MECHANICAL SUPPORT DEPARTMENT
ENGINEERING NOTE

NUMBER: MSD EN-1119 - KTeV
(WBS number items 1.1.1.9 - Vacuum Window)

DATE: 19 May 1995

TITLE: ANALYSIS OF THE KTEV WINDOW CREEP TEST

AUTHOR(s): Jim Kilmer

REVIEWED BY: Tom Shrymp

DATE REVIEWED: 5-22-95

KEY WORDS: KTeV Vacuum Window, Sailcloth Vacuum Window, Vacuum Window Failure Analysis, Vacuum Window Safety Barrier

ABSTRACT/SUMMARY:

This document is an analysis of the data from the six month long creep test of the KTEV vacuum window. The conslusion reached is that the window can be safely used for a period of at least two years of continuous operations without the possiblility of creep rupture failure.

Since November 1, 1994 the KTEV vacuum window has been undergoing a creep test at full vacuum. Creep failure of the window is expected to be the most likely failure mode which can be predicted. The test is accomplished by installing the window in the test fixture and pumping down. Periodically the vacuum is checked and at the same time the deflection of the window is measured in the center with an optical level.

The data from the first six months of the test are shown in figure 1. The graph shows the measured displacement versus time, the standard way to display creep data. From this figure it can be seen that the creep is clearly in the secondary creep phase. Kevlar shows a very long period of secondary creep. Figure 2 shows the measure data on kevlar fibers from DuPont. DuPont shows data points for 16,000 hours or two years on their graph. Our data has been drawn in over the top of their data for comparison. Note that the stress on the KTEV window is the same as the stress on the yarn fibers for the DuPont graph, so the comparison is legitimate.

To calculate the percent elongation of the central fibers the window is assumed to be shaped like a spherical dome. Let

r = radius of the window
R = radius of the spherical dome
h = height of the spherical dome

See Figure 3. Then

$$R^2 = r^2 + (R-h)^2$$

$$R = (r^2 + h^2) / 2h$$

The arc length can be calculated from

$$s = 2R\sin^{-1}(r / R)$$

$$s \cong 2r\left\{1 + \frac{1}{6}\left(\frac{2hr}{r^2+h^2}\right) + \frac{3}{40}\left(\frac{2hr}{r^2+h^2}\right)\cdots\right\}$$

The change in height dimension from the undistorted flat window to the first day's initial reading is 6.16 inches. In this report the measured creep numbers are always added to 6.16 inches to get the actual window distortion (h in the above equations) on that day. It is obvious that the largest stress (and strain) is on the center yarns crossing at the diameter. All other yarns are progressively less loaded. Inspection of the four windows that were tested to destruction hydraulically shows this. The tearing region is centered on the threads that run through the center of the window. Using the initial displacement in the formulas above gives an initial strain of 1.99% elongation as compared to the original length of 71 inches.

The results of this test show several important points demonstrating the safety of this window design.

1. In the DuPont data kevlar is shown to have a breaking elongation of 4%. After six months of testing so far the window has only shown an elongation from creep of 2.13%.
2. DuPont data shows that yarns of kevlar are not destroyed by creep at 50% of ultimate stress for at least two years under load.
3. Strains in the KTEV window creep at a slower rate than the data presented by DuPont for single yarns. The explanation for this further argues for the safety of the design. In the window as the highest loaded fibers elongate because of creep the neighboring fibers are

then able to pick up more of the load. This "relaxation" of load results in slower creep rates for the entire window by distributing the maximum load over more fibers.

The test will be continued for additional time consistent with the KTEV installation schedule. It can be seen from the testing done so far that this window can safely be used for any KTEV running schedule now in use. It is possible to estimate the value of strain in the future on the window by using a linear extrapolation. The following equation can be fitted to our measured data:

$$s = 2.1\% + \frac{.03\%}{180 days} t$$

where s is the total strain on the window and t is given in days under vacuum. Using this formula after two years the total strain in the window would be 2.22% which is still far from the breaking elongation point of 4%.

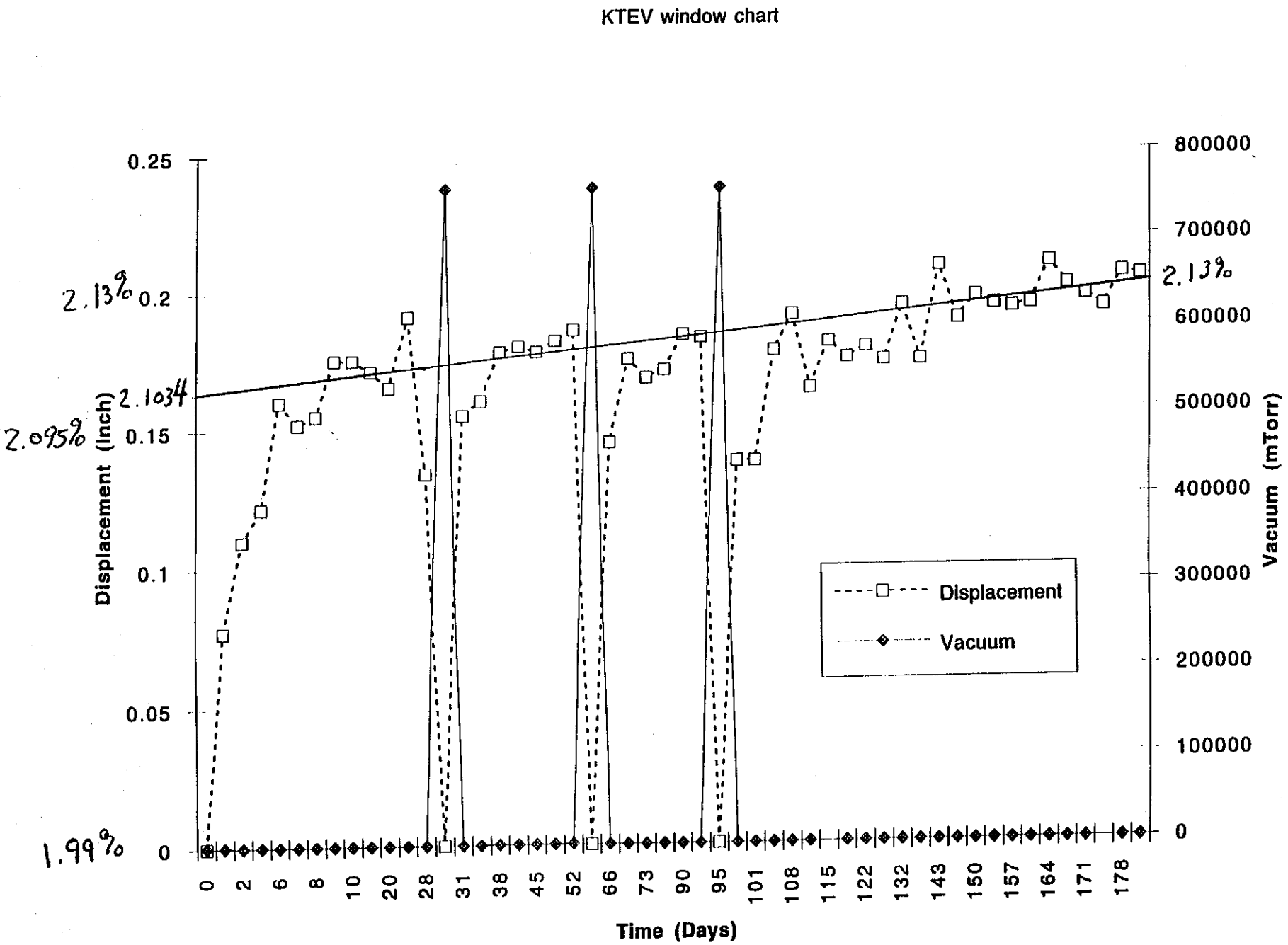
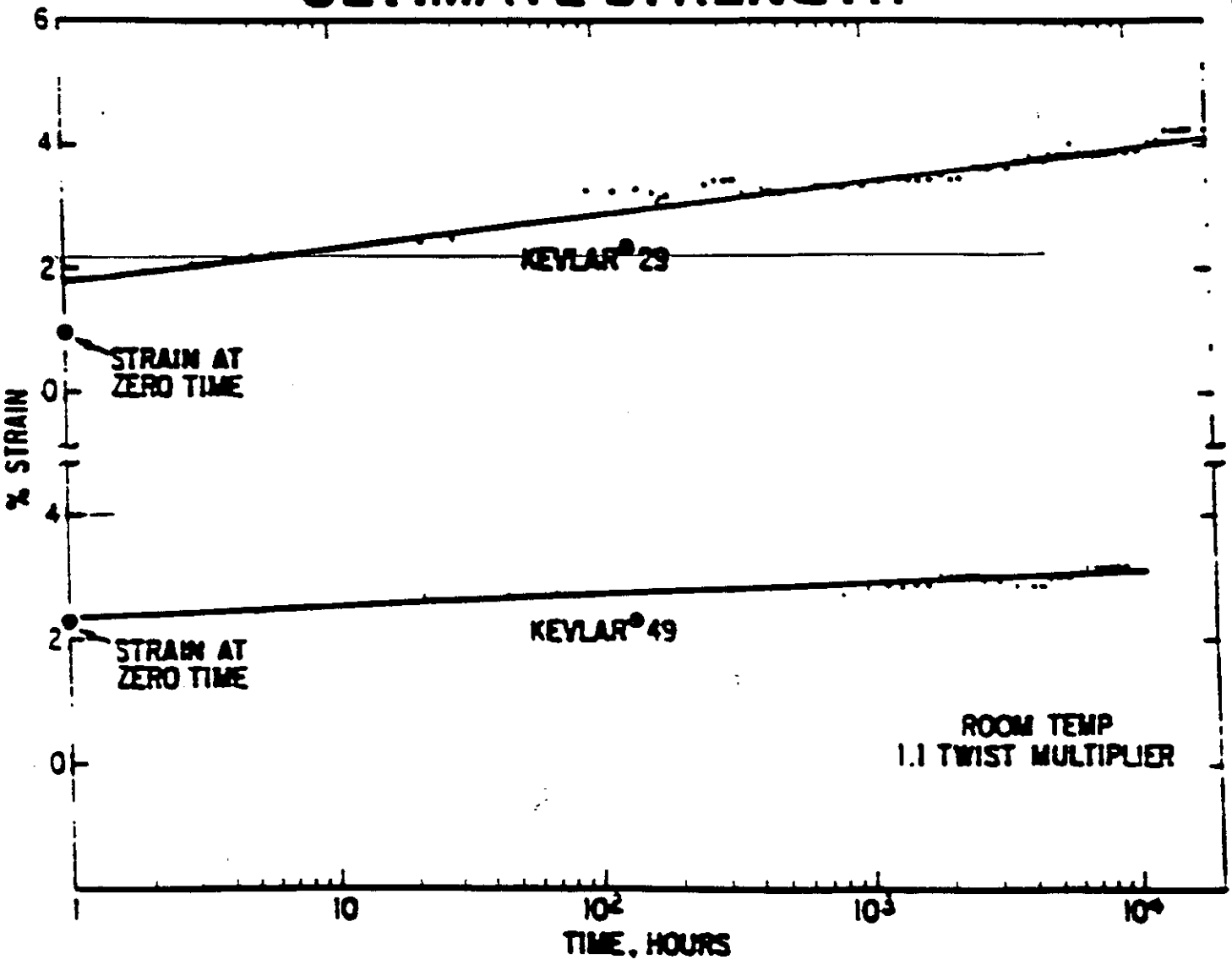

KTEV window chart
Displacement (Inch)
Vacuum (mTorr)
Time (Days)
Displacement
Vacuum
0.25
0.2
0.15
0.1
0.05
0
800000
700000
600000
500000
400000
300000
200000
100000
0
0
2
6
8
10
20
28
31
38
45
52
66
73
90
95
101
108
115
122
132
143
150
157
164
171
178
2.13%
2.1034
2.095%
1.99%

FIGURE 1

[redacted]

CREEP OF YARNS OF KEVLAR® 29 AND KEVLAR® 49 ARAMID AT 50% OF ULTIMATE STRENGTH



*Du Pont registered trademark

FIGURE 2

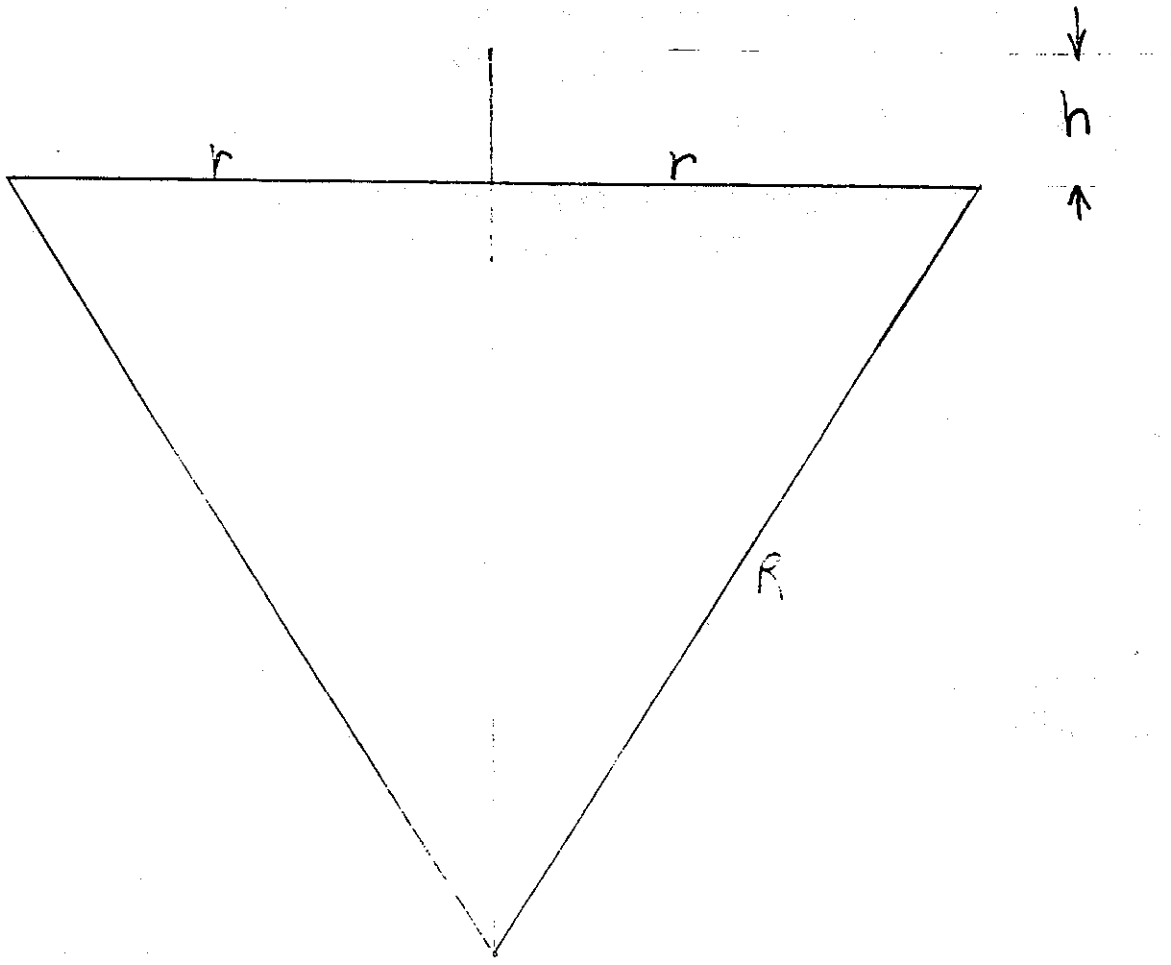


Figure 3

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October 6, 1994

TO: R. Stanek
J. Kilmer

FROM: A. Szymulanski

SUBJECT: KTeV 1.8m Vacuum Window Creep Test

This is to inform all interested parties that we are planning to perform a 6 month duration fabric tension creep test for the KTeV 1.8m kevlar window assembly.

The equipment is installed in the "TSB" building on the northeast side from the building's main entrance. This area is secured according to the requirements of the original testing document ("KTeV 1.8m Vacuum Window Testing Procedure", R. Currier, A. Szymulanski dated March 8, 1994). The testing involves possible health hazards such as 128 db noise, flying materials, etc. To safely handle the testing, it is recommended to follow specific requirements as given below:

1. Locate on each side of the entrance doors the sign:

   VACUUM WINDOW TEST IN PROGRESS - WEARING OF SAFETY GLASSES AND EAR PLUGS IS MANDATORY FOR ENTERING THE BUILDING"

2. The entrance is required to be normally locked during testing. (the "EAD" No. 10 keys to the 'TSB" area are located in the "MAB" building, Don Carpenter's office, and the Experimental Area Control building.

3. No one is allowed to be closer than 10 feet from the vessel when test is in progress. The secured area will be roped off, and signs will be provided to indicate this requirement.

4. When an access to that area is required during the time of testing, it shall be authorized by Andrew Szymulanski, x4870 or Don Carpenter, x3366. It is required to bleed the vacuum space of the test vessel and equalize at atmospheric pressure. Following the equalization to atmospheric pressure the area is safe and open for personnel to enter.

5. A stroboscopic lamp will be installed inside the roped area. When the test is in progress, the lamp shall be active and flashing.

It is anticipated that all interested parties will analyze and determine their needs for the duration of the test and inform me of those needs before test time. The test should take place this month. Please respond before October 17, 1994.

AS:ed

Attachment:
KTeV 1.8m Vacuum Window Overview of Test Procedure

Copies to:
D. Carpenter
P. Czarapata
D. Jensen
D. Johnson
W. Nicholson
D. Pushka
W. Smart/J. Misek
A. Stefanik

R.Currier
A.Szymulanski
March 8,1994

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KTeV 1.8m Vacuum Window
Overview of Test Procedure

This test is required to provide a suitable, safe, non metallic vacuum window for the KTeV experiment, which is running during the next fixed target run. To determine if the design of this window meets all of the parameters of the experiment and the KTeV ES&H Review Committee,the following set of tests were devised. The first test, initial pump down, proves that the window design works. The puncture test will give us an idea how the window will fail, if a hole were to develop (material failure), or was accidentally penetrated. The initial pump down and puncture test will require a single pressure test permit. The hydrostatic test is intended to give us an idea of the safety factor of the window and will require a separate pressure test permit. The long duration creep test will give us information on how the window survives or fails over a long period of time. If there are any deviations from expected results during any test, the tests will be stopped until the deviation can be understood then explained in writing to the KTeV ES&H Review Committee, exactly what happened, why, and how it will affect the rest of the test program. Interesting phases of the test should be put on video tape.Present at the beginning of each phase of the tests should be a representative of the ES&H Dept , the KTeV experiment, the KTeV ES&H Review Committee, Don Carpenter and Andrew Szymulanski.

Safety considerations:

A) During the vacuum test, no one will be allowed within 10 feet of the test vessel. This is to be assured by roping off the test area, appropriate signs, (keep-out test in progress), and supervisory vigilance.

B) Safety glasses and safety shoes are requirements of anyone working at MAB. Test observers will be required to wear safety glasses at all times.

C) Hearing protection will be required of all personnel in the building during the initial pump down, subsequent pump downs and during the puncture test only.

1) Make a kevlar and aluminized mylar, sandwiched window, and assemble with flanges etc. as specified on Dwg.# MD-285394 and attached information. Inform Andrew when starting, so the KTeV ES&H Review Committee and the experiment can be notified.

2) Set up for vacuum test as shown on Dwg.#MD-285391 and schematic attached. Arrange for surveyors.

2a) Prepare for pump down by clearing the test area and setting up as specified in A) above.Check for eye and hearing protection and display pressure test permit.

2b) Pump down test chamber to a minimum of 29" Mercury(Hg) and remotely measure and record the deflection of the window every 2 hours.The remote measuring is to be accomplished by using optical surveying instruments looking at the scale mounted in the center of the thin window as shown on page 7B. Shut down overnight and bleed up to atmosphere. Pump down again in the AM recording the deflection every 2 hours. Shut down overnight and bleed up to atmosphere. Pump down again in the AM to 29" Hg then shut down and bleed up to atmosphere.

e same window, prepare for puncture test. Follow the design data of sketch 1'.

Prepare for pump down and puncture test by clearing the test area and setting up as specified in A) ve.Check for eye and hearing protection and display pressure test permit.

Set up puncture device as shown on attached sketch, start pumping down test chamber. At 29" Hg.

After double checking all of the appropriate safety precautions, remotely release spear to puncture idow.

ıg the first window worked, make a second window and proceed to Hydraulic test. Notify veyors.

or hydrostatic test inside the MAB shop per schematic attached. Assemble test chamber and place 2 x 4 to elevate bleed valve (as shown on attached sketch).Make sure to display pressure test permit.

Fill test chamber with water (make sure bleed valve is open.) After filled, lift chamber with crane ıg appropriate slings and rigging techniques. Remove 4 x 4s from under legs.(as shown on ıched sketch)

) Prepare for hydrostatic test by clearing the test area and setting up as specified in A) ove.Check for eye protection.

) Pressurize test chamber, as shown in subsection 3, using a hydrostatic tester pump, to 15psig n carefully measure the window deflection. Continue to add pressure and remotely measure flection at 5psig increments, to destruction of window or 45psig whichever comes first. (failure pected at 31psig to 38psig)

) Clean up mess, then disassemble window flanges and check window, o-ring, and aluminum ring irregularities.

ıformation learned from the fabrication of the first windows, make another window for the long 3 month, creep test.

) Find an area in the shop, out of the normal traffic pattern, away from people and well protected from casual contact to set up the test chamber and new window.

) Prepare for pump down and long duration creep test by clearing the test area and setting up as specified in A) above.

) For the duration of the test, maintain the area to the same degree of security and safety as originally set up.

) Test chamber and window are to be under vacuum, with vacuum pump running, 24 hours a day 7 days a week.

) Bleed up to atmosphere once per month, over the weekend only.

) Record the pressure level in a log at the start and the finish of each working day for the duration of the test. It's not necessary to use a strip chart recorder.

6g) It is possible that the window will creep,or move, or maybe even stretch, over a period of time. The result would be an increase in deflection. If the measured deflection is ever greater than the original by 1/4" notify Andrew.

6h) Remotely measure and record the deflection of the window each day for the first week.

6j) If a measurable change is not indicated during the first week then measure and record the deflection of the window at the end of the first and last day of the second week.

6k) If a measurable change is not indicated at the end of the second week then measure and record the deflection of the window at the end of first day of each week for the duration of the test.

6m) The duration of the test is expected to be 6 months.

6n) If any peculiarities or problems are encountered, call Andrew @ x4870.

Fermilab

September 23, 1994

TO: W. Smart/J. Misek
KTeV ES&QA Review Committee

FROM: A. Szymulanski — A. Sz —
KTeV Engineering

SUBJECT: 1.8m KTeV Vacuum Window Creep Test

This is to inform you that we are finishing the vacuum window creep test assembly installation. The installation is localized in TSB building. The arrangement will be ready for visual inspection next week.

The window assembly has been fabricated in the same way as hydrostatic test window No. 4, with controlled pneumatic pre stretch of the mylar/kevlar fabric.

During the hydrostatic testing we have reached the following failure pressure readouts:

1. 28 psig
2. 28 psig
3. 24 psig
4. 28 psig

That translates to safety factor values of 1.9 for tests 1, 2, 4 and 1.63 for test No. 1. The average value for all tests matches the range specified in the finite element analysis; "Engineering Analysis Report (EAR) No. 121; Ang Lee, RD/MSD, May 13, 1994.

The planned long duration creep test should give us more information on the performance of the window, under conditions matching those of a real application.

AS:ed

Copies to:
D. Carpenter
J. Kilmer
A. Stefanik

Fermilab

Date MARCH 22. 94

EXHIBIT B

Pressure Testing Permit*

Type of Test: VACUUM [ ] ~~Hydrostatic~~ [ ] ~~Pneumatic~~

Test Pressure: 14.7 NEGATIVE psig Maximum Allowable Working Pressure: 45 psig

Items to be Tested 1.8 m KTEV VACUUM WINDOW REF. DWG. 9220.832.MD-285394

Location of Test M.A.B. Date and Time MARCH 28.94 9AM

Hazards Involved RUPTURE OF THE WINDOW COMPONENTS, WHAT MAY GENERATE ABNORMAL SOUND LEVEL. OTHER HAZARDS RELATE TO TYPICAL INDUSTRIAL INSTALLATION WI

Safety Precautions Taken SEE SUBSECTION 1 OF THIS ELABORATION

Special Conditions or Requirements TESTING PROCEDURE HAS TO BE CONSISTENT WITH; " KTEV 1.8m VACUUM WINDOW OVERVIEW OF TEST PROCEDURE

Test Coordinator ANDREW SZYMULANSKI Dept/Date

Division/Section Safety Officer W.B. Wilson for T.J. Sarlina Dept/Date RD/ES&H 3-22-94

Division/Section Head [signature] Dept/Date RDO 3/23/94

Results

Witness (Safety Officer or Designee) Dept/Date

* Must be signed by division/section safety officer and division/section head prior to conducting test. It is the responsibility of the test coordinator to obtain signatures.

March 21, 1994

TO: R. Dixon - Research Division Head

FROM: J. Misek and W. Smart - KTeV ES&H/QA Review Committee J. Misek W. Smart

SUBJECT: KTeV 1.8 m Vacuum Window Test Procedure Review Report - Recommendation to Proceed

Pursuant to the Committee charter, a summary report of the compliance status for the KTeV Window Test program - WBS 3.1 is provided. Mechanical aspects were the primary focus of this review, though per the WBS List, electrical and conventional safety aspects were also to be included. The Committee has no electrical or conventional safety concerns for this testing program.

Committee members J. Misek, R. Bossert, E. Haggard, P. Hurh, and W. Smart have reviewed documentation received from KTeV Engineering Staff outlining the testing program and conclude that sound engineering practices have been employed. In addition, the Committee made an inspection walkthru of the test area and viewed the equipment setup. This walkthru was made on 3/2/94 and no deficiencies were noted.

The window testing program does not require adherence to any specific standards set forth in Fermilab's ES&H Manual. The *KTeV E-832 1.8 m Vacuum Window Testing Procedure for Vacuum and Hydrostatic Tests* dated 3/8/94 is made part of this report. See attachment. Please note that the KTeV Engineering Staff and this Committee have agreed that they will observe the Fermilab Pressure Testing Permit formalism (Fermilab ES&H Manual 5034) with one permit to cover all vacuum testing and a second permit to cover the hydrostatic tests.

In making its recommendation to proceed with window testing in accordance with the attached documentation, the Committee would like to include as part of the documentation file W. Smart's calculations and discussion on the vessel movement from window failure.

Please note that the draft version dated March 4, 1994 of the *Window Assembly Procedure* is the current version. A change in the assembly procedure document does not require formal Committee action.

We recommend that you approve this testing program for the KTeV 1.8 m Vacuum Window.

I hereby approve the window testing program for the 1.8 m vacuum window subject to the conditions outlined above.

Roger L. Dixon
3-22-94

cc:
-without attachments-
W. Smart
P. Hurh
R. Bossert
E. Haggard
A. Szymulanski
D. Pushka