Liquid Helium (LHe) usage and storage at the South Pole

South Pole station is closed to cargo shipments for approximately 270 days each year.

It is desirable to maintain a LHe supply at the Pole during the period of closure. In recent years, this has been accomplished by shipping into Pole one or more LHe storage dewars, and transferring LHe from those dewars as needed during the winter. There has never been a transfer of LHe **between** storage dewars (although this has been extensively discussed), simplifying the analysis.

An assumption which further simplifies the analysis of the problem is this:

- Each storage, temporary transport, or experimental dewar which uses or stores LHe causes the LHe it

This is approximately true because the internal construction of a dewar conducts heat inwards to the LHe it holds at a roughly constant rate. (This rate is affected by temperature, and the temperature of the dewar's internal parts changes depending on how full it is, but this is a minor effect which is neglected here.) LHe is also evaporated in the process of transfer from storage to transport dewar and from transport dewar to experimental dewar; this loss is included below as part of the average loss from each dewar, since the transfers occur at regular intervals.

Under this assumption, each dewar has a "hold time" defined by:

hold time = T_{dewar} V_{dewar}/R_{dewar} ,

V_{dewar} = tot

R_{dewar} = rate of evaporation from dewar.

Here are evaporation rates for some of the dewars used at the Pole:

3000 Gallon	1000 Gallon	Wessington 3820 l	temporary store 250 l	temporary store 100 l	AST/RO	SPARO	SPIFI	ACBAR	NOAA
R_{big}	R_{small}	R_{Wess}	R_{250}	R_{100}	R_{ASTRO}	R_{SPARO}	R_{SPIFI}	R_{ACBAR}	R_{NOAA}
17 to 33 liters/day	12 to 25 liters/day	6 to 8 liters/day	3 liters/day	2 liters/day	7 liters/day	5.5 liters/day	50 liters/day	10 liters/day	5 liters/day

Each dewar uses R liters each day it is in use. Assume that each dewar is in use for t days, and that the number of dewars is n. Then the total volume of LHe consumed is the sum:

$R_{big}\, t_{big} + n_{small}\, R_{small}\, t_{small} + n_{250} R_{250}\, t_{250} + n_{100}\, R_{100}\, t_{100} + R_{ASTRO}\, t_{ASTRO} + R_{SPARO}\, t_{SPARO} + R_{SPIFI}\, t_{SPIFI} + R_{NOAA}\, t_{NOAA} = V_{total}$

Each winter of operation can be laid out as a spreadsheet:

The winter of 1995 was a success, and a demonstration that winter-over LHe at Pole is possible.

Winter 1995			
	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)

3000 gallon	1	17	270	4590
1000 gallon				
temp 250	3	3	270	2430
temp 100				
AST/RO	1	7	270	1890
NOAA	1	5	270	1350
			total on site at closing =	10260

The winter of 1996 was a failure, because the 3000 gallon dewar was unavailable and the two 1000 gallon dewars only lasted until August 8:

Winter 1996				
	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)
3000 gallon				
1000 gallon	2	12	160	3840
temp 250	2	3	170	1020
temp 100				
AST/RO	1	7	170	1190
NOAA	1	5	170	850
			total on site at closing =	6900

The winter of 1998 was essentially identical to the winter of 1995:

Winter 1998				
	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)
3000 gallon	1	17	270	4590
1000 gallon				
temp 250	3	3	270	2430
temp 100				
AST/RO	1	7	270	1890
NOAA	1	5	270	1350
			total on site at closing =	10260

Winter 1999				
	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)
3000 gallon	1	30	250	7500
1000 gallon	1	20	90	1800
temp 250	2	3	270	1620
temp 100	3	2	30	180
AST/RO	1	7	270	1890
SPARO	1	8	60	480
SPIFI				
NOAA	1	5	270	1350
			total on site at closing =	14820

Winter 2000 has been semi-disastrou On
contain helium after base closing, an
maintained and therefore has a high Cuttin
and an improved boil-off rate for SPA

Winter 2000				
	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)
3000 gallon	1	40	120	4800
1000 gallon				
temp 250	3	3	150	1350
temp 100	3	2	60	360
AST/RO	1	3	150	450
SPARO	1	5.5	150	825
ACBAR	0	10	0	0
NOAA	1	5	150	750
			total on site at closing =	8535

Plans for 2001 call for three Wessington storage dewars, 3820 liter model CH-4000, for a total of 11460 liters on-station at base closing.

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	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)
3000 gallon	0			
Wessington 1	1	7	90	630
Wessington 2	1	7	180	1260
Wessington 3	1	7	270	1890
temp 250	2	3	270	1620
temp 100	3	2	60	360
AST/RO	1	7	270	1890
SPARO	1	5.5	90	495
SPIFI	0	50	60	0
FTS	1	7	90	630
ACBAR	1	10	180	1800
NOAA	1	5	270	1350
			total needed for season =	11925
			actual amount on site =	11460

Additional helium is needed on-site at base closing. This can be accomplished by the delivery of additional helium, to be stored in other dewars. Suppose that six 250 liter dewars were full, in addition to the three Wessington dewars. These six 250 liter dewars would be used for the first 90 days after base closing, until their helium is gone:

Winter 2001 staged Wessington dewars + helium in smaller dewars				
	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)
3000 gallon	0			
Wessington 1	1	7	180	1260
Wessington 2	1	7	270	1890
Wessington 3	1	7	270	1890
temp 250	6	3	90	1620
temp 250	2	3	180	1080
temp 100	3	2	60	360
AST/RO	1	7	270	1890
SPARO	1	5.5	90	495
SPIFI	0	50	60	0
FTS	1	7	90	630

ACBAR	1	10	180	1800
NOAA	1	5	270	1350
			total needed for season = 14265	
			actual amount on site = 12960	

Having helium on-site in dewars which have a short hold time does not help very much, as the above example shows. The total consumption goes up by an amount which consumes nearly all of the additional helium.

If instead the three Wessington dewars are supplemented by the 3000 gallon dewar, and it works better than it did in 2000, arriving at Pole half full with an improved evaporation rate, there will be a total of 16914 liters on-station at base closing. This plan is marginally compatible with a successful season, but still leaves some single points of failure. Staging of the dewars would provide some backup and margin.

Winter 2001, Wessington + 3000 gallon				
	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)
3000 gallon	1	30	100	3000
Wessington	3	7	270	5670
temp 250	2	3	270	1620
temp 100	3	2	60	360
AST/RO	1	7	270	1890
SPARO	1	5.5	90	495
SPIFI	0	50	60	0
FTS	1	7	90	630
ACBAR	1	10	180	1800
NOAA	1	5	270	1350
			total needed at closing = 16815	
			total available at closing = 16914	

A comparison of the two examples above shows the futility of attempting to preserve helium by transferring it to short hold-time dewars (the 250 liter dewars have a hold time of about 90 days) from a longer hold-time dewar (the 3000 gallon dewar has a hold time of 200 to 350 days, depending on how well it is working). It is crucial that the helium be stored in dewars that have intrinsically long hold times, the longer the better. The Wessington dewars have the best hold time of any dewars available to us.

The original CARA plan for 2001 reqested four Wessington dewars, for a total of 15280 liters on-station at base closing. The CARA plan called for unmodified dewars with a slightly lower boil-off rate. This plan would have also worked.

Winter 2001, 4X Wessington

	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)
3000 gallon	0			
Wessington	4	6.5	270	7020
temp 250	2	3	270	1620
temp 100	3	2	60	360
AST/RO	1	7	270	1890
SPARO	1	5.5	90	495
SPIFI	0	50	60	0
FTS	1	7	90	630
ACBAR	1	10	180	1800
NOAA	1	5	270	1350
			total needed at closing = 15165	
			total available at closing = 15280	

These plans for the winter of 2002 are at present woefully inadequate, since SPIFI will be deployed after two seasons of non-deployment due to insufficient support.

Winter 2002				
	n	*R* (liters/day)	*t* (days)	*n*R*t* (liters)
3000 gallon	0			
Wessington	3	7	270	5670
temp 250	2	3	270	1620
temp 100	3	2	60	360
AST/RO	1	7	210	1470
SPARO	1	5.5	90	495
SPIFI	1	30	60	1800
FTS	1	7	90	630
ACBAR	1	10	180	1800
NOAA	1	5	270	1350
			total needed for season = 15195	
			actual amount on site = 11460	