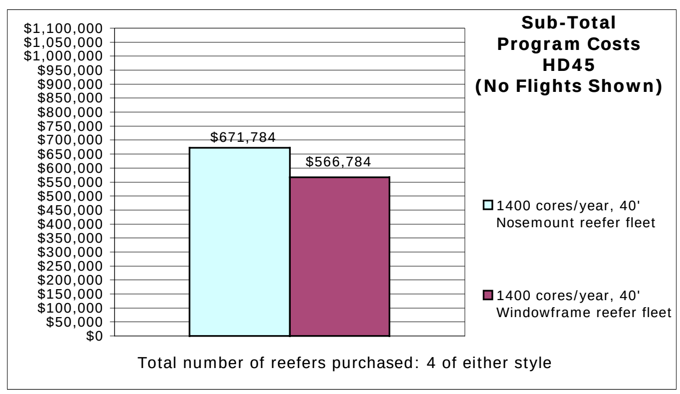


Figure 12B.

An LC-130 field camp departure ACL of 10,000 pounds is chosen because it is the typically-expected minimum Allowable Cabin Load at the 5,700-ft high WAIS Divide camp*. Each flight shown to and from the camp is estimated to cost $45,000, with only half of those flights assumed to be flown strictly to retrieve cores—these flights have thus been termed "50 percent dedicated", though the actual percentage will likely be different during any particular season.

Note

If the WAIS Divide transportation program is fortunate enough to have LC-130 ACL capacity of 15,000-pounds for the entire project rather than the 10,000-lb ACL that has been estimated, the only thing that would change is the number of seasonal and total flights, and the associated reduced flight costs. For 15,000-lb ACL, only 3.4 seasonal flights would be needed (rather than 5.2), and the project would require just 11.4 flights to remove 4100 ice cores from the camp (rather than 15.2). Using the "50 percent dedicated" flight cost calculation method, $85,417 would be saved due to fewer flights if the entire project has 15,000-lb ACLs while departing the camp with ice cores.

As the charts in Fig. 12A and 12B show, with or without LC-130 flights, the capital expenditure for the nose-mount upgrade option is $105,000 more than the window-frame upgrade option. But as explained in Sections 1.5.5.1 and 1.5.5.2, the nose-mount reefer is a better technical and logistical choice for the program than the window-frame reefer, and will thus be retained as a contender.

Figures 13A and 13B explode the charts in Figures 12A and 12B to further itemize the project-level constituent costs associated with the nose-mount and window-frame reefer options (when used with the recommended HD45 box, at the optimal 1400 core/season transport rate, at 10,000-lbs ACL departing camp).

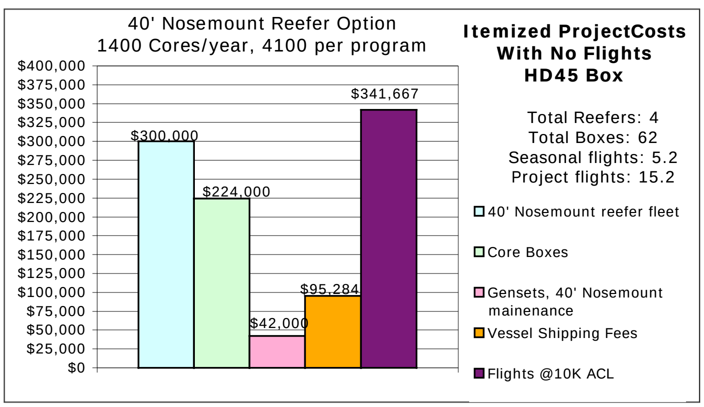


Figure 13A.

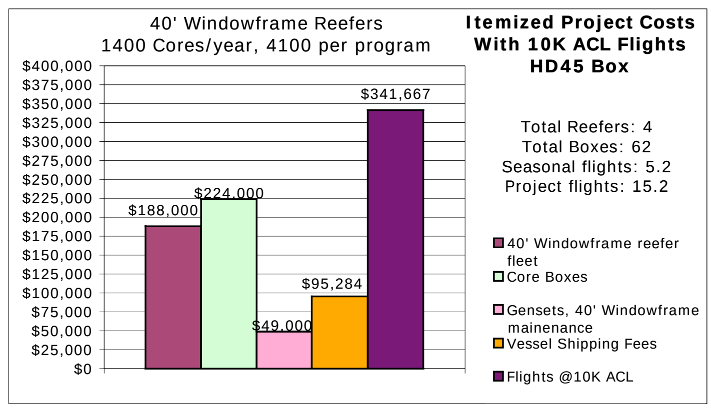


Figure 13B.

It is clear from Figures 13A and 13B that the biggest difference in cost between the two choices (nose-mount vs. window-frame reefer vans) is the purchase price of the different styles of reefers, as seen in each chart's left-most vertical bar.

Though the window-frame reefer can hold 810 ice cores (compared to 720 ice cores in the nose-mount reefer), there are several negative technical and logistical issues with the less-expensive window-frame reefer (discussed in Section 1.5.5.2) that seem to make the more expensive 40-foot nose-mount reefer option a more desirable and well-integrated choice for the overall program.

There is no inexpensive manner in which to improve the present ice core transportation shortcomings. The "Recommended Upgrade" option has the best technical merits, but costs $105,000 more (programmatically) than the less technically-desirable "Alternative Upgrade" using the higher-storage capacity window-frame reefer van. The "Minimum Upgrade" option, with window-frame reefers and existing ISC4 boxes, shows that more programmatic money would be spent by continuing to use the inexpensive ISC4 boxes than with the Alternative Upgrade approach. However, the continued use of cardboard ISC4 boxes may prove detrimental to ice core integrity and personal health and safety.

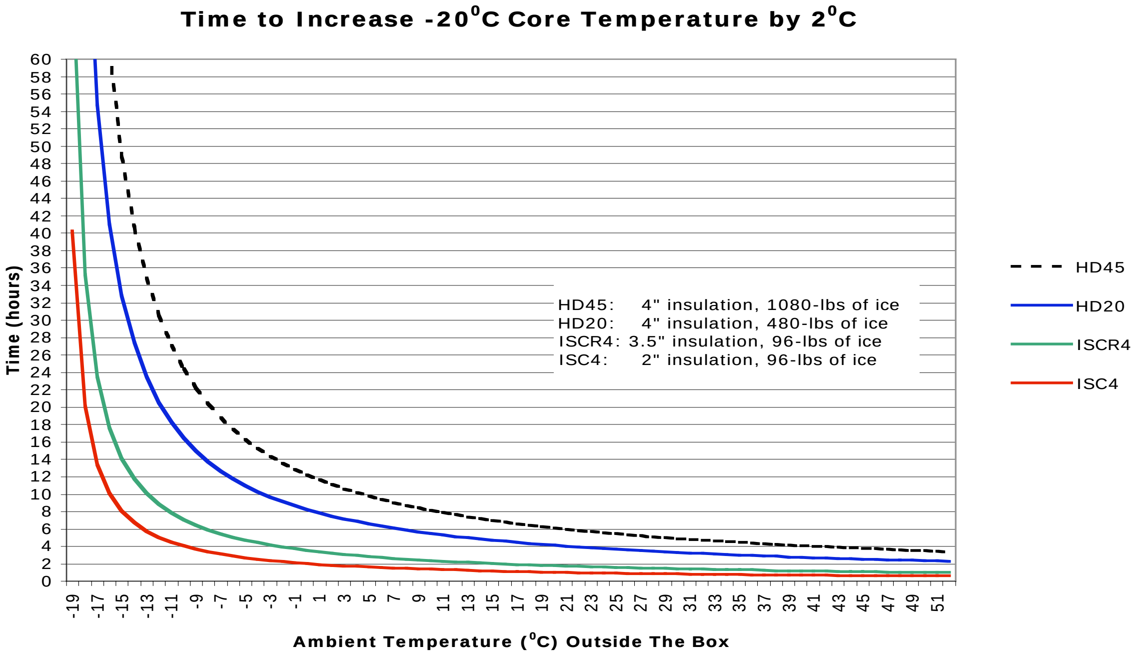
The nose-mount reefer with HD45 box is thus deemed the "Recommended Upgrade" for the proposed Safe-Core system, but the final choice between using nose-mount or window-frame reefers can be further explored by USAP and RPSC after review of this report, and with more input and discussion from all parties.

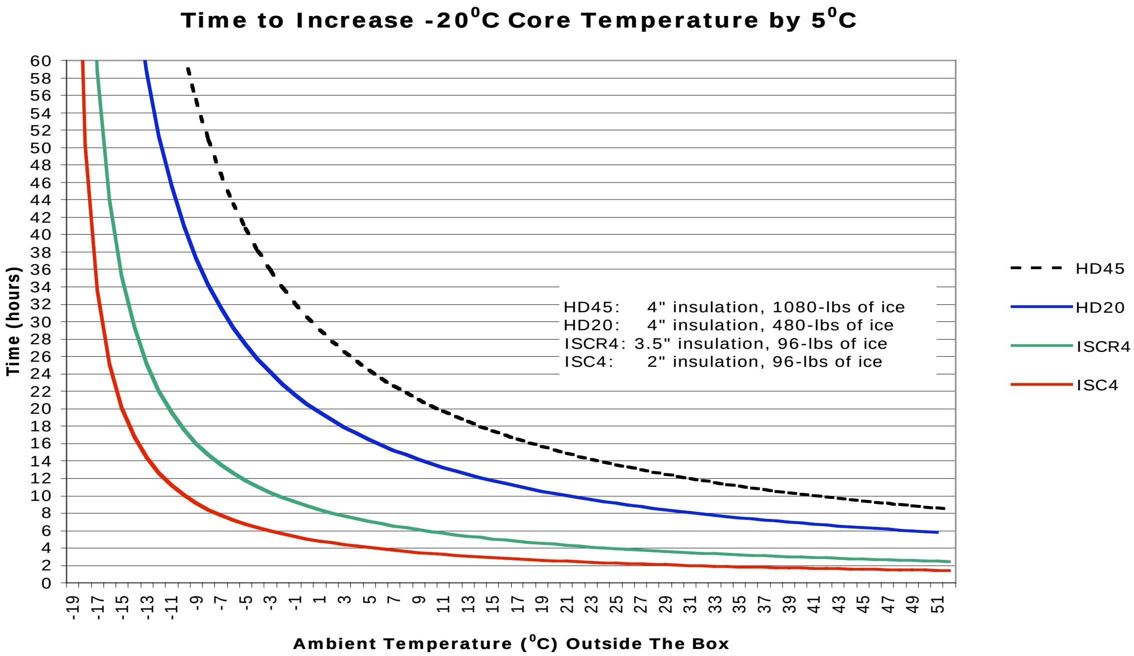
Overall, regardless of the final details of the Safe-Core equipment, logistics, and system decisions, when compared to existing equipment and procedures, the proposed large-format, high-density HD45 ice core transport boxes, redundant-system reefers, and closed-door-download temperature recorders will streamline the entire transport and logistics process, prevent injuries (due to mechanized rather than manual lifting), safeguard the ice cores from science-altering temperature excursions, and prevent ice core damage from shipping and handling abuses.

The NSF will need to review these proposed Safe-Core transportation options, and decide which upgrade system best fits their long-term logistical plans, while also remaining within the USAP science, equipment, and operations budgets.

Appendix A: Ice Core Warm-up Charts

The following two charts show that the ice core box insulation thickness, the outside area of the box, and the mass of ice in the box, are the major factors that determine the -20° C ice core warm-up time, when the box is placed in relatively warmer ambient conditions.

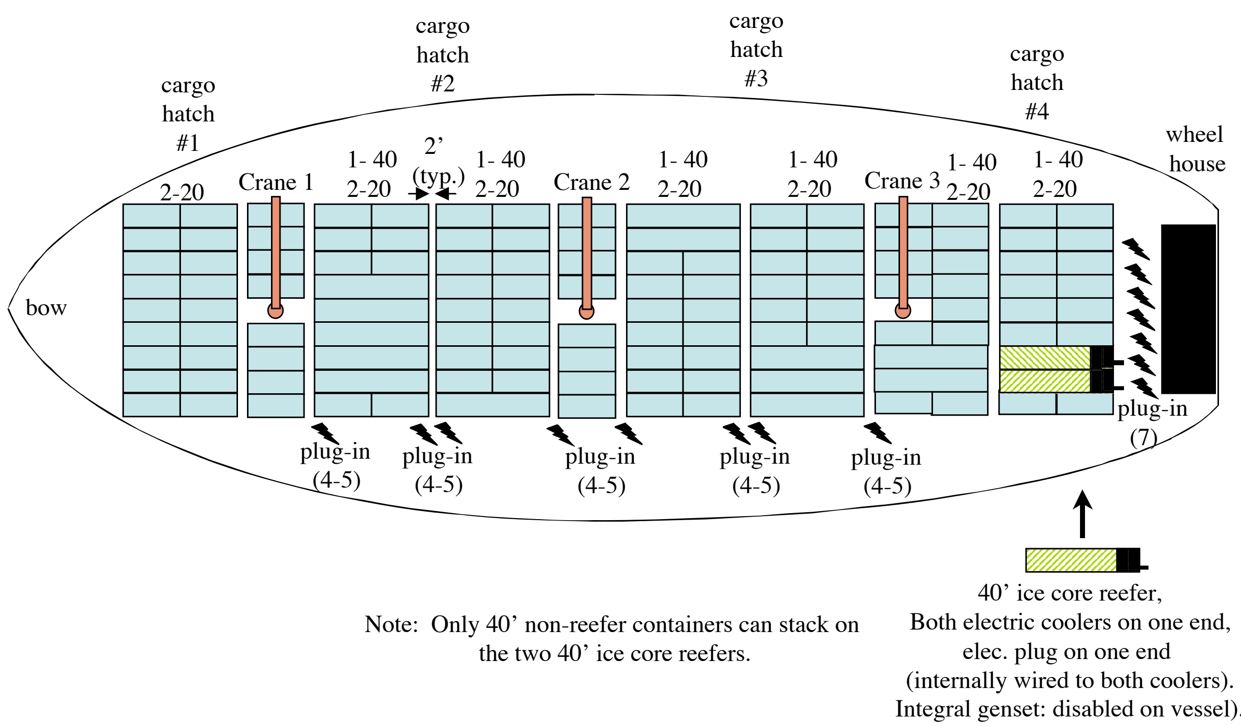




Appendix B: American Tern, Top Deck (Cargo Hatch) Layout

The sketch below represents a possible placement location on the American Tern container vessel for two, redundant-system, refrigerated ISO shipping containers. In this sketch, two nose-mount reefers are shown (in stripes), with their cooling units and gensets all on the same end of their respective container frames.

Northbound American Tern
Two 40' Dual Reefers (Both coolers on same end)
(With Rear Doors - no access)



Appendix C: Handling and Transport Equipment—Lifting Capacities, Weights, and Dimensions

Note

Available USAP equipment may need to be replaced over this several-year WAIS Divide drilling project, for various reasons. It is critical that any future changes proposed to these payload, lifting, and trucking devices address the impact to this proposed WAIS Divide Safe-Core ice core transportation plan. Any new equipment must meet the specifications shown below in order to allow the Safe-Core transport system to continue to operate in a safe, integrated, and efficient manner as designed.

Items shown in *italics* are the backup devices for the primary transport equipment.

1, 2, etc: Number required for project.

O = Owned or contracted by USAP or NICL already.

R = Required for the project; must be purchased or rented.

Ice Core Tube: (metallized cardboard)
4100, R
Dimensions: 5.125" ID x 5.575" OD x 42.25"L (.312" wall thickness)

HD45: (High Density Box for 45 Cores)
61, R
Empty Weight (cushions and partitions, but no tubes): 525 lbs.
Full Weight (cushions and partitions, 45 ice cores in tubes): 1785 lbs.
Dimensions: 49"L x 40"W x 74"H

Refrigerated ISO shipping Container ("Reefer"), Nose-Mount or Window-Frame style:
4, R
40' long, redundant cooler system, redundant genset system
Power: Dual-voltage transformer: 220-240/440-460V, 3-phase, 60 hz. (Amps or KVA TBD)
Max. Payload: 35,000 lbs.
Tare weight: 12,000 lbs.
Max. Gross Weight (within McMurdo and U.S. Dept. of Transportation truck limits): 50,000 lbs.
Floor capacity: 3100-lbs+ per HD45, rolled with standard wheeled pallet jack.
Door Opening: 91"H x 91"W, double swing-out.
Door Location: Nose-Mount style = Rear. Window-Frame style = Side.
Interior Height: 89"H Usable: 84" (minimum 5" clearance to ceilings)
Interior Width: 91"W Usable: 86" (minimum 2.5" clearance between cargo and each wall)
Interior Length - Usable: 33'6" (nose-mount). 36'6" (window-frame).
Number of HD45 boxes inside: 16 (nose-mount). 18 (window-frame)
Number of ice cores inside: 720 (nose-mount) 810 (window-frame)
Side Fork Pockets: Each Pocket: LxWxH: Spacing: Outer Width:

AFP: (463L Air Force Pallet)
4-10, O

AF pallet
Floor dimensions: 108"L x 88"W x 2.25"H
Usable dimensions: 98"L x 84"W x 76"H (above AFP floor) (or 95"H if not on ramp)
Desired maximum AFP payload capacity (with straps and nets): 7,500 lbs.
Max allowable AFP payload capacity (with straps and nets): 10,000 lbs
AFP tare weight (each AFP): 290 lbs.
Strap and net weight (per AFP): 65 lbs.

Gross Weight:	One AFP	Two AFPs
	1 HD: 2,140 lbs.	1 HD: 4,280 lbs.
	2 HD: 3,925 lbs.	2 HD: 7,850 lbs.
	3 HD: 5,710 lbs.	3 HD: 11,420 lbs.
	4 HD: 7,495 lbs.	4 HD: 14,990 lbs.

Figure C1. 463L Air Force Pallet (AFP)

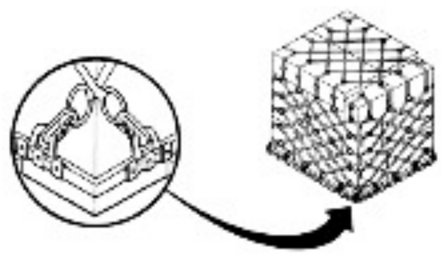


Figure C2. AFP with cargo, straps, and net

Camp:

1, O: Cat 953C SLGP Fork Loader lift capacity: 10,000 lb. Tow capacity: 40,000 lbs.
Each Tine: LxWxH: Spacing: Outer Width:
1, O: *Tucker SnoCat* Fork lift capacity: 2,500 lb. Tow capacity: TBD lbs.
Each Tine: LxWxH: Spacing: Outer Width
1, R: Pallet jack capacity: 5,000 lbs. Each Tine: LxWxH Spacing: Outer Width:
1, R: Floor-Rolling Gantry Hoist capacity: 10,000 lbs. Hook Diameter:
1, R: Floor Roller-Set capacity: 15,000 lbs.
Arch double-door dimensions: WxH:
Number of AF Pallets inside -20° C staging area: 2 (with or without HD45s on board)
1st Floor capacity: Point: Distributed: Rolling Load:
1, R: Elevator capacity: ~5,000 lbs. Note: HD45 Boxes will *not* be lowered into the camp "basement" due to basement space constraints.

LC-130 Hercules Aircraft:

Theoretical Max. ACL at WAIS camp: 22,300 lbs.
Allowable Max. ACL at WAIS camp: 15,000 lbs.
Probable ACL at WAIS camp: 10,000 lbs.
AF pallets per flight: 2 desired, 3 Max, always within aircraft ACL and balance limits.

McMurdo Airfields:

1, O: Cat 988 Fork Loader capacity: 28,000 lbs. Each Tine: LxWxH: Outer Width:
3, O: Cargo Delta flatbed truck capacity: 27,000 lbs.
1, O: *Cat 966 Fork Loader* capacity: 22,000 lbs. Each Tine: LxWxH: Outer Width:
1, O: *Cat 950 Fork Loader* capacity: 16,000 lbs. Each Tine: LxWxH: Outer Width:

4, O: Volvo Flatbed Truck (20' or 40' container-capable) capacity: 45,000 lbs. Platform: LxW:
This truck used on snow??
1, O: *Tucker SnoCat* Fork lift capacity: 2,500 lb. Each Tine: LxWxH: Outer Width:

McMurdo Townsite:
Power: 460V, 3-phase, 60 hz, (TBD) amps
1, R: Pallet jack capacity (inside reefer): 3,000 lbs. Each Tine: LxWxH: Outer Width:
1, O: CAT IT28 Fork Loader capacity: 7,500 lbs. Each Tine: LxWxH: Outer Width:
4, O: Volvo Flatbed Truck (20' or 40' container-capable) capacity: 45,000 lbs. Platform: LxW:
1, O: FatCat container handler capacity: 60,000 lbs. Attachment: Standard ISO Twist-Lock.
1, O: *MK4 Fork Loader* capacity: 4,000 lbs. Each Tine: LxWxH: Outer Width:
1, O: *Tucker SnoCat* Fork lift capacity: 2,500 lb. Each Tine: LxWxH: Outer Width:
1, O: *Grove crane* capacity: 150,000 lbs.
1, O: *Mantis crane* capacity: TBD lbs.

Vessel (American Tern):
Power: 440V, 3-phase, 60 hz
3, O: Crane capacity: 60,000+ lbs. Attachment: Standard ISO Twist-Lock.

Port Hueneme:
Power: 220V, 3-phase, 60 hz
1, O: Crane capacity: 60,000+ lbs. Attachment: Standard ISO Twist-Lock.
2+, O: Container handler capacity: 60,000+ lbs. Attachment: Standard ISO Twist-Lock.

Over-Road to NICL:
2, R: 40'-48' flatbed or chassis air-ride truck/trailer capacity: 45,000 lbs.

NICL:
Power: 230V, 3-phase, 60 hz
1, O: Cat FC40 Fork Loader capacity: 10,000 lbs. Fork: LxWxH: Outer Width: Adj.
1, O: Pallet jack capacity: 5,000 lbs. Fork: LxWxH: Outer Width: 27"
1, O: *Drexel SLT30 Fork Loader* capacity: 10,000 lbs. Fork: LxWxH: Outer Width: Adj.
Loading dock door dimensions: 11'11"W x 10'H
Ramp Plate dimensions (metal edge to metal edge): 82.5" W
Distance between Ramp Plate edge and Concrete Sidewall: 28"
Core storage room door dimensions: 8'W x 8'H
Core processing room door dimensions: 39"W x 78"H

Appendix D: Partial List of Potential Vendors

Redundant Refrigerated ISO Shipping Containers (Nose-Mount and Window-Frame)

Seabox (Window-frame only)
856-303-1101 Bob Welsch

RCS Group
800-766-1924 Mike Alecock

Sonic Enclosures
604-946-6100 Stan King

ThermoKing (cooling unit and genset manufacturer)
952-887-2200

Arkema Group (Nose-mount system owner)
302-477-1745 Bill Schlifke

Ice Core Box/Vault

Dometic S.a.r.l. (rotationally-molded plastic)
540-720-8400 (U.S. distributor - SintPlast/KC (Charlie Velez))

ThermoSafe (fabricated cardboard - ICS box only)
800-323-7442

ATS Cases (fabricated wood, metal, plastic)
800-451-4242 Ron Orlando

Sonic Enclosures (fabricated wood, metal, plastic)
604-946-6100 Stan King

Thermal Insulated Systems (fabricated metal, wood)
714-674-1804 Joe DiBenedetto

Bellcomb (Honeycomb panels)
763-201-6576 Steve Munz

F.P. Woll and Co. (Rubberized Fiber)
800-637-9655 Steve Woll

Flextron Industries (Rubberized Fiber)

610-459-4600

Temperature Recorders

OnSet (HoboTemp, portable wired)
508-759-9500

Global Cold Chain Solutions (Escort/REDi, portable wireless)
+61 3 9846-647 (Australia)

Escort Dataloggers, LLC (Escort/REDi, portable wireless)
425-861-9606 (Washington, USA)

Partlow (digital reefer recorder for reefer)
800-390-6405 (Distributer: Danaher Industrial Controls)

Appendix E: Additional Technical Review of Equipment

E1 Tubes

The cardboard tubes used to hold "shallow", "brittle", and "ductile" ice cores have a good history of use with the USAP program. The predominant ice core size for the WAIS Divide project is 4.8-inch diameter x 39.37-inch long (there will be smaller diameter cores shipped early in the WAIS Divide project).

For the WAIS Divide project, the primary tubes to be used will be sized as 5.125"ID x 5.575"OD x 42.25"L.

The tube's cardboard is metallized inside and outside to prevent moisture absorption into the cardboard, the tube walls are 0.312-inch (5/16") thick, the end plates are galvanized steel, and the tube is designed to open via a slip-off, friction-fit cap that fits onto the main tube body.

Shock-absorbing cushions (possibly rubberized fiber) will be placed inside each end of the tube to help protect the core from end impacts and core-sliding during handling and transport.

E2 Core Boxes—Details Of Technical Decision Points

Considerable effort has been put into the research of improved box designs and materials, how the choices would integrate with the rest of the transport system options, and an analysis of the financial and technical impacts of each choice.

After intensive research and analysis, a long list of ice core box contenders (Section 1.7) has been narrowed down to three potential candidates. These three candidates are compared to the existing (baseline) ISC4 cardboard box holding four one-meter long cores – see Figs. E1-E4. The ice core transport box found to have the best cost/performance ratio and best integration with other transport variables, on a programmatic basis, is a large, tall box holding 45 one-meter long cores, known as an HD45. The runner-up candidate is a half-height, stackable version of this box holding 20 one-meter long cores (HD20), and in third place is a small, robust (plastic, wood, or metal) box holding 4 one-meter long cores (ISCR4). Figures E1-E4 below provide a basic visual overview of candidate boxes:

Figure E1.
ISC4 (cardboard)
Box: 50"L x 18"W x 20"H
Stack: 50"L x 36"W x 80"H
Empty Box: 24 lbs
Full Box: 136 lbs

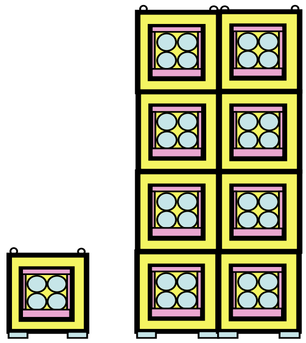


Figure E2.
ISCR4 (robust ISC)
Box: 48"L x 19"W x 18"H
Stack: 48"L x 38"W x 76"H
Empty Box: 30 lbs
Full Box: 150 lbs

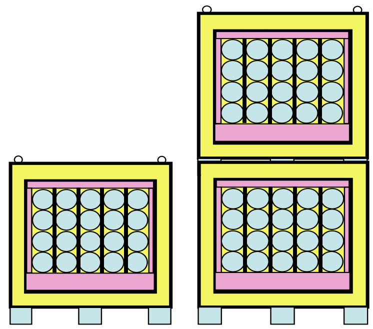


Figure E3.
HD20 (stacked)
Box: 48"L x 40"W x 37"H
Stack: 48"L x 40"W x 74"H
Empty Box: 250 lbs
Full Box: 810 lbs

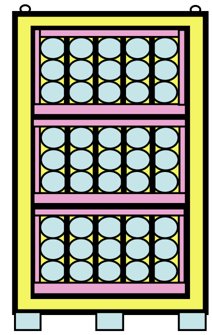


Figure E4.
HD45 (recommended)
49"L x 40"W x 74"H
No Stacking
Empty Box: 525 lbs
Full Box: 1785 lbs

Possible box materials and construction methods of the HD45 box include molded plastic, or fabricated wood, metal, honeycomb, plastic construction. All of the construction choices lend themselves to using high R-value, injected polyurethane foam as the thermal barrier.

Regardless of the material and construction choice to make the required strong and protective box, outer box dimensions are a critical factor in this system. The box must be small enough to efficiently fit into the arch building at WAIS Divide, onto Air Force pallets, into the LC-130 aircraft, into refrigerated ISO reefers, and into the NICL building. At the same time, the box must hold as many one-meter long ice cores as possible for efficient transport to NICL (with minimal box handling), while providing maximum thermal and physical protection to the cores. But, the full ice core box can't weigh so much that it overloads the AFP, LC-130, various fork loaders, flatbed cargo trucks, pallet jacks, and hoists used during transport (see Appendix C for equipment load and dimensional capacities). The optimal HD45 box dimensions and features were developed after several iterations of the following parameters:

A. Optimal fit within the allowable cube of a 463L Air Force pallet (AFP). (Figures E5 and E6).

Based on USAF 109th Air National Guard requirements for deep field cargo on the LC-130 Hercules, the AFP's allowable payload "cube" (volumetric space or envelope placed on the AFP) is 98"L x 84"W x 76"H. This maximum payload “cube” will allow the loaded AFP at the WAIS Divide camp to fit properly in the LC-130 cargo cabin, and abides by USAF aisle clearance and tail-end latrine access regulations inside the LC-130. Note that the allowed horizontal footprint of the payload is slightly smaller than the AFP’s platform size of 108”L x 88”W.

Note

AFPs loaded with full HD45 ice core boxes will be prohibited on the ramp position during McMurdo-bound flights, since the gross weight of the loaded AFP will likely be heavier than the ramp’s 4600-pound in-flight load limit. However, at the discretion of the LC-130 Load Master (and if within load, balance, and other USAF limits), an AFP with empty core boxes (such as on camp-bound flights) may be placed on the sloped ramp.

Figure E5. 463L Air Force Pallet (AFP)

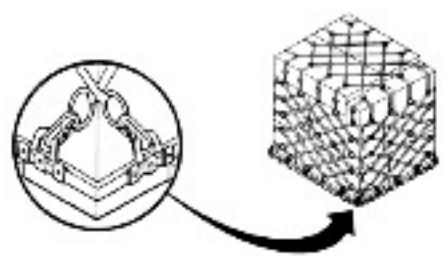


Figure E6. AFP with cargo, straps, and net

B. Optimal payload weight of boxes loaded on the Air Force pallet to stay within AFP gross weight limits.

For the WAIS Divide project, the 5,700’ elevation and high frictional drag of the camp’s snow skiway limits the LC-130’s available ACL (Allowable Cabin Load) to between 10,000 pounds (likely) and 15,000 pounds (less likely) for most of the season.

Note

There is a theoretical, maximum departure ACL of 22,300 pounds from the WAIS Divide camp, but the skiway and weather conditions will rarely allow this amount of LC-130 loading, so this “absolute” limit is not considered in the calculations.

Also, only two HD45-loaded Air Force pallets will typically be on any particular McMurdo-bound flight, because only two loaded AFPs can fit on the floor rollers within the -20°C staging area at the camp as they await the LC-130’s arrival for ice core pickup.

Thus, dividing the available 10,000-lb to 15,000-lb ACL by two AFPs means that each HD45-loaded AFP will be allowed to have an approximate gross weight of between 5,000 pounds (or less) and 7,500 pounds for a typical departure flight from camp. For this report, these are optimal baseline values used to calculate the number of flights needed to fly 1400 to 1500 one-meter cores per season from the camp, and an expected total of 4100 cores for the multi-year project.

C. Maximum weight capacities of the various fork loaders, pallet jacks, hoists, floor rollers, trucks, etc.

The approach used within this Safe-Core proposal is to use as much existing USAP infrastructure and equipment as is feasible, to minimize the WAIS Divide project's financial impact to the NSF. After thorough research, it has been determined that all of the existing USAP, American Tern, Port Hueneme, and NICL cargo handling equipment has enough load capacity and are of the proper dimensions and design to safely and efficiently handle the required tasks. Ice core handling equipment that is presently on order for the drilling camp, as well as the reefers and ice core boxes/vaults recommended in this report, also meet or exceed the required specifications. Contracted (non-USAP) air-ride flatbed trucks used from Port Hueneme to NICL will also need to be carefully selected to meet Safe-Core requirements.

See Appendix C for the list of equipment and capabilities required throughout the Safe-Core transportation process.

Note

It is critical that future changes proposed to the various Safe-Core lifting, trucking, and storage devices first be reviewed to address the impact to this proposed WAIS Divide Safe-Core ice core transportation plan.

D. Optimal number of cores that can be loaded inside the ice core transportation box.

Taking the above driving factors into account (and knowing that a high-quantity, "high-density" (HD) ice core packing arrangement provides several advantages over the present configuration), various horizontal core loading schemes for the HDs have been analyzed in terms of total number of one-meter long cores, packing configuration (tube-above-tube vs. close-pack "honeycomb method), matrix size within the box (for instance, 5 across x 9 tall, (i.e. 5x9), compartmentalization of cores to prevent crushing weight (for instance, 3 compartments of 5x3 matrices), shock and vibration cushioning requirements, overall interior and exterior box size (including insulation, cushions, pallet feet, lifting eyes), etc.

After numerous iterative calculations and decisions with various options of box sizes, ice core quantities per box (from 4 to 50), total box weight, box costs, and numerous inter-related variables from other aspects of the proposed Safe-Core project, the final decision is that a box holding 45 one-meter ice cores in a compact arrangement offers the best overall technical and financial attributes.

The 45 one-meter long cores will be stacked in three separate chambers within each HD45 box (to prevent crushing of lower tubes), and each chamber will be configured as a 5x3 (5 across x 3 tall) matrix of cores in each of the three chambers.

Note

As described in the financial analysis section (Section 1.6), the ice core box size analysis is based on transporting between 1400-1500 cores per year; either number is acceptable to the scientists and NICL staff.

E. Maximum number of boxes (and thus ice cores) that can be placed into a refrigerated ISO container.

Empty space during the ice core transportation process is to be avoided where possible, so as to maximize the number of one-meter cores shipped to NICL per programmatic transport dollar spent. Thus, the HD45 ice core transport box is sized for efficient packing into the refrigerated ISO shipping container (reefer), while still abiding by the reefer's maximum payload limit, and by the required airflow clearances (3"-6") near the reefer's walls, ceiling, floor, door, and the cooler ductwork.

The recommended 40' redundant-system "nose-mount" reefer (with rear doors) provides 33'6" of easily accessed internal cargo space, and can hold up to sixteen of the proposed HD45 boxes (720 ices cores per reefer). Two of these reefers are needed at McMurdo to hold up to 1440 one-meter cores per season.

E2.1 High Density 45-Core Box (HD45), and Logistics Of Use

Figure E7.

Figure E8.

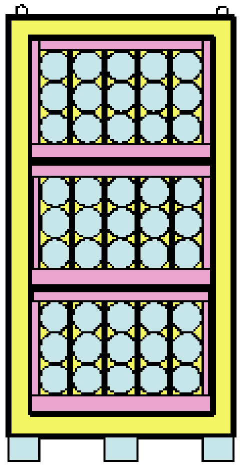


Figure E9.

Figure E10.

A large, durable box (much like a wide, deep refrigerator cabinet (Figs. E7 - E10), the HD45 holds and protects 45 one–meter sections of core in a "high-density", horizontal packing arrangement (hence the nomenclature). There are numerous methods of stacking the cores in the box, including "tube-above-tube" (as shown in Figure E9) and "close-packed" nesting like a honeycomb (not shown). All box dimensions and core loading calculations in this report are based on the tube-above-tube design, as it is the easiest method to implement and use.

The outside dimensions of the recommended HD45 box is approximately 49"L x 40"W x 74"H. The height dimension includes built-in four-way pallet blocks on the bottom, and eye rings on the top capable of hoisting a fully-loaded, 1785-pound HD45. The HD45 can be fabricated using skins of wood, metal, plastic, or honey-comb panels, or can be rotational-molded using durable, linear low-density polyethylene plastic. More details of the proposed HD45 are provided in Sections 1.5.2 – 1.5.4.

E2.2 HD45 Pros:

- Consolidates the cores into a minimum number of boxes (31) that must be loaded seasonally. A total of only 62 HD45 boxes are needed for the project (31 northbound with cores, 31 southbound with empty tubes).
- Endures years of impacts without undue damage to box.
- Isolates cores from transport impact with interior shock/vibration-absorbing cushions.
- Provides the best temperature protection for the cores compared to other box designs and insulation values (see Appendix A).

- Requires the use of mechanized devices to lift and move the boxes. This will significantly reduce the risk of personal injuries resulting from attempts to lift or move them unaided.
- Integrates pallet blocks and lifting rings into the box design.
- Is compatible with all lifting and transport devices (hoists, fork loaders, floor rollers, pallet jacks, etc.) that will be used to transport it in the USAP system, from field camp to NICL.
- Can be either loaded with cores and then hoisted/forked onto an AFP, or hoisted/forked empty onto an AFP and then loaded with cores.
- HD45s can be easily and quickly placed or removed on an AFP as the LC-130’s camp departure ACL (Acceptable Cabin Load) allows.
- Durable door, triplex seal, and robust latches remain tight during the journey, but can be quickly opened to insert or remove temperature monitoring devices, as needed.
- Requires only 31 temperature monitoring devices for a season, with one in each box.
- Any HD45 door on a full AFP load can be fully opened without having to move other HD45s for clearance.
- Maximizes the use of space inside the recommended 40’ refrigerated ISO shipping container.

The HD45 box is designed to fully and efficiently integrate with virtually all aspects of the WAIS Divide ice core transportation project. (Note: One door at NICL may need to be widened to accommodate the 40”-wide HD45, with the door purchase and modification labor estimated to cost up to $20,000. Other NICL core-handling and staging alternatives are currently being explored to avoid widening the NICL door).

E2.3 HD45 Cons:

- Not possible to lift an empty or full HD45 by hand if planned mechanized methods and various backup methods fail.
- Must spend $224,000 up front to design, manufacture, and acquire sixty-two plastic-molded HD45 boxes.

As far as the brief logistics of using the proposed HD45 are concerned (more details are provided in Section 1.4 and Appendix G), each HD45 is picked up and placed on an AFP inside the drilling camp’s -20°C ice core staging area with a small hoist (or outside with a fork loader), either before or after the HD45 is filled with cores. Loading two, three, or four full, 1785-lb HD45s onto an AFP enables a flexible and fast loading scheme into an awaiting LC-130 cargo aircraft.

It also provides an easily-selectable range of LC-130 total payload weights, from 7,140 pounds to 14,280 pounds (before straps and netting) that can be agreed upon between the camp’s cargo master and the LC-130 Load Master. By design, this AFP payload range nicely matches the anticipated LC-130’s 10,000-lb to 15,000-lb ACL as it departs the WAIS Divide skiway. Also, the loaded HD45s on the two AFPs will fit within the “allowable payload cube” dimensions of the LC-130 payload bay.

Once loaded with HD45 boxes, each AFP is forked over to (and into) the waiting LC-130’s cold deck cargo bay, secured to the floor, and flown to one of the three McMurdo airfields. The AFPs are forked off the LC-130 at the McMurdo airfield, forked directly onto a waiting flatbed truck, trucked to McMurdo Station, and the AFP is then forked onto the ground (on wooden dunnage).

One of McMurdo’s fork loaders then lifts each HD45 from the AFP and places it inside the rear door of a pre-chilled 40’ ISO reefer van, and a person inside the reefer with a pallet jack raises and rolls the HD45 to the back of the reefer. The HD45 is then strapped to the unique T-slot floor (which allows airflow under the cargo), and the process continues until all sixteen HD45s are in the reefer.

The reefer has a very unique redundant cooling and power system (described in Section 1.5.5, with two styles available) to obviate the need to remove the HD45s should one cooling unit or electrical genset fail. Once filled with cores at the drill camp, the HD45s are not opened again until reaching NICL.

Upon the arrival of the shipping container vessel at McMurdo in January or February of that season, the full reefer is on-loaded to the ship and plugged into the ship’s power cord. Upon ship arrival at Port Huenmene several weeks later, the reefer is off-loaded and placed on a waiting air-ride flatbed truck for delivery to NICL (with the reefer operating on its own gensets the entire time). The reefer doors are not opened between McMurdo and NICL.

Upon their arrival at NICL in March or April of that year, the HD45 boxes are fork-trucked out of the ISO reefer and placed into the NICL –36°C freezer for storage and processing.

More details of the entire handling, loading, storage, and transport process envisioned with the HD45s and redundant-system reefers are described in Sections 1.4, 1.5, and Appendix G.

E2.4 High Density 20-Core Box (HD20)

Figure E11. HD 20 Box (closed and open)

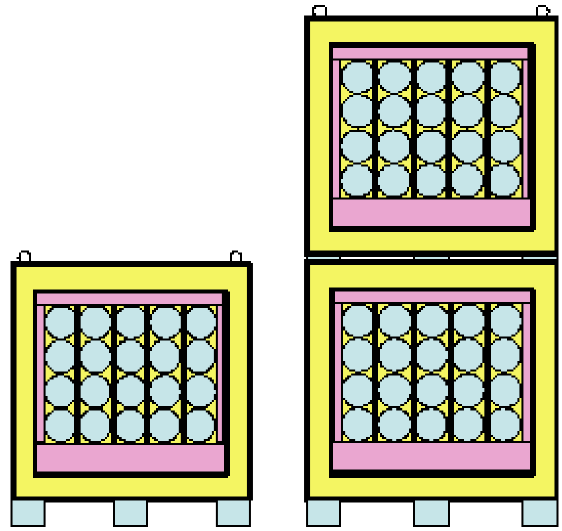


Figure E12. HD20 Box Interior Configuration
Each: 49"L x 40"W x 37"H (outside dims.)
Stack: 49"L x 40"W x 74"H

Similar to the HD45 in design and construction, the smaller HD20 contains 20 one-meter sections of cores each, as demonstrated in Figs. E11 and E12. The shorter ("half-height") HD20 boxes can be stacked as shown in Figure E12, and still be within all required height and weight restrictions for the project. (Note: A taller version, HD25, was evaluated but a "double-stacked" HD25 is too tall for the various height limits. And wider boxes were also evaluated, but didn't fit within the AFP's allowable width envelope).

Each molded-plastic HD20 weighs 810 pounds with ice and other interior components, and a total of eight HD20 boxes (stacked in twos) fit on an AFP. This results in a full AFP payload of 6,480 pounds (two full AFPs per LC-130 weigh 12,960 pounds, without straps or nets). As with the HD45, the number of HD20s per AFP can be easily adjusted to match the LC-130's actual ACL for any given flight.

If molded with linear low-density polyethylene plastic (as described for the HD45), the estimated cost is $2200 for each HD20 (including setup/engineering fees and mold/fixture costs). Fabricated boxes of wood, plastic, or metal cost only slightly less per box than the molded version, but are generally heavier, may have less insulation and air-infiltration integrity, and may be less durable. 140 HD20 boxes would be needed for the project, for a project cost of $308,000.

E2.5 HD20 Pros:

- Smaller HD20 boxes allow fine-tuning of AFP loads to closely match the Herc ACL.
- Smaller HD20 boxes will more easily fit into camp storage areas not suitable to HD45s.
- Otherwise similar to the HD45.

E2.6 HD20 Cons:

- Costs $84,800 more to purchase the required 140 HD20s, compared to the 62 HD45 boxes.
- Less financially desirable than HD45s when compared on a total, programmatic basis.
- Stacked boxes are more easily dropped during lifting than a single tall box.
- Cores will warm 5°C in half the time as compared to an HD45 (see Appendix A).

E2.7 "Robust" 4-Core Box (ISCR4)

Figure E13. Existing cardboard ISC4 stacked 3-high inside reefer.

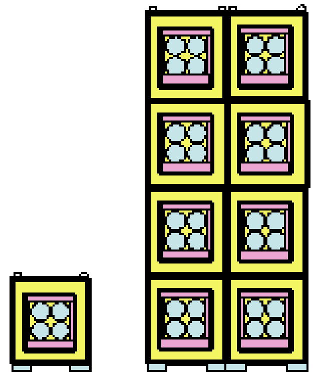


Figure E14. ISCR4 ("Robust")
Box: 48"L x 19"W x 18"H
Stack: 48"L x 38"W x 7

Built a bit smaller (49"L x 19"W x 18"H) and more durably ("robust") than the present cardboard ISC4 box (Figure E13), the candidate four-core, "robust" insulated shipping container (ISCR4, Figure E14) eliminates the insulation, air infiltration, cushioning, and grasping problems known to exist with the cardboard ISC boxes, as described in Section 1.3. The ISCR4 box would be manufactured using similar materials and techniques as the HD45 boxes, but at a much smaller scale. It has a top-opening hinged or removable lid with durable latches and seal, and is designed to hold 4 one-meter sections of WAIS Divide ice cores in 5.575"-diameter tubes.

The ISCR4 has built-in handles, hoisting rings, and top and bottom nesting features to interlock each box in a stack. The stack of ISCR4s will be placed on a separate wooden pallet at the field camp. The ISCR4 is filled with injected polyurethane foam to an insulating value of R20-R25, with no exposed foam edges. The box interior is lined with shock-absorbing rubberized fiber cushions.

A full ISCR4 (with 4 one-meter sections of ice cores) weighs 150 pounds and is picked up and stacked inside the camp's -20°C staging area with a small hoist, or manually stacked by four people in an emergency. Like an ISC4, the ISCR4 is stacked 2 across and 4 high on a wooden pallet pre-placed on an AFP. Each such stack of eight ISCR4s weighs 1200 pounds. The stack is then banded and stretch-wrapped to the wooden pallet to help consolidate and secure the loose boxes. With four stacks packed tightly together on an AFP (128 ice cores), the full AFP payload (with wood pallets, straps, and nets) weighs 4900 pounds.

The full AFP can be forked to the waiting LC-130 at the skiway, as would be done with any of the box designs previously described. The ISCR4 box is sized slightly smaller than the existing cardboard ISC4 to allow the block of four stacks (32 ISCR4s) to fully comply with the AFP's allowable "cube" limit.

To match the actual LC-130 ACL on a given flight, any number of ISCR4 boxes can be removed from any of the four stacks as needed. The ISCR4s are designed to allow mechanized handling. However, because the boxes also have grab handles, it would most likely be picked up and carried by hand (with four people) during such an event. Thus, handling the ISCR4 boxes is apt to become a more cumbersome, dangerous, resource-intensive, and time consuming manual procedure than doing so with the large-format (mechanized-only handling) HD45 boxes. Whether people will ignore their own health and safety when maneuvering and transporting ISCR4s is unknown, but it is a risk because the boxes are just light enough, at 150 pounds, to make two people think they can pick an ISCR4 up by hand, despite the new RPSC lifting limit of 40 pounds per person.

The estimated cost for each plastic-molded ISCR4 is $300 (in bulk purchase, including setup/engineering fees and mold/fixture costs). 700 ISCR4 boxes are required for the project, resulting in a total ISCR4 box cost of $210,000 for the project.

E2.8 ISCR4 Pros:

- Full ISCR4 would be only slightly heavier than present 130-lb cardboard ISC.
- Durable exteriors will handle numerous impacts without undue damage to box.
- Shock/vibration-absorbing cushions inside box will help protect cores from damage.
- Cores warm up less fast in an ISCR4 box than with the existing ISC4 cardboard box (see Appendix A).
- Durable lid, latches, and seal remain tight during journey, but can be quickly opened.
- Handles and lifting rings are integral with the box.
- Can lift box with mechanized lifting devices if desired– less personal injuries.
- Stacks can be pre-placed onto Air Force pallet inside the camp, out of the weather.
- Stacks are less prone to damage due to bundled effect and minimal manual handling.

- Consolidated stacks will be lifted, moved, and placed faster than individual boxes.
- People are accustomed to using this type and size of ice core box.

E2.9 ISCR4 Cons:

- People will attempt to manually lift each 150-pound box up to five-feet high onto the stack.
- The new RPSC lifting regulation requires that 4 people are used to lift each 150-pound box.
- Possible personal injuries due to manual lifting, and possible damage to cores if dropped.
- Cores load from the top of the box; bending motion required during loading and unloading can cause injuries to the ice core handlers, and possible resulting damage to the ice cores if dropped.
- Temperature recorders only can be located in top-most boxes in a stack if mid-transport data download is needed. (Other locations require the disassembly of the stack to download data).
- Cores warm up significantly faster than with the HD20 or HD45 box when in warm air (see Appendix A).
- Separate wooden pallets, banding, and hard-to-handle stretch-wrap plastic is required.

Appendix F: Detailed Description Of Current Ice Core Transport Process* (ISC4 boxes with permanent outdoor freezer and transfer refrigerated ISO shipping containers)

The present USAP method of shipping ice cores across and off the Antarctic continent is by using insulated shipping containers which each hold (typically) four one-meter long ice cores, but may hold up to nine cores if they are of smaller diameter. The box is deemed an “ISC” or “ISC4” for the sake of this report.

The 18”Wx20”Hx50”L ISC4 ice core box is constructed of single-ply, coated, corrugated cardboard inner and outer walls, with standard box flaps on the bottom and top. A 2-inch layer of expanded, open-cell polyurethane foam is injected between the four wall cavities and the bottom cavity (between the inner and outer layers of cardboard). The two top flaps remain un-foamed and hinged for access to the interior space. This design creates a fairly rigid, self-bonded structure, similar to the construction technique of a plywood-foam-plywood structural insulated panel (SIP) used in modern house construction. There are no handles or indents on the cardboard ISC4 box to facilitate grabbing or lifting. The empty box weighs approximately 20 lbs.

Several hundred empty ISC4s are vesseled to McMurdo in ISO shipping containers (non-reefers) in January/February each year. The 20-foot non-refrigerated containers, each holding up to 64 ISCs, are placed on a flatbed truck and driven to a winter storage area in town, such as the Ball Park. The following spring, the ISCs are hand-unloaded from the stored ISO containers, one-by-one, and placed in 4-high stacks on Air Force pallets (AFP), which are designed to fit inside the LC-130 (“Herc”) deep-field cargo aircraft. Thirty-two ISCs can fit on an AFP. The ISCs are strapped to the AFP, and the loaded AFP is lifted onto a flatbed truck by a fork vehicle. Two AFPs can fit on a flatbed truck. The two loaded AFPs are then driven from McMurdo to one of the three nearby airfields. The AFPs are lifted off the flatbed by a fork loader, placed on the tail ramp of the LC-130, and pushed into the plane’s belly on floor rollers. Up to six AFPs can physically fit inside an LC-130 Hercules, but weight and balance limits also apply. The AFPs are secured to the Herc floor and the flight departs for the deep field drilling camp.

Upon arrival at the drilling camp, the AFPs are rolled back out onto the Herc tail ramp and lifted off by the waiting fork loader. Each AFP with its stack of ISCs is then driven to the camp’s ISC storage area, where the cardboard ISCs are hand-unloaded, one by one, into a -20°C dry environment. The ISCs are “cold-soaked” in the -20°C air for a sufficient time to ensure the interior of each box is at -20°C or lower before ice cores are placed inside.

Within the -20°C core processing area at the drilling camp, each processed 4.8”OD x 39.37”L ice core is inserted into a lay-flat polyethylene plastic sleeve/bag, and the bag ends are heat-sealed on one end, and stapled shut on the other end. The bagged core is

* A brief description of this process is also provided in Section 1.3. Also see RPSC document LO-A0109 - Shipping Retrograde Science Cargo – Revision 0, 10/28/03.

then inserted into a 5.125"ID x 5.575"OD x 42.25"L cardboard tube that has metallized surfaces inside and out, and galvanized steel endplates. The tube has a slip-off, friction-fit cap that fits onto the main tube body. A deliberate excess of plastic bag material on the ends of the core fills some of the space in the tube ends and provides some degree of end-shock attenuation, although the amount of plastic cushion is variable and unpredictable. Each bagged & tubed core assembly weighs approximately 28 lbs.

Four tubed (one-meter long) cores are placed horizontally (stacked two-on-two directly above each other) in the ISC, directly on the inner cardboard of the ISC's bottom surface. A large, 1.5"-thick piece of medium-density open-cell foam is inserted into the box on each end of the tube stack to take up some of the space and to provide cushioning within the ISC as the core tries to slide end to end within the tube. In some ISCs, a small, pre-tested/calibrated HoboTemp digital temperature recording device is placed in the cavity on top of the tubes. A large 4"-thick block of foam is then dropped in place on top of the upper tubes, followed by a sheet of corrugated cardboard on top. The box's top flaps are then are closed, and two nylon straps are cinched around the box's girth. The box flaps are not sealed shut with tape because of the frost and snow on the surface. ISCs with a HoboTemp onboard are marked as such for later retrieval and data download to verify proper temperatures are held. A fully-loaded box (4 cores) weighs approximately 130 lbs.

> **Note**
>
> The top and end foam blocks do not fit precisely and tightly into the ISC cavity, and are often placed in ISCs other than the one they were originally fitted to. Also, the cardboard box has some compliance when handled or when under the load of ISCs stacked above it. The resulting ISC deformation and deflection can thus create a non-insulating, air-leaking space between the foam block inserts and the interior walls, which are ultimately connected to the box's top flaps and outside air. This lack of insulation, and possible air intrusion, could create temperature variations within the ISC, and lead to possible warming of the ice core.
>
> In a stacked configuration the top flaps of the box are covered by the flat bottoms of other boxes (except for the top boxes in the stack), and thus the air gap and potential leakage are blocked, and probably only a small amount of air infiltration is allowed into the core area. Nonetheless, it is an area of ISC design weakness and concern. Taping the flaps shut would help reduce air infiltration, but will not reduce the gap of uninsulated air space along the foam block caused by ill-fitted foam or contorted ISCs.

At a typical Herc-supported drill camp, each loaded ISC is then hand-carried to a stack of other ISCs in a temperature-controlled (-20°C or colder) temporary storage area, which is typically a tunnel or covered trench below the snow surface. Within one hour of the pre-scheduled Herc arrival, the pilot verifies to the cargo supervisor that they are on schedule. At that time, a crew of people (at least six) load Nansen sleds with the ISCs, and a snowmobile pulls the loaded sled up a ramp to the surface. From there, another crew of people lift the loaded ISCs from the Nansen sled and hand-carry (2 people per ISC – now required by RPSC to be 4 people) each ISC to a waiting 463L Air Force pallet (AFP), which has been placed near the sled. Once the ISCs have been removed from the -20°C trench, time is of the essence to get them back into the controlled permanent outdoor -20°C freezer at McMurdo, so the workers must move quickly.

Note

The loaded cardboard ISCs each weigh 140 pounds and are slippery and smooth. Using gloved hands, the 2-to-4 person handling team can either tilt the ISC from the stack or floor and get their hands underneath each end to lift it, or can try to grab under or onto the tight straps encircling the ISC to try to gain purchase on the box. Either way is difficult and tiring, especially when this bend-grab-lift maneuver is repeated dozens of times in a rapid manner.

Wearing thick gloves and heavy "bunny" or FDX boots, the handlers walk each ISC to the AFP over slippery plywood and the uneven and variable-firmness snow; there is significant risk of tripping, slipping, or loosing their grip on the ISC and dropping it, especially when in a hurry to not delay the transfer and flight takeoff process. If the ISC falls 3 feet down to the ground (onto plywood or snow), only 2 inches of stiff foam protects the valuable ice cores from the impact. Dropping and banging the ISCs is a common occurrence, and ice core damage has occurred because of it.

The ISCs are then manually stacked up to four high on the waiting AFP; a total load of 32 ISCs per AFP is possible within the dimensional constraints of loading into the aft-end of an LC-130. A full AFP payload of 32 ISCs (containing 128 ice cores) weighs approximately 4500 pounds (well within the maximum allowable AFP payload of 7500 pounds). Only ice cores are loaded on a particular AFP; no mixed loads are allowed.

The final stack of ISCs are strapped to the AFP, netted, and the AFP is winched into the lowered tail ramp (or placed onto a horizontal ramp with a fork loader) of the Herc and rolled into its cargo bay area on the built-in floor roller system. The ice core AFPs are always placed in the Herc towards the back of the aircraft for coldest ambient temperature, and for last on/first off logistics to minimize transfer delays to McMurdo. The Herc cargo bay is pre-cooled to the lowest possible temperature (known as a "cold deck") on the way into the camp, and remains "cold-deck" until the ISCs are removed at one of the McMurdo airfields.

Note

The LC-130 "cold-deck" temperature is variable from flight to flight as it is dependant on outdoor air temperature, but is usually 0°C or lower. The cabin temperature chills from lack of heater output to that area, and from the transfer of interior heat out through the aircraft walls to the outdoor cold air. A HoboTemp temperature monitor is placed on the outside of the ice core cargo for post-flight temperature analysis.

> Herc cabin pressure is at camp elevation during loading, and when the flight takes off, the pressure is allowed to gradually decrease to only 10,000' or so, even when the Herc is at 30,000' elevation. During descent to McMurdo, the cabin pressure is gradually increased to sea-level.

The flight from the WAIS Divide camp to McMurdo is approximately 3-1/2 hours, with an additional 1/2 hour of pre-flight and post-flight operations and maneuvers. The Air Force Load Master keeps an eye on the cargo, and a designated ice-core overseer may be on the flight as well.

Two pre-scheduled, empty, dedicated cargo trucks or Delta flatbed vehicles (one for the AFPs, one for backup) await the arriving LC-130 aircraft at the pre-designated McMurdo airfield. The AFPs with ice cores are removed from the Herc with a fork loader, which then places an entire AFP onto the truck flatbed. Only ice core AFPs are loaded on a dedicated truck—no mixed loads. A logbook of ISC off-load time and other transport details are kept starting at this moment, and the contents of the cargo temperature recorder are also downloaded and reviewed by the Cargo Supervisor.

The two trucks, one with strapped-down AFPs, one empty as backup, are driven from the airfield to the McMurdo town site, where appropriate personnel were previously given notification and expected arrival time, and the pre-chilled freezer was made ready to accept the ice cores. A spare fork loader is placed on standby in case of trouble on the snow road to McMurdo.

In McMurdo, the AFPs are forked onto pre-placed ground-level dunnage near the special permanent outdoor Ice Core Freezer Building's doors (near the Crary Lab cargo doors). The cores are then unstrapped from the AFP and manually carried by two (now four, per RPSC rules) people/box, up the stairs into the freezer. A minimum of six (now twelve) people per off-loading session are required to do the transfer as fast as possible.

HoboTemp recording devices that have traveled along with the AFP cargo (outside the stackes of ISC boxes) are removed, and the temperature data is downloaded and reviewed for temperature excursions above the limit. The HoboTemp devices inside the specially-marked ISCs (red paint on the corners) remain untouched as they continue to record the interior temperatures of their ISCs. Crary Lab personnel note the time of core arrival at the freezer, and check the outdoor freezer temperature twice daily. Also, the outdoor freezer's temperature alarm is remotely monitored at the Power Plant's central alarm board.

> **Note**
>
> The following description of on-loading ice cores to the vessel does not appear to be described in the document LO-A0109—Shipping Retrograde Science Cargo—Revision 0, 10/28/03. There are apparently no written procedures for the logistics of reefer transfer, chain of custody, temperature check and logging, reefer operational checks, and reefer repair parts or procedures.

At the end of the season when the container vessel arrives at Winter Quarters Bay, the boxes are hand-lifted from the freezer one at a time (12 people minimum for the task) onto small wooden pallets that have been placed onto a large "slave" pallet. The slave pallet is driven by fork loader to the nearby Chalet, and the palletized ISCs (8 per wood pallet) are forked off the slave pallet into the awaiting, pre-cleaned, -20°C pre-chilled 20' refrigerated shipping container plugged into the 230-volt 3-phase power cords near the Chalet. In addition to the certain ISCs containing HoboTemp temperature recorders, other HoboTemps are placed in each reefer to provide a redundant temperature record of the contents. Also, the reefer's outside-mounted temperature chart recorder—with digital display and analog historical output (data is not downloadable)—provides triple redundancy on the reefer's immediate and historical temperature.

The loaded reefer is closed up and lifted onto a flatbed truck for transport to the ice pier. From there, the container vessel's crane lifts the reefer into the pre-assigned cargo hatch bay, and the reefer is then plugged into ship's power via a 460V 3-phase, 60 amp power umbilical for the duration of the journey to Port Hueneme, CA.

It is worth noting a few of the American Tern's vessel regulations regarding reefers:

- Reefers are not placed below deck due to lack of ventilation fans and power circuits.
- Reefers are always placed on the cargo hatch deck, in specific locations.
- Reefers are only placed where there are electrical 460V plug-in circuits /cords.
- Reefers always, and only, go on the lowest (bottom) level of a particular container stack.
- A stack of up to four containers is allowed on the cargo hatch (top deck).
- The total stack of containers (1, 2, 3, or 4) can weigh up to 60,000 lbs.
- Only 8'6" tall standard ISO containers are allowed to be stacked.
- A 40' container can be placed on another 40' container.
- A 40' container can be placed on two 20' containers.
- A single 20' container can only be placed on another 20' container.
- Two 20' containers cannot be placed on a 40' container.

Note

These regulations may be different should the USAP contract another container vessel in any particular season. Those future differences are unknown at this time.

The reefer's temperature chart recorder is checked twice daily by the ship's crew. (Note: This is per RPSC's verbal description of the process. No written documentation specifying this protocol has been found during the research for this proposal). If the reefer cooler fails or can't keep up with the cooling demand, there is no backup cooling system on the reefer or ship. The only way to prevent cores from melting is to have the onboard maintenance personnel quickly repair the cooling unit using the spare parts previously stowed on the ship by RPSC, specifically for this reefer.

By design, the cooling units can be fully repaired and maintained from outside the reefer. Thus, ISO reefers are always loaded on only the bottom of a (up to) 4-high stack of ISO containers (60,000 pounds per total stack) so that repair personnel have walk-up access to the end-mounted cooling units and can do their repair work without standing on ladders or scaffolding. Due to the tight fit (1-foot gap) of neighboring reefers or non-reefer containers against the rear door of the ice-core reefer, contents of the ice core reefer are not accessible nor removable while on board. On the vessel, what's in the reefer, stays in the reefer.

If the 460-volt 3-phase power cord/circuit or ship power fails (a highly unlikely event), there is no auxiliary power source to power the reefer cooling units. Only by restoring the ship's electricity to the reefer circuit can the ice cores be saved from excessive warming, or outright melting, during the several-week journey to Port Heuneme, California.

The vessel arrives at Port Hueneme, CA approximately five weeks after departure from McMurdo, with a brief, intermediate stop at Port Lyttelton, New Zealand. The ice core reefer is unplugged and quickly (goal is within 30 minutes) offloaded from the vessel and placed in a staging area. A 230-volt 3-phase power cord is then plugged into the reefer, with power provided via the Port's electrical grid.

The temperature chart recorder paper is replaced with a fresh sheet, and the historical data chart is sent to the USAP cargo supervisor.

A contracted refrigerated container truck (reefer truck) and a redundant reefer truck arrive at Port Hueneme the night before the cores are to be transferred to them. Both truck reefers' interiors are pre-chilled to -20°C and held there for overnight to ensure proper reefer operation.

Note

The following description of driving the ice cores to NICL does not appear to be described in the document LO-A0109—Shipping Retrograde Science Cargo—Revision 0, 10/28/03. The trucking information was verbally shared by RPSC during the research for this project – no formal backup plan was provided to address a problem occurring while on the road.

Early the next day, the ice cores are transferred to the waiting reefer truck, one stack of 8 ISCs at a time. The HoboTemp temperature recorders that were placed in the reefer at McMurdo are transferred into the Denver-bound reefer trucks, and the temperature chart from the now-empty reefer is reviewed and retained by USAP personnel.

Upon arrival at the NICL facility in Denver, the stacks of ISCs on wooden pallets are removed from the truck reefer with a fork truck and driven into the NICL -36°C ice core storage freezer. The circular temperature chart is removed from the reefer recorder and compared to the temperature history downloaded from the on-board HoboTemp recorders.

Inside the -36°C freezer, the stacks of ISCs are dismantled and opened, and HoboTemps are removed from each ISC containing one. All temperature data is downloaded and reviewed for temperature excursions during the entire journey. The rental reefer trucks are then sent on their way, and the ice core journey is complete.

Appendix G: Detailed Description of Proposed Safe-Core Transport System*

G1 Arrival of Custom Refrigerated ISO Shipping Containers (Reefers) At McMurdo

In February 2007, two custom-built, 40' reefers arrive at Winter Quarters Bay via the American Tern container vessel. Each 23,000-lb reefer (containing empty ice core boxes) is loaded by the FatCat container handler (60,000-lb capacity with 20' or 40' spreaders) onto a waiting 40' Volvo flatbed truck (45,000-lb capacity), and trucked up to the front of the Science Support Center (SSC).

> **Note**
>
> Some other possible reefer placement options include parking at or near the following locations: Chalet, Crary Lab, Fire House, permanent Ice Freezer, and Ball Park).

The two reefers are removed from the trucks and lowered onto pre-placed dunnage in front of the SSC, taking up some of the vehicle plug-in rack area.

Once parked at the SSC, the dual-voltage (220-240v/ 440-460v) reefers are plugged into 460-volt, 40-amp power cords from a nearby transformer and distribution box, which were pre-inspected for capacity and wired specifically for these reefers during the 2006/2007 season. A pre-run LAN wire is connected from each reefer to the Power Plant central alarm panel, allowing for remote sensing and reporting of a high-temperature condition inside the reefer (when the reefer monitoring system is armed).

Each recommended "nose-mount", redundant-system reefer (Fig. G1) has two high-capacity cooling units on one end (one primary cooler, one fail-safe redundancy cooler). Each also has an integral power generator within each cooler unit, with a shared fuel tank. Standard, end-wall, swing-away doors are located on the far end of the reefer (which will face Crary Lab and the Chalet when parked at the front of the Science Support Center). More details of the nose-mount reefer are provided in Section 1.5.5.1, and details of an alternative "window-frame" reefer are provided in Section 1.5.5.2.

* A brief description of this process is provided in Section 1.4 (i.e., using the recommended HD45 box with recommended 40' redundant-system nose-mount refrigerated ISO shipping container).

Figure G1. Nose mount Reefer (dual coolers with integral gensets)

Loaded inside each ISO nose-mount reefer are up to sixteen large, super-insulated, reusable plastic ice core transport boxes, termed “HD45” boxes (Figures G2 and G3). Each box can hold up to 45 empty one-meter cardboard ice core tubes in a cushioned, high-density packing arrangement. (For more details of the HD45 box, see Sections 1.5.2-1.5.4).

Each of the two WAIS Divide ISO nose-mount reefers arriving at McMurdo on the vessel thus contains up to 720 empty ice core tubes (with up to 1440 total tubes in the two reefers).

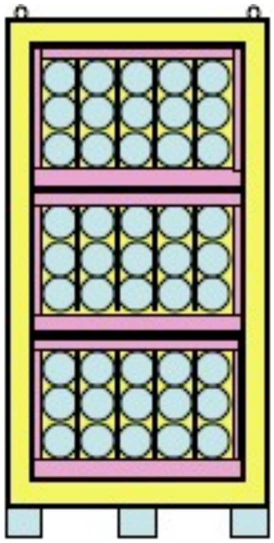


Figure G2.

Figure G3. Rotationally-molded HD45 box

G2 Transferring Ice Core Boxes (With Empty Tubes) To Cargo Delta Truck.

Using a 5000-pound capacity pallet jack inside the reefer, one or two people rolls each 705-pound HD45 (which includes 180-pounds of empty tubes and other interior items) towards the reefer door threshold to allow outside forking access. Using a fork loader (Cat IT28, capacity 7500 lbs; or M4K Pickle, capacity 4000 lbs), each HD45 is individually lifted off the floor of the reefer via the built-in four-way forking feature on the bottom of each HD45. The HD45 is then lowered onto the deck of a pre-placed AFP, which itself is on dunnage at ground level. The four HD45s are oriented and squared up on the AFP so that the HD45 refrigerator-style doors face outward towards the short sides of the AFP (i.e., the HD45s are placed back-to back on the AFP). The four HD45s (with a total of up to 180 empty tubes) are then strapped and netted to the AFP deck.

Each 3175-pound loaded AFP (AFP, four HD45s with empty tubes, straps, netting) is lifted with a fork loader (Cat IT28; 7500-lb capacity, or M4K Pickle; 4000-lb cap.) off the ground dunnage and placed onto a waiting flatbed vehicle (cargo Delta-capacity 27,000-lb cap.) for delivery to a waiting LC-130 at one of the three McMurdo airfields. This HD45 loading and strapping procedure is repeated with a second AFP, which is also placed on the truck's flatbed. Up to three AFPs can fit on a cargo Delta flatbed platfom, although only two are typically carried. Both AFPs (8 HD45s, 360 tubes total) are then strapped to the Delta platform and made ready for travel to the appropriate airfield. Travel over the cinder road, the Transition, and the snow road is done with standard precautions and care for loaded cargo trucks. There is no temperature-sensitive payload on board at this time.

G3 LC-130 Departure From McMurdo Airfield

Upon the cargo Delta's arrival at the waiting LC-130 at either the Ice Runway, Williams Field, or Pegasus Airfield, each 3175-pound AFP is lifted off the cargo delta flatbed by a fork loader (Cat 988; 28,000 lb cap., Cat 966; 22,000-lb cap., or Cat 950; 16,000-lb cap.) and placed on the LC-130's horizontal tail ramp. The AFP is then pushed or winched inside the aircraft bay on sets of aircraft floor rollers designed to interface with the smooth bottom of the AFP. Both AFPs are then locked into position and secured for flight. Up to six AFPs with HDs (or other cargo) can also be placed in the LC-130 belly for the camp-bound flight, at the discretion of the flight Load Master, and depending on the camp-arrival Allowable Cabin Load (ACL) limit.

G4 LC-130 Arrival At WAIS Divide Camp

The loaded LC-130 flight arrives at the WAIS Divide camp 3-4 hours later and stops at the airstrip apron. A fork loader (Cat 953C; 10,000-lb cap., alternative Tucker Sno-cat; 2500-lb cap.) staged at the apron removes the aft AFP from the Herc ramp (which is propped up with braces) and drives the 3175-pound AFP to the entrance of the arch building. Alternatively, the AFP can placed on a large sled and dragged to the arch building with the fork loader or Tucker SnoCat.

G5 Bringing AFPs Inside The Arch Building

Up to three sets of light-weight floor rollers (wheel, rolling-pin, or ball type) are placed in parallel on the load-rated plywood floor just inside the arch threshold behind the double doors, leading to the -20°C staging area near the core processing area. The roller sets have outer guide rails to avoid AFP derailment, and the load-rated plywood floor sections in the -20°C staging and core processing areas are flush with each other to prevent a tripping hazard, and to facilitate the use of wheeled devices throughout as needed.

The double swing-in doors at the end of the arch are opened, and the fork loader places the first AFP on the end set of rollers just inside the double doors.

The first 3175-lb AFP (with the four pre-strapped, empty-tube HD45s) is quickly rolled forward (by hand) into the -20°C staging area by three or four people, and the double doors are closed behind them. In the meantime, the fork loader drives back to the Herc and retrieves the second AFP (with HD45s and empty tubes). Returning to the arch with its new fetch, the fork loader places the second AFP onto the arch rollers, and the process is repeated.

Inside the staging area, the netting is removed from both AFPs, and some of the cargo webbing (running side-to-side over the HD45 doors) is removed. The other webbing running front-to-back over the four HDs remain in place. All the empty tubes are removed from the four HDs and stored in the core processing area.

In the staging area, the door of each AFP-mounted HD45 faces the curved sides of the arch, for the most efficient ice core loading into the HD45s. The HD45's door is specially designed and double-hinged to allow opening for full interior access, yet not interfere with the neighboring, touching HD.

Note

If desired, the use of the arch building's floor-rolling hoist will allow the HD45s to be unloaded from the AFPs and placed right next to the core processing line, for better core-loading efficiency. An empty HD45 weighs 525 pounds, and a fully-loaded HD45 weighs 1785 pounds.

G6 Loading Ice Cores Into HD45s At WAIS Divide Camp

Processed, ready-to-ship ice cores in their protective plastic bags and cardboard tubes are taken from the core processing line (or hauled up from the basement via the elevator) and placed on a heavy-duty rolling cart that can hold 10-25 cores.

The ice core cart is wheeled along the side of the AFP for loading into the desired HD, and the HD door is opened frontward (towards the sides of the arch) as on a refrigerator. Each core is hand-lifted and inserted into one of the three HD45 cavities, end-first and horizontally like a log.

The one-meter cores can be loaded into the HD45 in any order (relative to how they came out of the drill hole) as desired by the scientists, and depending on unloading and processing logistics at NICL. In general, however, cores are stacked from bottom-to-top within each HD45 cavity. Between loading sessions, the front door of the HD45 is closed.

When an HD is filled, the loading of cores proceeds to the next available HD45. Contiguous core segments can also be split amongst several HDs so that an entire sequence of one-meter core lengths are not damaged en-masse should an HD45 somehow (unlikely) get inadvertently overheated or destroyed.

HoboTemp or Escort/REDi temperature recording units are placed inside the HD45, and the device is are turned on to begin recording temperature. (Note that recording device model and protocol are still to be determined).

All the HD45 doors are verified closed, and the pre-placed "retrograde" TCN (return Transportation Cargo Number) tags and HD45 content information are verified correct.

All HD45s are then fully strapped onto the AFP per written Air Force protocol.

G7 Blanket (Optional)

The HD45, with 45 tubes of -20°C ice, is designed to be placed in a +10°C ambient for 8 hours and still not see an internal temperature rise of more than 2°C (see Appendix A). Nonetheless, as an additional thermal and time buffer should the HDs be in the direct sun longer than planned, a large, durable one-piece thermal blanket can be draped over the entire block of four HDs, with the silver, solar-reflective side of the blanket facing up. The blanket is slightly pulled away from areas where the cargo strap buckles are located, so that the flight Load Master can check tightness and adjust the webbing as needed in-flight. The use of a thermal blanket is optional at this time.

G8 Cargo Net

A standard AFP cargo net is placed over the block of HD45s and secured to the AFP per written Air Force protocol.

G9 Spare, Empty HD45 Boxes In Storage At Camp

Spare, empty HD45s are placed for short-term or long-term storage along the walls of the arch area and staging area, in another enclosed structure (to be determined), or stored outdoors, as deemed most suitable at the time. Loaded HD45s cannot be stored in the basement as there is not enough room there.

Wherever stored, the empty HD45s are placed to prevent them from being a logistical nuisance, and to ensure that adequate working space and required emergency egress clearances are maintained at all times. If outdoors, the empty HDs preferably remain under cover and protected in some manner to minimize UV exposure, possible snow infiltration, snow burial, and to prevent them from becoming snow-drift makers.

The HDs can be lifted and maneuvered with the various pieces of equipment at the camp (CAT 953C SLGP fork loader, Tucker SnoCat, pallet jack, overhead hoist, floor rollers, etc.). The entire premise and design of the new HD45 system is to obviate the need to manually lift or move the ice core box, and to use the existing equipment at the camp for all HD45 maneuvers and lifting operations. This is for the sake of safety, injury-reduction, ice core protection, and efficiency.

G10 Full HD45s In Storage At Camp

Unlike empty HD45s, full HD45s (with ice cores) will only be stored in -20°C controlled-temperature areas (perhaps except when being staged for imminent flight arrival). The only such area at the camp is within the staging and core processing areas of the arch building. Storing loaded HD45s outdoors should be prohibited due to highly variable outdoor temperature swings that may compromise core temperatures and data.

G11 Hercules ACL (Allowable Cabin Load)

At this point in the process, each HD45 is loaded with 45 one-meter sections of ice cores and weighs 1785 pounds, gross. Assuming only three HD45s are loaded on each AFP (due to that particular flight's ACL limit), the net payload on the three-up AFP is 5355 pounds. Including the AFP weight, the straps, and the netting brings the gross weight to 5710 pounds.

Alternative, four HDs might be placed on the AFP, so that the AFP payload becomes 7140 lbs, and the four-up AFP gross weight becomes 7495 pounds.

The decision to have three of four HD45s per AFP depends on the LC-130's Allowable Cabin Load (ACL) for that particular McMurdo-bound flight. ACL is the total amount of payload weight allowed in the belly of the aircraft, including other cargo besides the ice cores and all people in the cargo bay. It does not include the tare weight of the AFPs, straps, and netting.

The McMurdo-bound ACL at WAIS Divide changes daily and seasonally based on weather and runway conditions. Thus, the loaded AFP gross weight must be carefully pre-arranged between the flight crew and the camp cargo supervisor to be no more than the available ACL. In the description above, a pair of three-up AFPs weigh 11,420 pounds gross (11,130-lb payload with straps and net). The alternative, a pair of four-up AFPs, weighs 14,990 pounds gross (14,700-lb payload with straps and net).

By removing one or two HD45s per AFP, the load can be very quickly adjusted to suit the ACL at the time. This is a good, flexible arrangement, especially when the removal of an HD45 from the AFP is so easily and safely accomplished. HD45 removal can even be done right at the skiway apron using the fork loader, should it turn out that ACL was misjudged at the last second. Once lifted off the AFP with the fork loader (at the airstrip apron), the extra one or two HD45s are then driven back to the arch and transferred back into the -20°C area to await a later flight.

Note

In early season or after a snowfall, the LC-130 skiway at the WAIS Divide camp (at an 5,700-foot elevation) is apt to be soft and have a fair amount of resistance (surface drag) against the LC-130 skis, requiring a reduction of the departure ACL. Other departure ACL variables include temperature, airstrip hardness, and amount of on-board fuel. Thus, an ACL of approximately 10,000 pounds may be determined at those times to ensure that the aircraft can achieve the required speed to rotate (liftoff) in a safe distance. When the skiway hardens later in the season, an ACL of perhaps 15,000 pounds or more may be available. In supreme (perhaps rare) conditions, an ACL of as much as

22,300 pounds might be available, but this extremely high and unlikely departure ACL is not considered in this ice core logistics analysis. As mentioned several times previously in this report, only realistic camp-departure ACLs of 10,000 pounds and 15,000 pounds are being used in the financial and logistical analysis to determine the seasonal and programmatic costs to remove 1400 cores or 1500 cores in the maximal transport year.

G12 Number of AFPs With Ice Cores On A Departing Flight

Only two AFPs will be loaded (with full HD45s) per departing LC-130 flight, regardless of the number of full HD45s on each AFP. This is the RPSC protocol because only two loaded AFPs can be held within the temperature safety zone of the -20°C staging area for long periods, on the floor rollers, when flights are unexpectedly delayed or boomeranged (sent back to McMurdo before touchdown). If a flight arrives and the loaded AFPs are placed onboard, but the flight is then aborted, the loaded AFPs can be quickly and safely be unloaded from the LC-130 and returned to the -20°C staging area floor rollers until the aircraft is ready for reloading.

G13 Moving The Loaded AFPs To The LC-130 Aircraft

When the arrival of the LC-130 is imminent, each loaded AFP is rolled to the outer door of the arch building door, lifted by the fork loader, and driven (or dragged on a sled if needed) to the side of the skiway apron to await the LC-130.

G14 Loading The Full AFPs Into The LC-130 Aircraft

Upon landing, the LC-130 tail ramp is lowered, and other departing cargo (if any) is first loaded onto the plane towards the front. The amount and type of other cargo is predetermined by the cargo logistics manager for each flight and is coordinated with the number and weight of HD45s that are to placed on the AFPs.

Note

The McMurdo-bound ACL is for the entire aircraft payload (personnel, retrograde waste, equipment, dunnage, etc.), and not just for the AFPs loaded with ice cores.

After that initial cargo is inserted into the aircraft, the two ice-core AFPs are rolled in on the floor-mounted rollers. The ramp is closed, but the aft-most AFP is too heavy to secure on the ramp (which has a 4600-lb in-flight limit). Also, the ramp position imposes other dimensional and clearance restrictions that conflict with loading the most efficient number of cores per flight. Thus, the ramp position is prohibited for stowage of ice cores.

G15 Flight To McMurdo Airfield

When the LC-130 lands at the WAIS Divide camp, the cargo bay is a "cold deck", which means that the cargo area floor, side, and ceiling heaters have been turned off for several hours during flight so that the space is chilled to the minimum possible temperature in anticipation of the ice core cargo to be loaded. An exact cold-deck temperature cannot be specified, since it is based on the varying outdoor ambient temperature at flight altitudes, but it is typically below 0°C.

> **Note**
>
> The incoming and departing flight is not necessarily dedicated for the retrieval of ice cores. There are numerous cargo and passenger retrogrades that need to be made to McMurdo or from/to Byrd Camp or other locations during any given week, so the flight schedule is a constantly-changing load and schedule optimization task. In the financial analysis of this project, only 50% of the flights (at $45,000 per flight) are assumed to be solely for the purpose of picking up ice cores from the camp. This assumption has been termed "50%-dedicated flights" for this report.

The loaded, cold-deck flight departs for McMurdo, and in 3-4 hours, lands at either at Williams Field, Pegasus, or the Ice Runway. The flight crew is in constant contact with McMurdo Flight Ops and the cargo ground operations supervisor, and the landing location is coordinated with the placement of cargo Delta flatbeds (27,000-lb capacity), the appropriate airfield Cat fork loader, and the proper personnel. A backup fork loader and flatbed truck are also on hand should trouble occur with the primary equipment.

Weather, especially ground fog, sometimes changes the landing location at the last moment. If that occurs, the ground crew must be informed immediately, and then must quickly relocate the required equipment and personnel to provide a quick and safe unload and transfer of the ice-core-laden AFPs to the cargo Delta. Each 5,710-lb to 7,495-lb AFP is lifted from the ramp of the LC-130 with a Cat fork loader, placed onto the cargo Delta, are strapped to its flatbed.

G16 Convoy To McMurdo ISO Reefer Van

A convoy of vehicles (the loaded Delta, a spare (empty) cargo Delta, and a fork loader) then departs the runway and travels to the McMurdo townsite. This contingency flatbed/loader arrangement allows transfer of the AFPs to another Delta at any location on the drive should the primary Delta become disabled or stuck. Although the HD45s are designed to allow only a 2°C temperature rise inside (to -18°C) when exposed to +10°C ambient temperatures for 8 hours (see Appendix A), at this point in the journey, half of that time allotment has already been used, so even with the thickly-insulated HD45 design, time is of the essence to get the cores back into a controlled-temperature environment. Unforeseen interruptions or problems that may at first seem minor can often turn into a delay of several hours. Thus, this pre-planned equipment redundancy and transfer capability is necessary to ensure no risk to the ice cores, and to eliminate an unprepared, seat-of-the-pants, reactive response to a transport problem.

The LC-130 landing is scheduled to occur during late night, when the coldest temperatures usually occur on the Ross Ice Shelf. At that time, the snow roads and Transition (at Scott Base) are in their most firm and drivable condition. Even so, in the warmest of times, the Transition sometimes becomes a sloppy mess of snow and dirt and is almost impassible, even to Deltas. It would be prudent to have a second fork loader (Cat IT28, with winch) and flatbed vehicle (cargo delta or Volvo flatbed truck) on the dirt side of the Transition in case all the convoy vehicles become hopelessly mired or damaged at the Transition. If available at the time, a Tucker Snocat with forks or winch would also be useful.

After the Transition is crossed, the cargo Delta drives on the cinder road to two pre-chilled (-30^{0}C), 40-foot, end-loading, ISO reefer vans (with built-in, redundant cooling and power systems) parked on dunnage in front of the SSC building. Other reefer parking locations may be deemed suitable, but there must be a nearby 230V or 460V 3-phase transformer with adequate power capacity (electrical ampacity to be determined) to power the two reefers’ primary cooling units.

G17 Transfer Of Full HD45s Into Redundant-System Nose-Mount Reefer Vans

Each 5,710-lb to 7,495-lb AFP is forked (using the Cat IT28; 7500-lb capacity) down onto leveled dunnage pre-place on the ground, and the netting is removed from one AFP. All HD cargo straps are removed, and the data from the temperature recording devices in each HD are downloaded via either wireless telemetry to a handheld reader or laptop computer (Escort/REDi system – see Section 1.5.6.1), or by plugging in a laptop computer to an external plug on the HD case (HoboTemp system with remote sensor – see Section 1.5.6.2). The least desirable method is to open the HD45 door to retrieve the recorder, due to possible loss of cold air from within the HD45. However the data is downloaded, the intent is to review the trip-temperature data so far, and do a quick review/resolution of any temperature excursions warmer than the -20°C upper temperature limit.

For the first-time reefer loading, the nose-mount reefer van has been pre-chilled to -30°C for 24 hours to ensure that the system works properly and can maintain the desired set point. As described in Section 1.5.5.1, the primary cooler unit on the reefer is set at -30°C, and the backup cooler unit on the reefer at -25°C. Both are colder than the -20°C maximum core temperature to provide a buffer of available temperature excursion within the reefer, but still maintain a safe core temperature of -20°C. Ice cores are not adversely affected if held colder than -20°C; it is when they become warmer than -18°C for more than a couple of hours that damage occurs.

To help preserve the reefers interior temperature at -30°C, the reefer coolers (primary and backup) are shut off when the rear door is opened so that the forced-air circulation does not pump the cold air out (and draw warm air in) through the reefer door opening. This must be a documented procedure.

A 5,000-lb to 8,000-pound pallet jack is forked through the rear doors of the reefer and placed inside. The Cat IT28 lifts each HD45 off the AFP and places it (long-ways with its door facing the IT28) inside the reefer opening, deep enough into the reefer so the pallet jack can be rolled behind the HD45. The HD45 is wheeled on the pallet jack to the far end of the reefer (two abreast), with their doors facing the reefer's rear door.

As each HD is placed on the floor, cargo straps are hooked into the T-slot reefer floor attachment, lifted up and over the HD (and fitted into the webbing grooves molded in the HD), and cinched down into the T-slot floor again on the other side; this is the correct method to secure the HDs within the reefer, as the floor is the strongest point for load attachment.

> **Note**
>
> Using airbags that press between the cargo and the reefer sidewalls risks damage to the walls (buckling, denting) should the cargo shift in transit. Also, using airbags causes interference with proper airflow distribution and uniform cooling within the cargo bay. Airbag dunnage should not be used in these ice core reefers.

To help preserve the cold air in the reefer, the loading should happen in a quick, safe, methodical, pre-planned manner, being sure that each HD is tight and secure in the reefer before proceeding to add the next HD. When finished with that session of loading, the reefer door is closed, and the cooling system is turned back on and verified operational. After several of these reefer-loading sessions, both reefers at McMurdo will be full, and the reefer doors will not be opened again until arrival at NICL in Denver.

Up to sixteen HD45s can be placed inside the each reefer, for a total reefer payload of 720 one-meter ice cores. Two such reefers (if full) would hold up to 1440 one-meter ice cores. When fully loaded with sixteen full HD45s, each reefer will have a payload of 28,560 pounds, and will weigh 40,560 lbs, gross. That gross weight is within the payload capacities of all vehicles and lifting devices required from this point forward (see Appendix C).

G18 Checking Status Of Reefer Van

The reefer temperature is wired via a Local Area Network (LAN circuit) - newly placed for this project - to an alarm panel at the Power Plant. During an HD45 transfer session into a reefer, the reefer interior temperature will most likely rise above the alarm level and stay there for a while, until the doors are closed and the reefer’s interior air space can chill back down to the -30°C setpoint. The Power Plant operators will be notified that this particular alarm is to be ignored, and they will be notified again (when the loading session is complete and the reefer is back to the -30°C setpoint) that any further alarms should be acted upon. The on-board Partlow temperature recorder will collect a historical log of the reefer’s interior temperature; the data can be downloaded to a laptop computer at any time, or it can be viewed on-the-spot via the digital view screen. A backup “ink-on-paper” temperature recorder may also be installed on the reefer for redundancy and archival purposes.

The McMurdo cargo supervisor will make twice-daily documented reviews of the reefer’s actual internal temperature, setpoint, cooling unit control and functional status (via LCD display), door latches, cooling unit cowlings and fans, plug-in cord and receptacle condition, snow buildup, and observations for strange noises, smells, and other anomalies. All gensets will be periodically operated to exercise the components and avoid malfunction surprises.

Problems will be immediately acted upon and fixed, using the appropriate responsible departments and personnel. A complete kit of multi-year spare parts and operation/repair manuals will in a box affixed to the outside of each reefer. It is strongly recommended that several people attend the cooler manufacturer’s (ThermoKing) U.S. or New Zealand repair and maintenance classes each year (for these specific cooler units, gensets, and temperature recording systems), before deployment to McMurdo.

G19 Moving The Full 40’ Reefer Vans To The Vessel

The American Tern (or other) container vessel will arrive at McMurdo Station January/February, 2008. At the appropriate time, the 42,000-lb, fully-loaded, -30°C 40’, nose-mount reefers (with full HD45s parked at the SSC) are unplugged and lifted onto a Volvo 40’ flatbed truck (45,000-lb capacity) using the FatCat container handler (20’ and 40’ spreaders, 60,000-lb capacity). When unplugged, the primary genset on each reefer will automatically start to ensure the reefer’s primary cooling unit will continue to maintain the -30°C setpoint during the duration of the transfer onto the American Tern. A backup cooling unit and genset on each reefer ensures uninterrupted service.

On the Ice Wharf, the Volvo flatbed truck pulls up alongside the vessel. The primary and secondary gensets are disabled by the foreman (i.e., the main genset disconnect switches are turned off), since genset operation is prohibited on the American Tern. Temporarily, the highly-insulated reefer maintains its temperature without any cooling system operation.

The vessel’s 80,000-lb capacity crane then hoists the 40’ reefer into its pre-designated bay on the upper-level cargo hatch (with the reefer placed on the deck level to allow walk-up access to the reefer cooling unit for repair if needed – See Appendix B). The reefer's redundant cooling system has one electrical receptacle on the reefer, and it is plugged into the ship's 40 amp, 460V, 3-phase power circuit via an umbilical cord from a nearby power distribution stanchion near the ship's wheelhouse. This is repeated for the second 40' ice core reefer van.

Note:

The following protocols/procedures do not seem to be officially documented by RPSC/USAP:

- Vessel on-load procedures
- Reefer placement on vessel
- Reefer restrictions on vessel
- Reefer Temp data audits on ship
- Reefer repairs on ship
- Vessel offload procedures

G20 Full Sail To Port Hueneme

The vessel voyage between McMurdo and Port Hueneme lasts several weeks, with an intermediate stop at Port Lyttelton, NZ. During the voyage, the reefer's operational status is checked several times daily by ship personnel. If a reefer problem develops, they are responsible to fix it using the included spare parts, or by whatever means necessary. The ice cores cannot be removed from a malfunctioning reefer and transferred to a backup reefer, due to space and access constraints on the vessel. (This is one of the main reasons this proposal recommends an ISO reefer having a standalone, dual-system, automatic cooler redundancy).

G21 Offload At Port Hueneme

Upon vessel arrive at Port Hueneme, the two nose-mount ice core reefer vans are offloaded onto the Port's flatbed transfer trucks using the Port's container handler. The reefers are driven to the Freezer Warehouse where they are lifted with a mobile container handler, placed on the ground, and plugged into the Port's 220-volt, 3-phase power system. The reefer gensets (primary and backup) are then reactivated by USAP personnel (i.e., switched back on), and long-term temperature data are retrieved from the reefers' temperature recorders and reviewed for problems.

If pre-outfitted with the Escort/REDi wireless temperature recorders (see Section 1.5.6.1), independent temperatures inside the reefer and inside each HD45 box can also be downloaded for comparison and validation, without opening the reefer door or any HD45 doors.

Two pre-contracted air-ride flatbed trucks (40' to 48' platform or chassis) pull up near the reefers. The reefers are unplugged from the Port's power cords, at which point the primary genset on each reefer automatically starts. The reefers are hoisted up onto the contracted trucks air-ride platforms and hit the road. An RPSC representative should either be in one of the trucks of following in a chase vehicle for the trip to NICL.

G22 Driving To NICL In Denver, CO

As is the case for the entire season of reefer operation with ice cores, the reefer temperature is maintained at -30°C +/- 2°C for the duration of the road trip to NICL as long as the primary cooling unit is functioning. Should the primary unit fail, the backup cooling unit will automatically start, and the setpoint will be maintained at a reduced (preset) -25°C +/-2°C for the remainder of the road trip to NICL. If the primary *genset* fails, the backup genset will automatically start to provide electrical power.

The drive to Denver should take approximately 2 days, depending on which of several routes are taken, unexpected road delays, and other factors. The fuel tank is designed to continuously fuel the genset for at least 3 days of operations.

Note

The fuel tank is loaded with JP-5 fuel at McMurdo Station, and standard diesel fuel should not be mixed with it due to possible gelling issues at lower temperatures. The fuel and tank (perhaps one for JP-5, and one for diesel) will need more thought before committing to a design and/or operating protocol.

G23 Arrival At NICL

The contracted air-ride flatbed or chassis trucks arrive at NICL. The first reefer's rear doors are opened, and the truck backs up to the main loading dock door at the facility. The NICL fork truck (10,000-lb capacity) drives into the reefer payload bay, picks up a 1785-pound HD45, backs up, and drives it up a ramp into a +5°C staging area. From there, a pallet jack (5000-lb capacity) moves the HD45 through an 8-foot wide overhead door into the -36°C main ice core storage room. This process continues until the reefer is empty, and continues again to unload the second reefer which has been waiting in the parking lot. Up to thirty-two HD45s (up to 1440 one-meter ice cores) have now been placed in the NICL freezer.

The Escort/TREDi temperature recording devices inside the each reefer and inside all HD45s are removed, and the information is downloaded to a computer and reviewed for problems (and shared as needed). The temperature data is also compared to the temperature data downloaded from the reefers' Partlow digital temperature recorders at upon arrival at NICL. After the download, the temperature recorders are placed aside for later battery replacement.

Over the course of several weeks, the 1400+/- ice cores are gradually moved into the -20°C core processing area ("Exam Room"). To do this, the 40-inch wide HD45 boxes are either pallet-forked through a newly-widened door into the Exam Room, or they are removed from the HD45s in the -36°C room, placed on narrow, rolling Metro carts, and wheeled through the existing 36-inch wide Exam Room door. The final method is to be determined.

Once the HD45 boxes are emptied of ice cores, they are removed from the cold areas, inspected for damage (and repaired if needed), and placed into temporary storage.

G24 Reefer Refurbishment

While still on the contracted flatbed trucks, the two reefers are inspected at NICL for damage and operational problems. They are then driven to a pre-qualified and approved (by USAP and RPSC) ThermoKing-licensed reefer maintenance and refurbishment facility in Los Angeles, CA.

That facility will thoroughly maintain, refurbish, repair, and replace all needed items (per a thorough checklist and operation protocol which was jointly developed and approved by the ThermoKing, the original reefer manufacturer, and USAP).

G25 Reefer Upload To Vessel

Later in the summer or fall of 2008, portable Escort/REDi temperature recorders (with fresh batteries, but turned off) and empty ice core tubes are placed inside the HD45s. The HD45 boxes (as many as needed) are shipped via trucking company to mate up with the refurbished reefers being stored in Los Angeles, Port Hueneme, or other suitable location. In November 2008, the vessel is uploaded with the reefers containing HD45 boxes, recorders, and empty core tubes. No reefer power or cooling is necessary for the south-bound trip to McMurdo.

The vessel arrives in McMurdo in January/February, 2009, to start the WAIS Divide Safe-Core transportation process all over again.

Note

All dollar figures, percentages, and other financial and technical background information noted in this report were gathered from Raytheon Polar Services Company (RPSC), the National Ice Core Laboratory (NICL), the National Science Foundation (NSF), the United States Air Force (USAF) 109th Air National Guard, the Principal Investigator and other scientists for this project, and from 2005 budgetary estimates provided by various potential equipment vendors.

Appendix H Timeline