“Safe-Core”
WAIS Divide Ice Core Transportation Proposal
Summary

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Summary

1.1 Overview

The current United States Antarctic Program (USAP) deep-field ice core packing and transportation process has several areas that require improvements to assure adequate and continuous thermal and physical protection of the valuable scientific ice cores, and to minimize the risk of injury to ice core and cargo handling personnel. The improvements will be especially critical to the successful, safe, and efficient transportation of the West Antarctic Ice Sheet Divide (WAIS Divide) project's 4100 one-meter long ice cores that will be shipped to the United States over the next few years.

This report reviews the existing deep-field ice core transportation process from Antarctica to Denver, Colorado, and offers several recommendations on improved devices and methods to minimize or eliminate the identified problems. The report details the technical reasoning for the choices, and provides financial comparisons of the proposed solutions.

The present deep-field USAP ice core transport system uses thinly insulated cardboard boxes (holding four to nine one-meter long cores, depending on core diameter) strapped to metal Air Force pallets (AFPs) and flown from the drilling camp to McMurdo Station via an LC-130 (Hercules, Herc) cargo aircraft. At McMurdo, various methods and equipment are used to lift, stack, and move the cardboard boxes (with cores) to a stand-alone, limited-space, controlled-temperature freezer building near the Crary Science and Engineering Center (CSEC, or Crary Lab). At the end of the austral season, the boxes (with cores) are manually transferred from the stand-alone freezer to a 20-foot refrigerated International Standardization Organization (ISO) shipping container outfitted with a single (no backup) cooling unit, for the multi-week vessel transport to Port Hueneme, CA. From there, the full ice core boxes are transferred into a contracted refrigerated cargo truck for over-the-road delivery to the National Ice Core Laboratory (NICL) in Denver, CO. Temperatures inside the various permanent and portable ice core freezers are attempted to be maintained at -20°C or colder.

To provide the required continuous, multi-month, thermal protection for the ice cores, a back-up refrigerated ISO container, spare lifting and transport vehicles, and numerous on-call box lifters (people) are made available for most of the transportation process.

Despite detailed protocols and precautions designed into the existing ice core transportation system, unexpected delays or errors in returning the ice cores to the required controlled-temperature environment can place the cores at risk of warming or melting, due to several inadequacies in the present equipment and methods.

Posing perhaps the highest level of risk to the ice cores' thermal protection is the fact that there is no way to remove the cardboard ice core boxes from a malfunctioned refrigerated ISO shipping container once placed on the American Tern shipping container vessel (the present contracted vessel used by USAP). If the electricallypowered, single-unit refrigerator system mounted on the refrigerated ISO shipping container breaks down, it must be repaired on-the-spot by the ship's mechanic, or the ice will warm and possibly melt during the multi-week vessel voyage to the United States.

Also, throughout the current transport process, each of the numerous cardboard ice core boxes (weighing 130 pounds when full of cores) must be individually lifted and moved several times, by hand; each box movement places the ice cores at risk of damage due to tired or cold workers inadvertently dropping or mishandling the box.

If the present ice core transportation equipment and processes are left unchanged, there could be a 1.5% ice core breakage rate. This historical value, applied to the 4100 one-meter cores from WAIS Divide, 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). As well, a failed (or mistakenly left unplugged, as recently occurred) cooling unit on an existing 20-foot refrigerated ISO shipping container (holding 256 WAIS Divide cores in cardboard boxes) would place up to $5 million[*] worth of cores at risk of warming or melting.

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.

Finally, the current handling process requires appreciable physical labor (with occasional resulting injuries) to manually lift and move the 140-pound ice core boxes throughout the process. RPSC now restricts their employees to lifting no more than 40 pounds (versus the previous 70-pound limit), thus mandating that more people be used to lift each box. This reduces physical strain, but increases the strain on resources.

[*] The $20,000-per-meter 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.

Specific identified problems to be resolved are as follows:

- Existing McMurdo stand-alone permanent freezer will not provide sufficient ice core storage space for the WAIS Divide program and for concurrent drilling programs during the highest-output seasons.
- Existing USAP plug-in refrigerated ISO 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 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 full, 140-lb, cardboard ice core box.

Given these problems, the research and analysis done for this report yields the following summary of proposed ice core transport improvements 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 an electrical plug-in feature, and also with built-in, fail-safe redundant cooler units and redundant electrical 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 improved temperature recorder device or wiring, designed to allow fast, easy data download without corrupting the cold space around the ice cores.

The proposed 40-foot refrigerated ISO shipping containers will alleviate the reliance on the undersized outdoor permanent freezer building. During the season, each shipping container will be plugged into McMurdo's grid power, and the built-in gensets (primary and backup) on the shipping containers will provide automatic backup power if needed

Financial

Table: 1. Comparison of WAIS Divide Ice Core Equipment and Transportation Costs *(with Quantities)*

(Based on shipping 1400[1] 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[2]	$224,000 *(62)*	$224,000 *(62)*	$70,000 *(700)*
Refrig. ISO Container [3]	$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[4]	$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*

[1] 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.

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

[3] 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.

[4] Assumes operational cost of $45,000 per LC-130 round trip flight between McMurdo and WAIS Divide. Assumes that 50% of the flights to/from the WAIS camp are solely dedicated for transport of ice cores. Assumes an LC-130 Allowable Cabin Load (ACL) 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 ISO shipping container. Cost TBD.
- LAN temperature alarm-system wiring to be installed from parked refrigerated ISO shipping containers to the Power Plant central alarm board. Cost TBD.

In Table 1, the Recommended Upgrade option consists of the "nose-mount" refrigerated ISO shipping container (with dual cooling and genset systems), a highly-insulated, shock-absorbing, robust ice core box designed to hold 45 one-meter cores in a "high-density" packing configuration ("HD45" box), and a wireless temperature recording system installed in each box and nose-mount reefer for closed-door temperature viewing and wireless data download to a hand-held reader.

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, 40' refrigerated ISO shipping containers, and 35 wireless digital temperature recorders). Multi-year fees for vessel payload (not including the tare weight of each empty ISO container), 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 to McMurdo, the total project cost of the Recommended Upgrade is $1,013,451.

The Alternative Upgrade differs in that it uses the window-frame, redundant-system style of cooling system on the refrigerated ISO shipping container. This alternative window-frame option is programmatically less expensive by $105,000, but is also less technically-appealing and slightly less logistically-streamlined compared to the recommended nose-mount choice. The proposed wireless temperature recorder remains unchanged, and the same number of ice core transport flights (15.2) from the camp are required for the project.

The Minimum Upgrade option incorporates the existing cardboard boxes (ISC4), and uses the relatively-inexpensive window-frame refrigerated ISO shipping container. This option is the least expensive of the three choices if LC-130 flights are not included, but is in the (financial) middle of the pack if the 21.4 LC-130 flights are included (more flights needed due to less packing efficiency when using ISC4 cardboard boxes). This Minimum Upgrade approach only resolves the issues of warming and melting while cores are within the refrigerated ISO shipping container. It does not address the cardboard box's poor thermal performance when outside the controlled-temperature reefer, the box's limited shock-absorbing properties when dropped, nor the injuries incurred by workers who must lift the 140-lb cardboard boxes by hand. The specified temperature recorder is the same wireless system as used in the other options described above.

A "do nothing" alternative is not shown in Table 1, as it is not seen as a viable solution to the challenges being faced.

The various costs of the 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, and the other half would be in transit to or from Denver, on a continuously rotating schedule.

Though the Recommended Upgrade option is programmatically more expensive than the other options shown in Table 1, it will efficiently, reliably, and safely resolve all identified concerns with the existing ice core transportation system, while significantly streamlining the process.

If needed, additional HD45 boxes and a refrigerated ISO shipping container can be purchased and staged in McMurdo to accommodate a "surge" of up to 720 extra meters of ice (per 40' ISO container) from the WAIS Divide project or concurrent drilling programs. Each HD45 box is estimated by the vendor to cost $3,600, and a nose-mount, redundant-system ISO shipping container (which can hold up to sixteen HD45 boxes) costs $75,000. (The less-technically desirable window-frame reefer costs $47,000 each).

As an alternative method to handle "surge", a third reefer and empty HD45 boxes from NICL could be staged in Christchurch, New Zealand 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.

The proposed Safe-Core 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 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 for other delicate or temperature-sensitive artifact transportation missions.

To better understand the reasons for recommending the more expensive HD45 box and nose-mount refrigerated ISO shipping container, please read the following brief descriptions, and also see the full Safe-Core report (Sections 1.5.2 - 1.5.5, and Appendix E). Improved temperature recording device recommendations are also discussed in more detail in the full Safe-Core report (Section 1.5.6).

1.2 Ice Core Box

1.2.1 HD45 (High-Density box with 45 cores)

The preferred HD45 box (Figure 1) is an engineered and manufactured unit presently used by US military, the Federal Emergency Management Agency (FEMA), and others requiring the most durable, thermally-stable, transportable storage box for temperature-sensitive payload in extreme-environment, rough-handling conditions. At $3600 each, the proposed HD45 box design includes a high-strength, one-piece, double-wall polymer shell injected with 4" of void-free polyurethane foam (R25 insulation 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 will protect the cores from impact and vibration damage, and shelves will separate the cores into three bays to minimize crushing loads on the core tubes. A custom box mold and post-mold fixture must be manufactured to accommodate the one-meter long ice cores, but that one-time tooling and fixture fee is factored into the vendor's budgetary estimates.

Figure 1. HD45 Box (Configured to hold 45 ice cores)

1.2.2 ISC4 (Insulated Shipping Container With 4 Cores)

The less-desirable cardboard ISC4 box (Figure 2) is presently used by USAP for ice core transport, and has numerous shortcomings, including lack of sufficient insulation (R13 value), air infiltration gaps, poor shock-absorption properties of the stiff foam, difficult-to-grasp slippery outer surface, and propensity to cause injuries during lifting operations. Its present use is not well designed or efficiently integrated into the overall ice core transportation process. The primary benefit of the $100 ISC4 box is that it is much less expensive (programmatically) than the HD45 box, even though 700 ISC4 boxes are required (compared to 62 HD45 boxes).

Figure 2. ISC4 Boxes (Existing Design - Stacked)

1.3 Refrigerated ISO Shipping Container With Redundant Systems

1.3.1 Nose-Mount Style

The preferred "nose-mount" refrigerated ISO shipping container (Figure 3), with built-in redundant cooling and power systems, is presently engineered and manufactured for the chemical industry by a high-quality container manufacturer, and is used for transoceanic and over-road transport of hazardous organic peroxides. Outfitted with the highest quality, state-of-the-art equipment and controls, the $75,000 nose-mount ISO shipping container system has proven itself highly reliable and efficient while maintaining long-term temperatures to -30°C +/- 2.5°C in all ambient conditions, without any failures. Also, the reefers can be plugged into McMurdo power, thus alleviating the reliance on the McMurdo stand-alone freezer. Access to the cargo bay is through traditional rear doors to allow efficient loading and unloading of up to 16 HD45 ice core boxes (i.e., 720 cores) per unit. The rear-door access will also offer numerous parking and orientation options at McMurdo and NICL. To meet vessel restrictions, the two electrical generator sets can be disabled during vessel voyage, and then switched on again at Port Hueneme. An on-board fuel tank and spare parts box are standard equipment, and the ThermoKing cooling unit and genset components are widely available and serviceable throughout the world.

To further protect the ice cores from over-road shock and vibration damage, the refrigerated shipping container will travel via air-ride flatbed or chassis truck while being transported from Port Hueneme to NICL.

Figure 3. Nose-Mount Reefer

1.3.2 Window-Frame Style

The alternative style of refrigerated ISO shipping container is the "window-frame" unit (Figure 4). The window-frame cooling unit built into an ISO container is an industry-standard system for seagoing containers and is manufactured by ThermoKing, as is the separate "clip-on" electrical generator. However, a *redundant-system* design incorporating this cooling unit and genset on *each end* of the cargo box is only conceptual at this time; such a dual-system unit has not yet been engineered, manufactured, or tested by any of the key shipping container vendors contacted for this project. The conceptual, dual-ended window-frame design also results in less favorable side-door access to the container (with possible loading and unloading inefficiencies at McMurdo and NICL, and possible parking and access issues at McMurdo).

With the envisioned dual-system window-frame reefer, the two clip-on generator sets (one on each end with their own integral fuel tank) must be removed for vessel voyage due to space constraints, with the clip-on gensets (same or other) then reinstalled at Port Heuneme for over-the-road power to NICL. There is no external spare parts box.

At $47,000 each, the window-frame refrigerated shipping container's most favorable features are that it costs significantly less than the nose-mount style, and the longer usable space in the interior means it can hold up to 18 HD45 ice core boxes (i.e., 810 ice cores) per unit, as compared to 16 boxes (720 cores) in the nose-mount style. A total of four window-frame units are required for the WAIS Divide project.

Figure 4. Window-Frame Reefer (with single cooling unit on the bottom of the endwall, and clip-on genset mounted above it)

1.4 Portable Temperature Recorders

The existing HoboTemp temperature recorder installation and download protocol used by RPSC/USAP during ice core transportation logistics is sorely lacking a method for effective real-time, closed-box temperature download and instantaneous readout, to see and head off warming problems within the ice core box before they reach a critical level.

The primary concerns are that (a) retrieval of the "drone" HoboTemp devices (installed in pre-selected ice core boxes) for temperature data download may allow corruption of the cold-temperature envelope around those ice cores; (b) only a small percentage of ice core boxes have a HoboTemp device inserted inside, for direct evidence of the ice cores' temperature history; and (c) damaging warmup of the ice core may have already occurred before the HoboTemp temperature download is undertaken and data reviewed.

A proposed wireless temperature recorder device with handheld reader, known as the Escort/REDi system, will allow simple, fast, closed-door temperature transmittal through the proposed HD45 ice core box, as well as through the refrigerated ISO shipping container, again, without opening any doors. The handheld data receiver/reader has a graphic display to quickly view the captured temperature data (instantaneous and historical) within each HD45 box or within the refrigerated ISO container. Once field-scanned for temperature anomalies or alarms, the data can be downloaded to a laptop or office computer for further review, file-sharing, or storage.

Alternatively, the existing HoboTemp device can be hardwired into the proposed HD45 box, so that the download cables are accessible on the outside of the HD45 box without needing to break the integrity of the interior cold space for temperature data download.

Details and photos of both methods are in Section 1.5.6 of the full Safe-Core report.

Closing Remarks

As can be seen in Table 1, 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 (i.e. "Total Project Cost") than the slightly less desirable Alternative Upgrade (which uses the window-frame refrigerated ISO shipping container).

The Minimum Upgrade option (with less expensive capital equipment offset by six additional, expensive LC-130 ice core flights) shows that more programmatic money would be spent by the use of inexpensive ISC4 boxes and window-frame reefers, than with the Alternative

Upgrade approach of HD45 boxes and window-frame reefers. Also, the continued use of cardboard ISC4 boxes in the Minimum Upgrade option may prove detrimental to ice core integrity and personal health and safety.

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.