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PROCEDURES FOR SCHEDULING ICE SHEETS

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SUMMARY

This report describes the computer tools used in preparing the Ice Tank Schedule which is distributed to ice facility staff and refrigeration operators and contains the necessary information in making ice sheets to specific targets of thickness and strength. A work instruction is provided in the appendices.

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PROCEDURES FOR SCHEDULING ICE SHEETS

1.0   INTRODUCTION

This document describes the tools used to schedule ice sheets which provide information on the length of freeze required and the length of tempering time needed to produce an ice sheet of known thickness and strength. This information is used to plan the overall time a project will be in the Ice Tank and to provide an estimate of cost. Details have to be provided to the refrigeration staff so they know how long to freeze and how long to warm up, and the people in the Ice Tank have to know when to start seeding and when the tests will take place. The three main types of ice, fresh, model and bubbled are discussed, and the recently used fourth type, unseeded bubbled ice, is briefly referred to.

2.0   TOOLS

There are two main tools used in the scheduling of ice sheets and these are 1) empirical equations that provide a quick and easy estimate for costing purposes, and 2) software routines that check the historical record in the Datatrieve database of archived ice sheet properties and which provide the accuracy required for producing the final refrigeration schedule.

2.1   Empirical Equations

2.1.1   Fresh water ice

When no tempering of the ice sheet is required as in the case of fresh water ice, (or in the case of model ice sheet at full strength without tempering) then the growth of thin ice covers can be calculated from the quasi-state model[1].

$$h_i = \frac{\sqrt{(1 + 2h^2\frac{FDH}{kl_f\rho_i})-1}}{\frac{h}{k}} \tag{1}$$

where, h_i is the required ice thickness, h is the heat surface transfer coefficient (12.0 W/m^2/K), l_f is the latent heat of freezing (3.35x10^5 J/kg), ρ_i is the ice density (920 kg/m^3), and k is the thermal conductivity of ice (2.0 W/m/K). This can be reduced to

$$h_i = 166.7\sqrt{(1+0.001682FDH)} - 1 \tag{2}$$

or, if the number of Freeze Degree Hours (FDH) for given thickness (mm) is required

$$FDH = \frac{(0.006\,h_i + 1\,)^2 - 1}{0.001682}$$ (3)

Equations 2 and 3 can easily be performed on calculators and spreadsheets and is currently available to Ice Staff in a spreadsheet named "Ice Scheduling.xls" on the Knarr network drive $Ice. Note that while, for example, 20 FDH could be 20 hours at –1°C or 1 hour at –20°C, the thermal conductivity of ice is temperature (and environmentally) dependant so the freeze rates and the resultant ice thickness would be different. $k = 2.0$ W/m/K is therefore only valid for temperatures approximating –20° in the Ice Tank and would change under conditions affecting heat loss such as increased wind velocity or snow cover.

2.1.2 Model ice

Through regression analysis of tempering curves and growth rates a series of 3 equations were derived to describe the processes in terms of the time required to manufacture an ice sheet ready for testing on the basis of target thickness and strength. They are based on unbubbled model ice and some allowance, in the order of 25% longer, has to be made when estimating the tempering time of bubbled ice. The tempering time, $T\sigma$, (hrs) is calculated first by:

$$T\sigma = 4.2593\,h_f^{0.5049} - 0.8969\,h_f^{0.4775}\ln\sigma_f$$ (4)

where h_f is the target thickness (mm) and σ_f is the target flexural strength (kPa). The initial ice thickness, h_i, is next calculated by:

$$h_i = \frac{h_f}{1 + \sqrt{\dfrac{T_\sigma}{0.0095\,h_f^{2.5684}}}}$$ (5)

From this the required FDH's are calculated from:

$$FDH = 0.04428\,h_i^2 + 5.8772\,h_i + 13$$ (6)

For thin ice sheets where the calculated FDH is less than 105 the value 13 should be subtracted to give the final value. The time required for the freeze is obtained simply by dividing the FDH by the value of the required freezing temperature, 18, 20, 22, etc.

These equations are also in the Excel spreadsheet, Ice Scheduling.xls, and easily executed by entering the target thickness and strength required. The cost of preparing an ice sheet based on the current freeze charges is also included which can then be added to the tank and technical staff charge out rates to provide a quick cost estimate. The cost displayed on the spreadsheet is a sum of the calculated freezing time at –20°C plus the 4½ hours that it takes to pull the temperature down to seeding temperature and perform the seed.

A similar program in VMS can be run from the VAX terminals. This program is part of the ice analysis suite of programs and can be run by the command > RUN ICE_ANALYSIS$:COMPUTE_ICE_SHEET.EXE . Similarly to the previous equations, these were compiled from regression of the freezing and tempering time of ice sheets to date. At the time, this was the newer version established from approximately the first 500 <u>unbubbled</u> ice sheets, somewhat more than the original version, and consequently the results can be a little different. The program is simple to run requiring only the target thickness, strength, and freezing temperature of the ice sheet (normally in the range –18° to –22°C), and returns the required FDH, the time for freezing and tempering and the expected initial ice thickness at the start of warm-up. Again, a 25% lengthening adjustment has to be made for bubbled ice. In all cases for costing purposes. the length of freeze is based on freezing at –20° even if a different temperature is selected for scheduling.

2.1.3   Scheduling

Either of the two above methods will give reasonable estimates as to the length of freeze and tempering times needed to produce the required ice sheets. The start of model tests is normally targeted for 10 a.m. on the test day which allows sufficient time in the morning before then to do the required initial ice properties, and to do the final checks on the model. It is then a straightforward matter of working backwards in time to figure out when the warm-up should start, when seeding should start and finish (½ hour), and when the refrigeration plant should be fired up to start bringing the temperature down (4 hours). Original calculations are based on freezing temperatures of –20°C, but if this gives an inconvenient seeding time such as in the middle of the night, the temperature can be changed by ±2°. If that does not help then it may more convenient to start the model tests at another time of day.

These scheduling times are calculated automatically when using the Datatrieve routines described below.

2.2   Datatrieve Ice Sheet Database

2.2.1   Overview

Before describing the scheduling routines a brief overview of the structure of the database will provide a basis for a better understanding of how the routines work. The database is an archive of, at the time of writing, some 1050 ice sheets. The information is stored in six primary collections. Two are database domains, Ice Project and Ice Sheet,

and the remaining 4 are ice type databases; one each for Model (Unbubbled) ice, Bubbled (CD – Correct Density) ice, Fresh water ice and Unseeded bubbled ice. These ice typedatabases contain all the mechanical properties, and the structure of each is identical containing domains for each of the ice properties.

2.2.2   Ice project

This domain contains primary information as to Ice Sheet Name, Project Number, Project Officer, Date, and Time that warm-up starts, and an ID number that is automatically and sequentially assigned.   This information is written automatically into the database every time a new ice sheet is initialized with the Warm-up program (see VMS Ice Analysis Procedures and Preparation of Ice Sheet Summaries[2]).

2.2.3   Ice sheet

This domain contains information on the physical aspects of the ice sheet as to EGADS concentration, ice type (model, bubbled, fresh, unseeded), Target Ice Thickness, Target Strength, Initial Air Temperature at the time of seeding, Final Air Temperature at the time of seeding. Tank Water Temperature, Seed Volume used, Ice Tank Humidity, Average Freezing Temperature, FDHs, Final Ice Thickness (Measured or Calculated), Final Ice Thickness, and Average Tempering Temperature.

2.2.4   Mechanical properties

The mechanical properties are contained in separate ice typedatabases (model, bubbled, fresh, and unseeded). In each database there are identical domains, one for each mechanical ice property, principally flexural strength, flexural strength Up to Down Ratio, Compressive Strength, Shear Strength, Density, Thickness, Characteristic Length, Elastic Modulus, Elastic Modulus divided by Flexural Strength Ratio, Characteristic Length divided by thickness ratio, and others, such as Fracture Toughness, now less commonly used. The domains can be listed by the commands SET DICTIONARY DISK$AP:[AP.DATABASES]AP.ICE.ANALYSIS , then SHOW DOMAINS . All the domains have the same structure or number of fields which are Ice Sheet ID Number, Ice Thickness of Measurement, Time when measurement taken, Tank Position (length along tank), Side (North or South), Mean Value of measurement, Standard Deviation, and Number of Samples.

In order to view the records within a domain, the domain has to be opened by a READY command. To avoid confusion between domains in moving from one ice type database to another (eg. Model to Bubble) any open domains should be closed by the FINISH command before opening one of the same name in a different database.

3.0   PROCEDURES

Datatrieve is accessed from the VMS prompt command by entering DTR. For the ice facility staff, a DTR start up command file is automatically run which, aside from

defining synonyms (displayed on screen), readies the Ice Project and Ice Sheet domains, and the Flex Strength domain of the Model ice type database which is the default. Refer also to Appendix A for an example of how these procedures are used in scheduling a CD Ice sheet of 30 mm at 40 kPa.

There are eight Procedures within the database that are used in scheduling. A Procedure in this context is a command file of instructions that has been saved and is executed with a : (colon) prefix to the saved name. The Procedures are:

> : Bubble
> : Fresh
> : Unseeded
> : Model
>
> : Sched
> : Plotsched
> : Seed
> : Recalc

The list of instructions for each procedure can be viewed by using the Show command as in, for example, SHOW SCHED .

The first four are commands for moving from one ice type database to the other, and the remaining four are used in calculating schedule time. Before moving from the default Model database the automatically opened Flex_strength domain should be closed with the Finish command, i.e:

  FINISH FLEX_STRENGTH

Any of the commands to move to another database can then be entered such as –

  :BUBBLE

This procedure name is a synonym for running a single line command, FN$CREATE_LOG("ICE_ANALYSIS_DATABASE","BUBBLE_ICE_DATABASE") Where the "Bubble" can be replaced by whichever database one wishes to access. After opening the new ice type database the Flex_strength domain in that database has to be opened with the Ready command, i.e:

  READY DISK$AP:[AP.DATABASES]AP.ICE.ANALYSIS.FLEX_STRENGTH

The first three scheduling procedures can then be executed in order, one after the other, with the option of executing the fourth. "Sched" determines the length of freeze; "Plotsched" helps determine the length of warm-up; "Seed" determines when to start seeding based on a 10 a.m. test time using the lengths of times just derived, while "Recalc" can be used to calculate a different test time.

3.1   :Sched

Sched is a set of instructions to interrogate the historical information in the database based on the target thickness and strength entered by the user, and which will at its

conclusion, display the calculated average of FDHs for any of the normal freeze temperatures used (-18°, -20° and –22°), and the length of freeze required at that temperature.

The program starts by requesting confirmation that one is in the correct ice type database. A negative response aborts the program while an affirmative continues it. The program then asks to confirm ice type (at the time of writing the procedure has not been modified to accept unseeded ice) as only Ice Sheets with the identifier M, B, or F will be selected. Since an ice sheet of a particular thickness may not have been made before, the user is then prompted to enter a lower and an upper target thickness so a that a range centred around the target thickness can be entered. For example, if a 46 mm sheet was being scheduled then one would enter 46 for both the upper and lower values, and if no record was found then on re-running the program 47 would be entered for the upper value and 45 for the lower. If no record was then found then one would try 48 and 44 and so on as long as the mean of these two values equals the desired target. If only a few records are found the procedure can be cancelled with a "Ctrl Z" and re-run with a wider range. Once the lower range has been entered the program automatically runs its first part selecting Ice_Sheet records with the criteria of thickness and ice type and matching those with records from Ice_Project based on common ID numbers to create a collection called "Range" and displaying selected fields from that collection on the screen. These fields are: Ice Sheet name, ID, Target Thickness, Final achieved Thickness, Target Strength, FDH used, Average temperature of the freeze, and finally the new Target FDH based on the freezing rate of that ice sheet and applying it to inputted thickness values just entered. The average of each of the calculated Target FDH values is also displayed on the screen.

The user is now prompted to select a range of flexural strengths by entering an upper and lower value. During the tempering phase of the ice making process, even with the room at positive temperatures, the ice is still growing ever so slowly which means that the ice for a given amount of FDHs is thicker at low strengths that at high strengths. This procedure now offers to fine tune the required FDHs based on ice strength. Once the strengths have been entered the procedure resumes and creates a further collection named "Target_Range" from the "Range" collection which is limited to the strength criteria, and displays those records on the screen along with the updated average FDH value, also displayed in FDMs. The procedure then displays the amount of freezing time required to reach this value based on sample standard freeze temperatures of –18°, -20° and –22°C along with the word "Estimated". Since the final thickness is also slightly dependant on the freezing temperature, the program continues by sorting the data into three collections one for each of the three freezing temperatures, T18, T20 and T22, and recalculates the required FDHs for each of these (where data is present) and displays the new FDH value and the freezing times on the screen with the word "Calculated". The names of the collections so far formed (T22, T20, T18, Target-Range and Range) are displayed. As the procedure closes it creates a new collection, "Range_Flex" which will be used in the next step. This contains all the data from the first collection, "Range", now matched with the corresponding Flexural Strength data in the Flex_strength domain using the ID number as the common identifier. A message is then displayed on the screen indicating to move to the next step.

3.2   :Plotsched

:Plotsched is a short procedure of one instruction which plots all the flexural strength (M_Val) data of the Range_Flex collection against time and displays on the screen for the user to estimate a reasonable warm-up time for the target strength. Since some of the plotting routines reside in a different dictionary (directory) of Datatrieve, and because the start up routines accessing Datatrieve may vary, the :plotsched procedure may not always work. However, it is basically the command:
PLOT X_Y TIME, M_VAL OF RANGE_FLEX
which will produce the same result and plot the data on the screen. Commonly, there is a lot of scatter in the displayed data. The data is from many years of operation and there may be slight differences in tempering time over these years due to subtle changes of operation and in the EGADS concentration. Occasionally, and for several reasons, there may have been very long tempering times. The x – y plot routine automatically sets the axis limits to cover all data so in plotting events with a long x-axis most of the data may be bunched together on the left hand side making interpolations difficult. These plots can be visually improved by limiting the x data as in the command:
PLOT X_Y TIME, M_VAL OF RANGE_FLEX WITH TIME LT x
where x = a suitable value on the x axis. LT stands for 'Lesser Than'. Other useful operators are GT for 'Greater Than', BT for 'Between" two values, and Eq or = for 'Equal'. The graph may be further simplified by selecting only the more recent data by using the ID number as in the command:
PLOT X_Y TIME, M_VAL OF RANGE_FLEX WITH TIME LT x and ID GT n
Where n is a suitable ID number.

The standard average tempering time (ATT) is 2°. Very occasionally it may be less than that so one can always check by including an expression such as [AND] WITH ATT BT 1.7 AND 2.2, or check for other tempering temperatures using ATT with the EQ, LT or GT commands.

From the plot, and from the mathematical model, one should now be able to make a reasonable estimate as to how long the warm-up should be to reach the target strength.

3.3   :Seed

Seed is the procedure that calculates when one has to seed based on the user's estimate of tempering time and FDHs. From an assumed test time of 10 a.m. the routine calculates, working backwards in time, when one has to do the various key steps as to turning on the tank perimeter heat, raising the water level, start seeding, and start warming up.

On running the procedure, the routine first asks for confirmation of the FDHs for each of the three standard freezing temperatures calculated or estimated in the Sched procedure. These numbers should be reviewed and compared with other estimates such as from the spreadsheet equations as the user is now prompted to accept these numbers or change them. One is then requested to enter the estimate for the length of tempering time. The

program then displays all the necessary information regarding seeding and preparation times, FDHs, and time of warm up for each of the three freezing temperatures for a 10 a.m. test time provided the seeding take places at a convenient time between 8 a.m. and 11 p.m. The warm-up time is expressed as hours in terms of a 24 hour clock. For example, 23 hours means at 23:00 that evening the day of the seed; 27 hours means 27 minus 24 being at 03:00 hours the next morning; 62 hours means 62 minus 48 being 14:00 in the afternoon in two days time.

If information for less than the three optional freezing temperatures is displayed it means that seeding is required at an inconvenient time for the missing options . If nothing is displayed at all it means that within the freezing temperature range of –18° to –22° no options are available which will give a test time of 10 a.m. The choice is then to change the test time, or seed at sometime between 11:30 at night and 7:30 in the morning. The next procedure, Recalc, is used to help decide.

3.4   :Recalc

Recalc is the procedure used to schedule an ice test for a 10 a.m. start when the seeding time lies at awkward hours of the night, or to schedule the test for another time of day when the seeding time is more convenient. It uses the same FDHs and temper times already derived so it is just a matter of re-entering them. The procedure starts by prompting when the user would like to finish seeding. The time is entered as decimal hours so, for example, 1:30 pm would be 13.5. The temper time is then entered and the program displays the length of freeze and time of warm-up for each of the standard temperatures along with the new test time. This procedure can be re-run as many time as it takes to find suitable times. Though it calculates for temperatures 18°, -20° and –22°, one can manually calculate for –19° and –21° by dividing the FDHs by the temperature to derive the required freeze time.

3.5   Print Out

Once satisfactory results have been obtained it is best to get a hard copy print out of the various steps. One relatively easy way to do this is to scroll up on the VMS window screen to the start point then select by dragging with the mouse and then use the down arrow on the keyboard to select the required text, then use 'copy' from the Edit dropdown menu and copy it into Notebook. Further edits can be done in Notebook to remove blank lines and the file can be printed off then, and saved if required.

All the above procedures can be repeated for each sheet requiring different thickness and strength targets.

4.0   MAKING THE DAILY SCHEDULE

The final process in scheduling is to draw up the daily schedule with the aim of having an efficient as possible use of time with minimal wait periods between ice sheets. The ice sheets may be of varying thickness and strengths requiring different seed times. There

are many other variables so there is no hard and fast way of joining all this together but one needs to know several things up front such as the complexity of model installation, how much open waster work is required, what model modifications are required between tests, refrigeration staff availability over weekends, etc. Not least is what is required during the test day. If tests are short then it may be possible to seed another ice sheet later that same day or in the evening. Scheduling often requires drawing up two or three different scenarios with sheets in different orders (it is normally best to start with the thinnest), assessing which is the most attractive and discussing the good and bad points with the project manager. Costs can be fairly quickly totted up using the standard daily rental rates (open water tests are charged at the standard Ice Tank ice rates if they are part of an overall ice project), freeze rates and staff charge out rates.

Once the overall schedule has been agreed on, and normally about a week before the project is due to start in the Ice Tank the daily refrigeration schedule, known as the Ice Tank Schedule, and normally for a two week period, is drawn up and distributed. Even if the project is longer than two weeks it is best to wait until into the second week before drawing up the next phase of the schedule as changes are always likely.

5.0   NAMING OF ICE SHEETS AND ARCHIVING OF SCHEDULES

Since fall 1989, electronic versions of the schedules have been kept in the VMS directory DISK$PROJECT2:[PJ88084.SCHED] and a hard copy of all the schedules is kept on a clipboard in the Ice Tank Office. There is a blank electronic form named SCHED.LIS in the directory, but frequently when making a new schedule, it is easier to edit a previous schedule which has similar time frames and targets than start afresh with a totally blank form. Some hints how to use the VMS editor are given in VMS Ice Analysis Procedures and Preparation of Ice Sheet Summaries[2]. The ice sheets are normally given some kind of descriptive name to identify their purpose, and are given chronological numbering so, for example "SHELL1", "SHELL2", etc, describes the ice sheets made for the client oil company Shell. Since the refrigeration control computer is DOS based the ice sheet name must not exceed eight characters so in deciding a name one should allow for the eventual possibility of two digits. The name, therefore, should not exceed six alpha characters.

The schedules are named in a similar identifying pattern as the ice sheet names. In the above example for Shell the first schedule is saved in the VMS directory as SHELLSCHED1.LIS . The maximum time frame that can be printed out on a single letter sized sheet is two weeks, a convenient period. Should the project extend beyond that time, or should the client return to the tank some time late, then additional schedules can be saved by sequentially numbering them as is SHELLSCHED2.LIS, etc.

6.0   SUMMARY

A combination of the equations and Datatrieve provide very useful tools for estimating ice growth and tempering times, and in constructing the Ice Tank schedule. But they are only tools and like any tools they should be used with care and caution. They are not fool

proof but do provide good estimates which together with checks against historical data will enable one to draw up the schedule with reasonable confidence.

7.0   REFERENCES

1.   Lozowski, E.P., S.J. Jones and B. Hill. Laboratory measurements of thin and flooded ice growth. Cold Regions Science and Technology, 20(1991)25-37 IR-1991-03

2.   Hill, Brian T. VMS Ice Analysis Procedures and Preparation of Ice Sheet Summaries. March 2006. LM-2006-05

Appendix A

Example Print-Out from using the Datatrieve Scheduling Procedures to
Schedule an ice sheet 30 mm thick and 40 kPa in strength

Appendix A

Example Print-Out from using the Datatrieve Scheduling Procedures to
Schedule an ice sheet 30 mm thick and 40 kPa in strength

N.B. Keyboard entries are in **Bold** and any explanatory comments are italicized and in brackets.

MICKEY $ **dtr**
DEC DATATRIEVE V7.2
Digital Query and Report System
Type HELP for help

Synonyms:
   VAR   for VARIABLES
   DEF   for DEFINE
   PROCS   for PROCEDURES
   EX   for EXTRACT
   FIN   for FINISH
   LI   for LIST
   WR   for WRITE
   STO   for STORE
   FI   for FIND
   PROC   for PROCEDURE
   DEC   for DECLARE
   DIS   for DISPLAY
   FMT   for FORMAT
   MOD   for MODIFY
   ST   for STARTING
   DEL   for DELETE
   ED   for EDIT
   REL   for RELEASE
   SH   for SHOW
   RDY   for READY
   PU   for PURGE
   SEL   for SELECT
   PL   for PLOT
   DIC   for DICTIONARY
   PR   for PRINT
   HE   for HELP

DTR> **finish flex_strength** *(Close the default 'Model' – unbubbled ice records before moving into another ice type database)*
DTR> **:bubble** *(enter the Bubble or CD Ice database)*

DTR> **ready DISK$AP:[AP.DATABASES]AP.ICE.ANALYSIS.FLEX_STRENGTH**
DTR> **:sched**

ARE YOU IN THE CORRECT DATABASE WITH
THE CORRECT FLEX_STRENGTH DOMAIN?

Enter Y or N: **y**

Enter Ice Type (B,F or M): **b**
Enter LOWER TARGET THICKNESS: **30**
Enter UPPER TARGET THICKNESS: **30**

Test Name	Test ID	Final Target Thickness (mm)	Ice Thickness (mm)	Target Strength (kPa)	Avg Freeze Hours (deg-hrs)	Freeze Temp. (deg)	Target FDH
KALVIK13	0450	30.0	31.0	30	163.5	-20.6	158.2
KALVIK14	0451	30.0	31.0	30	160.7	-20.2	155.5
KALVIK15	0452	30.0	29.7	30	160.8	-20.7	162.4
KALVIK16	0453	30.0	28.7	30	162.0	-20.3	169.3
AIRCUSH20	0520	30.0	28.9	30	161.2	-20.3	167.3
AIRCUSH21	0521	30.0	29.2	30	162.0	-20.2	166.4
EGADS34	0532	30.0	29.5	50	172.5	-17.8	175.4
AIRCUSH28	0650	30.0	31.8	30	158.4	-22.3	149.4
AIRCUSH29	0651	30.0	31.2	30	160.9	-22.1	154.7
PACK1	0701	30.0	33.0	60	180.5	-19.9	164.1
PACK2	0702	30.0	31.0	60	180.8	-17.8	175.0
MOORED1	0720	30.0	27.0	15	159.0	-15.4	176.7
MOORED2	0721	30.0	30.0	15	173.0	-16.1	173.0
MOORED3	0722	30.0	28.0	15	155.0	-19.8	166.1
URIDGE1	0723	30.0	30.2	15	156.0	-19.6	155.0
MOORED4	0724	30.0	32.0	15	155.6	-19.7	145.9
NEBRUB1	0751	30.0	32.2	60	174.0	-21.3	162.1
SAMS1	0784	30.0	30.2	20	166.0	-20.1	164.9
SAMS3	0786	30.0	29.8	20	158.3	-20.0	159.4
SAMS5	0788	30.0	29.5	20	160.6	-20.3	163.3
SAMS9	0794	30.0	29.9	20	161.1	-19.9	161.6
SAMS10	0797	30.0	30.9	20	160.6	-20.3	155.9
SAMS12	0799	30.0	31.3	20	160.7	-20.1	154.0
SAMS14	0801	30.0	31.1	20	160.5	-20.1	154.8
EXXON1	0809	30.0	30.2	40	164.1	-18.3	163.0
EXXON2	0810	30.0	30.5	40	167.3	-18.4	164.6
EXXON3	0811	30.0	32.8	40	158.4	-20.1	144.9
SDI2	0817	30.0	30.2	30	159.8	-21.6	158.7
SDI3	0818	30.0	30.4	30	161.5	-21.8	159.4

EXXON4	0819	30.0	30.0	40	157.4	-18.0	157.4
EXXON4X	0826	30.0	31.1	40	168.3	-18.4	162.3
EXXON5	0827	30.0	32.0	40	167.4	-18.6	156.9
EXXON6	0828	30.0	30.0	40	169.7	-18.4	169.7
VB9	0831	30.0	31.3	30	161.1	-21.7	154.4
VB15	0837	30.0	33.0	30	187.2	-20.2	170.2
VB21	0851	30.0	28.0	20	150.1	-18.3	160.8
VB23	0856	30.0	30.6	20	159.6	-20.2	156.5
VB27	0860	30.0	30.2	20	158.2	-20.4	157.2
MIL3	0862	30.0	30.1	30	167.2	-21.5	166.6
HEALY16	0901	30.0	31.4	30	157.9	-21.9	150.9
SAMS18	0958	30.0	31.9	20	159.8	-19.8	150.3
KULLUK1	0971	30.0	30.3	40	160.8	-17.1	159.2
KULLUK6	0976	30.0	31.9	20	166.6	-18.5	156.7
KULLUK8	1018	30.0	33.3	20	156.5	-21.9	141.0
KULLUK13	1023	30.0	30.5	20	156.3	-21.8	153.7
KULLUK15	1025	30.0	30.8	20	157.7	-21.9	153.6

AVERAGE
Target
 FDH

    159.969 FDH

Enter LOWER TARGET STRENGTH: **30**
Enter UPPER TARGET STRENGTH: **50** *(a range has been selected to provide an adequate number of sheets)*

Test Name	Test ID	Final Target Thickness (mm)	Ice Thickness (mm)	Target Strength (kPa)	Avg Freeze Hours (deg-hrs)	Freeze Temp. (deg)	Target FDH
AIRCUSH20	0520	30.0	28.9	30	161.2	-20.3	167.3
AIRCUSH21	0521	30.0	29.2	30	162.0	-20.2	166.4
AIRCUSH28	0650	30.0	31.8	30	158.4	-22.3	149.4
AIRCUSH29	0651	30.0	31.2	30	160.9	-22.1	154.7
EGADS34	0532	30.0	29.5	50	172.5	-17.8	175.4
EXXON1	0809	30.0	30.2	40	164.1	-18.3	163.0
EXXON2	0810	30.0	30.5	40	167.3	-18.4	164.6
EXXON3	0811	30.0	32.8	40	158.4	-20.1	144.9
EXXON4	0819	30.0	30.0	40	157.4	-18.0	157.4
EXXON4X	0826	30.0	31.1	40	168.3	-18.4	162.3
EXXON5	0827	30.0	32.0	40	167.4	-18.6	156.9
EXXON6	0828	30.0	30.0	40	169.7	-18.4	169.7
HEALY16	0901	30.0	31.4	30	157.9	-21.9	150.9

```
KALVIK13      0450    30.0    31.0     30      163.5 -20.6  158.2
KALVIK14      0451    30.0    31.0     30      160.7 -20.2  155.5
KALVIK15      0452    30.0    29.7     30      160.8 -20.7  162.4
KALVIK16      0453    30.0    28.7     30      162.0 -20.3  169.3
KULLUK1       0971    30.0    30.3     40      160.8 -17.1  159.2
MIL3       0862  30.0    30.1     30     167.2 -21.5  166.6
SDI2       0817  30.0    30.2     30     159.8 -21.6  158.7
SDI3       0818  30.0    30.4     30     161.5 -21.8  159.4
VB15       0837  30.0    33.0     30     187.2 -20.2  170.2
VB9        0831  30.0    31.3     30     161.1 -21.7  154.4
```

TARGET
 VAL

1.6074E+02 FDH   9645 FDM

 8.9Hrs @ -18   ESTIMATED
 8.0Hrs @ -20   ESTIMATED
 7.3Hrs @ -22   ESTIMATED

TARGET
 VAL

163.6 FDH   9814 FDM   9.1 Hrs @ -18   CALCULATED

TARGET
 VAL

161.8 FDH   9708 FDM   8.1 Hrs @ -20   CALCULATED

TARGET
 VAL

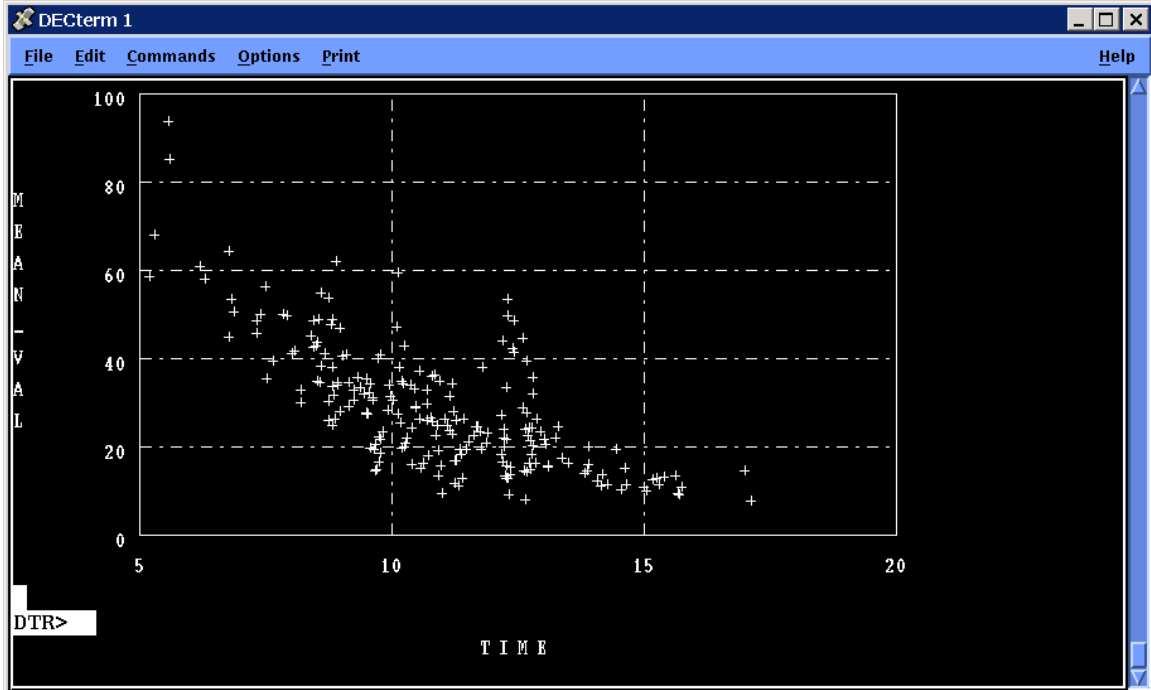156.3 FDH   9379 FDM   7.1 Hrs @ -22   CALCULATED

Collections:
    T22   (CURRENT)
    T20
    T18
    TARGET_RANGE
    RANGE

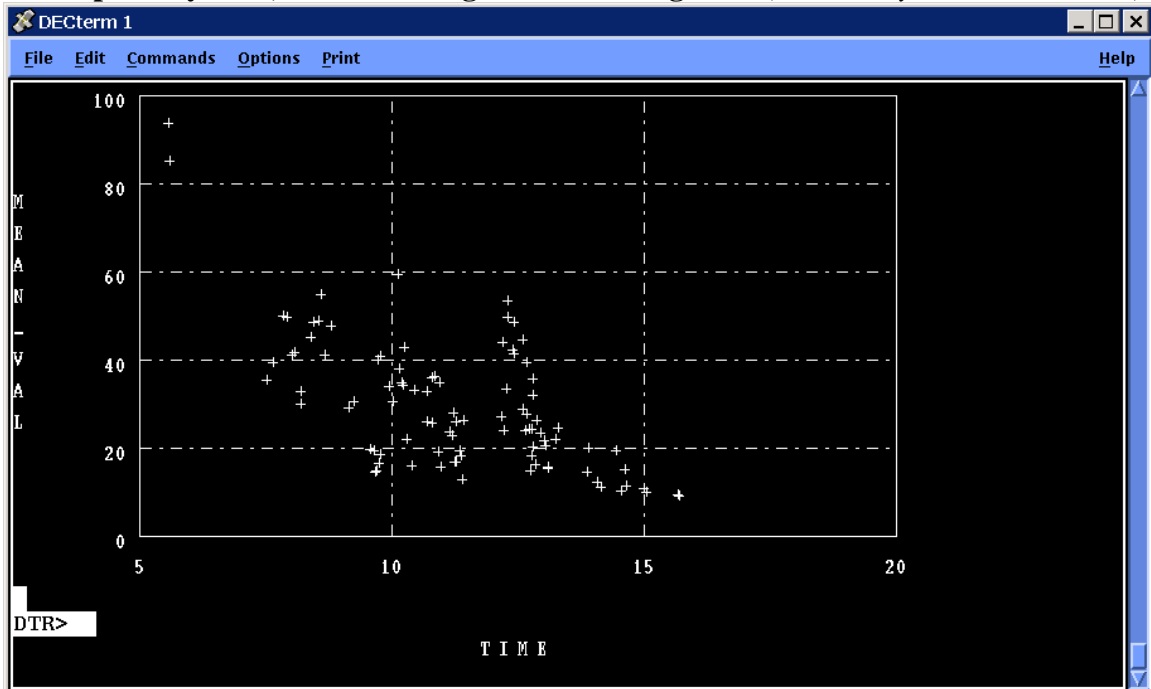TO PLOT, type :PLOTSCHED (plots from collection RANGE_FLEX)

DTR> **:plotsched**
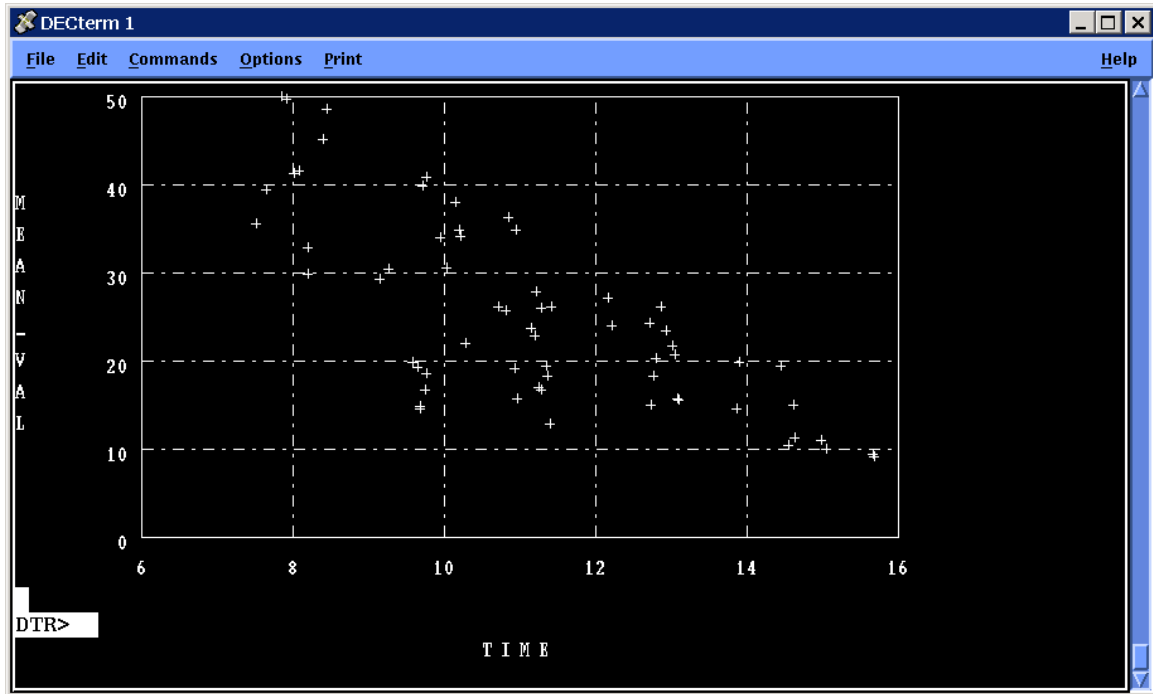Internal error (expected block id 10, encountered id 4). *(command procedure failure)*
DTR> **plot x_y time, m_val of range_flex** *(re-enter command using Datatrieve syntax)*

DTR> **plot x_y time, m_val of range_flex with id gt 800** *(select only recent ice sheets)*

DTR> **plot x_y time, m_val of range_flex with id gt 800 and ATT bt 1.7 and 2.2**
(ensures that plot shows only ice sheets tempered at ~2°C)

DTR> **:seed**

       FDH18

USE FDH FOR -18 =   163.6 ?
Enter Y or N: **y** *(accepts the calculated value based on –18° freezes & compares favourably with equation in spreadsheet)*

       FDH20

USE FDH FOR -20 =   161.8 ?
Enter Y or N: **y**

       FDH22

USE FDH FOR -22 =   156.3 ?
Enter Y or N: **n** *(rejects the calculated value based on –22°, probably too low)*
Enter NEW FDH: **159** *(a more likely estimate made)*
Enter ESTIMATE OF TEMPERING TIME (Hrs.): **8** *(from plots)*
FASTEST TIME IS: 15.2 Hrs.   SLOWEST TIME IS 17.1 Hrs.

FOR 10 AM TEST TIME

SEED OVER @ 16.9 Hrs. Freeze @ -18 for 09.1 Hrs. START WARM-UP @ : 26.0 Hrs.
Perimeter heat on : 12.4 Hrs. Water up for : 15.9 Hrs.
Start seeding 16.4 Hrs. TEST 1000 Hrs. NEXT DAY

SEED OVER @ 17.9 Hrs. Freeze @ -20 for 08.1 Hrs. START WARM-UP @ : 26.0 Hrs.
Perimeter heat on : 13.4 Hrs. Water up for : 16.9 Hrs.
Start seeding 17.4 Hrs. TEST 1000 Hrs. NEXT DAY

SEED OVER @ 18.8 Hrs. Freeze @ -22 for 07.2 Hrs. START WARM-UP @ : 26.0 Hrs.
Perimeter heat on : 14.3 Hrs. Water up for : 17.8 Hrs.
Start seeding 18.3 Hrs. TEST 1000 Hrs. NEXT DAY

FREEZE @ -18 USES 09.1 Hrs.   163.6 FDH   9816.0 FDM

FREEZE @ -20 USES 08.1 Hrs.   161.8 FDH   9708.0 FDM

FREEZE @ -22 USES 07.2 Hrs.   159.0 FDH   9540.0 FDM

To calculate test time from a seed time type :RECALC

(all the above results are quite acceptable with warm up scheduled to start at 2 a.m. the morning after the seed)

DTR> **:recalc** *(an example if one could not seed earlier, or wanted a later test time)*
Enter SEED FINISH TIME (decimal hrs.): 20
Enter TEMPER TIME (decimal hours.): 8

Perimeter heat on 15.5 Hrs. Water up for 19.0 Hrs. Start seeding @ 19.5 Hrs.

Freeze @ -18 for 09.1 Hrs. Start warm-up @ 05.1 Hrs. TEST AT 13.1 Hrs.
NEXT DAY.

Freeze @ -20 for 08.1 Hrs. Start warm-up @ 04.1 Hrs. TEST AT 12.1 Hrs.
NEXT DAY.

Freeze @ -22 for 07.2 Hrs. Start warm-up @ 03.2 Hrs. TEST AT 11.2 Hrs.
NEXT DAY.

Appendix B

Work Instruction for Using the Datatrieve Procedures to Schedule an Ice Sheet

Appendix B

Work Instruction for Using the Datatrieve Procedures to Schedule an Ice Sheet

Refer to example in Appendix A as required.

1. Enter Datatrieve by entering **DTR** at a VMS prompt.
2. The default ice type database is the Model – Unbubbled ice. If this is the one required jump to Instruction 5, otherwise enter finish **flex_strength** at the DTR prompt.
3. Enter command **:bubble** , **:fresh** , or **:unseeded** to move into the required ice type database. *(Procedure for scheduling within the Unseeded ice type has not been prepared at time of writing)*
4. Enter **ready disk$ap:[ap.databases]ap.ice.analysis.flex_strength**
5. Enter **:sched**
6. Confirm you are in the correct ice type by answering **y** on **n** to the prompt. If y you will proceed. If n the program will abort and proceed to Instruction 2.
7. Enter either the **value** for the target thickness you require, or the lower limit to the thickness range you require.
8. Enter either the **value** for the target thickness you require, or the upper limit to the thickness range you require. The mean of the two values must equal the required target thickness.
9. View the displayed list of ice sheets on the screen. If you think the number of sheets is insufficient for your purpose abort the procedure with **Control Z**, restart at Instruction 5 and widen the range, otherwise continue.
10. Enter a lower **value** for the flexural strength range you are interested in.
11. Enter an upper **value** for the flexural strength range you are interested in.
12. View the computed FDH information on the screen. Compare the displayed values with individual ice sheet information in the screen lists and compare with results from the empirical freeze model in the spreadsheets.
13. Enter **:plotsched**. If an error occurs type the complete command **plot x_y time, m_val of range_flex** .
14. From the plot estimate the amount of time required to reach the target strength. If necessary, improve plot by appending plot command with terms such as **with id gt** , **ATT bt** , and/or **time lt** .
15. Enter **:seed** and at the prompts either accept or reject with a **y** or **n** the program's FDH value for each of the three standard freezing temperatures. If **n**, then you are prompted to enter your best estimate.
16. Now at the prompt enter your best estimate for the tempering time. The program now displays on your screen the details for each of the three default freezing temperatures that will give a 10 a.m. test time. If any of these are acceptable to you proceed to Instruction 18.
17. If Instruction 16 does not provide the information you need, then at the prompt, enter **:recalc** and as required enter a suitable seed finish time (in decimal hours) and the estimated temper time. The program now displays the new test time for each of the three default freezing temperatures. If one of

those is acceptable to you then proceed to next instruction, otherwise repeat this instruction with new seed finish time until an acceptable result is obtained.

18. Obtain a print out of your results. This can be done by scrolling up to the start of procedures and selecting the text with the mouse and the keyboard down arrow, then using the edit copy command from the top menu bar and pasting into something like Notebook (from the Windows task bar – Start – Programs –Accessories –Notebook). Obtain a print out and keep for reference. If desired the file can be stored electronically though it has not been standard practice.

19. Repeat from Instruction 3 for each different ice sheet (previous commands can be recalled by using the keyboard up arrow).

20. Enter **Exit** to exit Datatrieve.

21. Sketch out a draft schedule based on the times acquired above taking into account model installation times, length of test days, etc.

22. At the VMS prompt enter SET DEF DISK$PROJECT2:[PJ88084.SCHED], or just SCHED if you have this assigned in your login.com file.

23. Using one of the edit commands such as EDIT/TPU either call up the blank schedule form SCHED.LIS or select a previously stored file for edit. Before proceeding any further use the WRITE command with a new file name to save your new file. The file name is normally based on the ice sheet names (see below) and is normally of the form SHELLSCHED1.LIS, for example.

24. Fill out the schedule (see Appendix C for an example) either as single or two week period, Sunday to Saturday. Limit the ice sheet name to seven, or preferably six alpha characters immediately followed by one or to numerals for no more than eight alpha numeric characters as in SHELL21, for example. Append this name with the chronological number of the ice sheet, as for example, SHELL21.1143. Note that this number is only for counting the number of ice sheets and is not to be used in file names.

25. Complete schedule, save, exit the editor, obtain a print out of the schedule, check for errors, re-edit and amend as necessary. Obtain a final print out.

26. Have the Project Manager sign and date the schedule, then make photocopies.

27. Distribute the schedule keeping the original in the Ice Tank office. Distribution may vary according to the complexity of the tests but normally include:

    Refrigeration Control Room (Essential!)
    Ice Tank Staff (Essential!)
    Project Manager
    FESM supervisors
    OWTF Supervisor
    Fabrication Supervisor
    Electronics Supervisor
    Director Facilities
    On site clients

Appendix C

Example of an Ice Sheet Schedule

Appendix C

Example of an Ice Sheet Schedule

REVISED 24 Feb 2006

ICE TANK SCHEDULE Project #:2155_18

DAY/DATE	TEST NAME	TEMP REQD	REMARKS
SUN FEB 19		2000->-5	Install rock berm model Chillers on, bubblers on ~ 2000 hrs.
MON FEB 20	KCO1.1015	0 1930->-20 -18	O/W Shakedowns Perimeter heat on 1930 Start seeding 2330 hrs., over 2400 hrs. Freeze @ -18 for 4.5 hrs. 4,740 FDM's
TUES FEB 21		0430->0 +0	Start warm-up ~ 0430 hrs. TEST 17 mm, 80 kPa CD ICE 0830 hrs.
WED FEB 22	KCO2.1016	1230->-20 -18	Perimeter heat on 1230,water up for 1600 Start seeding 1630 hrs, over 1700 hrs. Freeze @ -18 for 12 hrs. 13,080 FDM's
THURS FEB 23		0500->+2 +2	Start warm-up ~ 0500 hrs. TEST 35 mm, 80 kPa CD ICE 1000 hrs.
FRI FEB 24			
SAT FEB 25			
SUN FEB 26	KCO3.1017	1830->-20 -20	Perimeter heat on 1830,water up for 2200 Start seeding 2230 hrs, over 2300 hrs. Freeze @ -20 for 11 hrs. 13,080 FDM's
MON FEB 27	KCO4.1018	1000->+0 +0 1800->-22 -22	Start warm-up ~ 1000 hrs. TEST 35 mm, 80 kPa CD ICE 1400 hrs. Perimeter heat on 1800,water up for 2100 Start seeding 2130 hrs, over 2200 hrs. Freeze @ -22 for 25.0 hrs, 32,700 FDM's
TUES FEB 28		-22 2300->+2	Start warm-up ~ 2300 hrs.
WED MAR 1		+2	TEST 70 mm, 80 kPa CD ICE 1500 hrs.
THURS MAR 2	KCO5.1019	0 1530->-22 -22	Remove rock berm, install steel berm Perimeter heat on 1530,water up for 1900 Start seeding 1930 hrs., over 2000 hrs. Freeze @ -22 for 10 hrs. 13,080 FDM's
FRI MAR 3		0600->+0 +0	Start warm-up ~ 0600 hrs. TEST 35 mm, 80 kPa CD ICE 1000 hrs. Raft portion of sheet and TEST 70 mm.
SAT MAR 4			

PROJECT MANAGER: _____ DATE: 24 Xb '05

***** Demobilise equipment on Monday