TS-SSC 92-033

10-Stack Studies of Polyimide-Epoxy Insulation Systems

R.E. Sims

2/12/92

Perceived disadvantages of Glass Tape System:

1. Breaks down at lower pressure (high voltage breakdown, BNL study).
2. Tears during winding - sharp corners on torn glass (usually requiring hand repair).
3. High friction in mold => Less uniform distribution of conductors and more size variation.
4. Larger epoxy volume => Hydraulically stretching Kapton can lead to insulation failure.
5. Limits current density. An all polyimide insulation wrap can permit lower insulation volume and allow an additional turn of superconductor.

Perceived disadvantages of eliminating Glass Tape:

1. Change cross-section. (Assumes minimum insulation approach).
2. Increases creep. Higher initial collaring forces would be required.
3. Reduced control of coil size variation from component size variation.
4. Lower modulus (but this may partially compensate for #3).
5. Larger thermal contraction.

Author: Perceived advantages of eliminating Glass Tape (assuming all Polyimide Film):

1. Greater high voltage breakdown in midplane.
2. Lower overall labor.
3. Although these experiments have shown that utilizing adhesive on every layer improves creep, microscopic studies reveal "adhesive leakage" onto cable strands. An optimum configuration may be to utilize adhesive on both sides of the outer layers of insulation with no adhesive on the inside layers of insulation (per contribution by Amanda Spindel.)

Revised 2/12/92

CONCLUSIONS

Based on small quantities of ten stacks made from DuPont Kapton types H, HA, and LT. The epoxy used on the Kapton was 3M #2290

1. Removing the Glass-Epoxy tape increases stress relaxation as much as 2 to 3 times (unless under layers of polyimide utilize adhesive. See 5 below).

2. This stress relaxation can be minimized by:

   a. Use as few layers of Kapton as possible.
   b. Use high molding pressures (≥ 10 KPSI)
   c. Stay in the mold longer, preferably at the curing temperature
   d. A single ten stack made using DuPont CI and RCI at 225°C (438°F) showed a stress relaxation about 16% greater than Glass-epoxy, i.e., very close to glass epoxy.

3. The Glass-Tape system accommodates approximately twice the material tolerance variation that 3 layers of Kapton can. (.015" for glass tape, .007" for 3 layers of Kapton).

4. Single Kapton insulation systems <u>with no inner layer adhesive</u> have 10% to 25% lower final coil modulus of elasticity.

5. It appears that coils made <u>with inner</u> and <u>outer layer adhesives</u> would have creep levels <u>equal to or better than glass tape</u>.

6. It is difficult to extrapolate coil size from ten stack size with good accuracy. (Curved stacks would be better.)

7. Allied Signal Apical type NP film appears to provide lower creep than DuPont Kapton type K (by apprx. 22% to 50% depending on wraps and layers of adhesive).

8. Apical type NP film also appears to make ten stacks with slightly higher modulus of elasticity properties (by roughly 15%).

9. If "Loaded" films have lower cryogenic shrink and lower bulk modulus than non-loaded films, then DuPont "LT" film should be the "top" layer of insulation.

10. When adhesive is utilized on layers closest to cable, small amounts of adhesive can be found on the cable. (Could these small amounts of adhesive crack, exotherm, and cause a quench?)

11. A Spindel (SSCL) suggested utilizing adhesive on <u>both</u> sides of the top insulation layers, but not on the bottom layers. This should produce a good compromise which cannot leak adhesive onto the cable.

Follow-on Steps

(R.E. Sims, Revised 2-20-92)

1. Examine "cookies" of the coils to determine the "flow" of the Kapton epoxy system. (DSI340 & DSI341)

2. Take apart Kapton epoxy stacks with first layer adhesives and search for any epoxy leakage on cable. (Cryorad done, do Kapton +2290)

3. Make some Kapton and Apical ten stacks with increased cure temperatures (+20°F) and increased time (+30 min) to gauge reductions in creep, etc.

4. Make cryogenic shrinkage measurement of an assortment of ten stacks while under constant pressure (12 K psi).

5. Obtain Apical NP film coated on both sides with Cryorad adhesive and Kapton LT film coated on both sides with 2290 adhesive. Evaluate the creep and modulus of elasticity of the following ten stacks:

DSA332, DCA322, 323 inner — a. 1/2 NP, butt NP coated 2 sides — 212 P
   1) Cured at 275°F, 90 min, 10 KPSI
   2) Cured at 295°F, 90 min, 10 KPSI
   3) Cured at 275°F, 120 min, 10 KPSI
   4) Cured at 275°F, 90 min, 6 KPSI — .2 mils .2

DSA332, DCA322, 323 outer — b. 1/2 NP, 1/2 NP coated 2 sides.
   1) through 4) same as above.

DSA333 inner — c. 1/2 H, butt LT coated 2 sides.
   1) through 4) same as above.

DSA333 outer — d. 1/2 H, 1/2 LT coated 2 sides.
   1) through 4) same as above.

6. Measure cryogenic shrinkage of the "1" and "4" ten stacks in #5 above.

COMPARISON OF POLYIMIDE FILM DATA

All data on 1 mil thick film unless noted

RICHARD E. SIMS February 4, 1992

Physical Properties	Dupont	HN	Dupont	Dupont	Dupont	Allied (-Apical)		Dupont	
	Typical Values	Test Conditions	H	HA	LT	AV	NP	120 CT-1	135 RCI
Physical Properties at (Temp.)	23° C (73°F)	200°C (392°F)	23°C	23°C	23°C	23°C	23°C	23°C, 1.2 Mil	23°C, 1.35 Mil
Ultimate Tensile (MD) Strength, MPa (psi) (36.000)	231 (33,500)	139 (20,000)	(32 K psi)	(31 K psi)	(24 K psi)	(35 K psi)	(44 K psi)	(30 K psi)	(20 K psi)
Yield Point (MD) at 3%, MPa (psi)	69 (10,000)	41 (6,000)				(10,000)			
Stress to Produce (MD) 5% Elongation, MPa (psi)	90 (13,000)	61 (9,000)				(13,000)			
Ultimate Elongation (MD),%	72	83	70	83	80	95	90	85	65
Tensile Modulus, GPa (MD) (psi)	2.5 (370,000)	2 (290,000)	(400,000)	(310,000)	(500,000)	2.92 (460,000)	4.26 (600,000)	(350,000)	(475,000)
Impact Strength, Kg-cm (ft-lb)	8(.58)								
Folding Endurance (MIT), cycles	285000			>1,000,000		>1,000,000	>150,000		
Tear Strength (MD)-Propagating (Elmendorf),g	7		16	35		8	7		
Tear Strength (MD) - Initial (Graves),g	729					520	600		
Density, g/cm3	1.42					1.42	1.45		
Coefficient of Friction - Kinetic (Film-to-Film)	0.48					0.40			
Coefficient of Friction - Static (Film to Film)	0.63					0.5			
Refractive Index (Becke Line)	1.66								
Poisson's Ratio	0.34								
Low Temperature Flex Life	Pass								
Dielectric Constant		3.4				3.4	3.3	3.5	3.8
Dielectric Strength V/Mil		7,700		6500	3500	7800	8000	6000	4500

NOTE: All information supplied by the manufacturers.

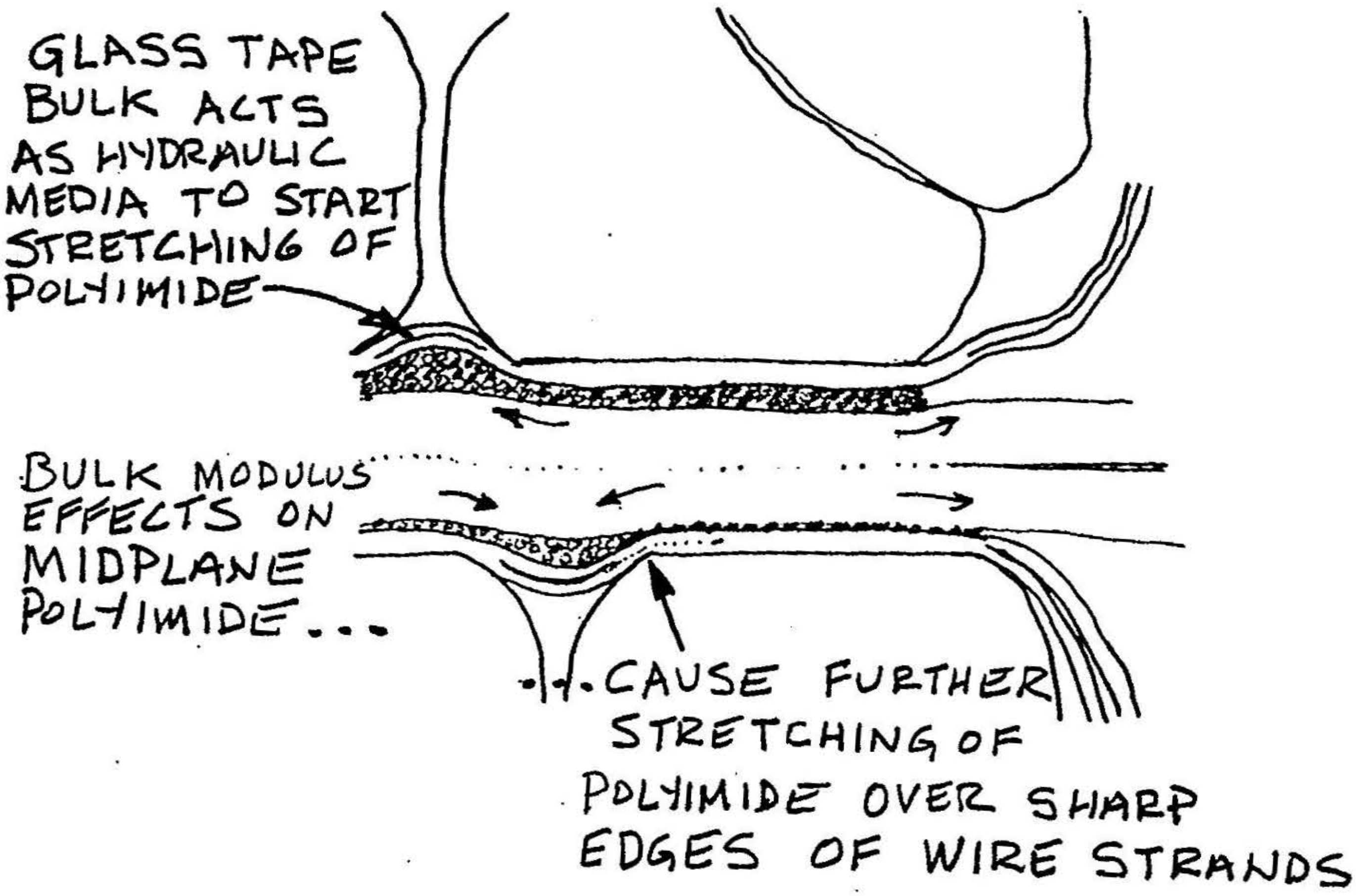
THERMAL PROPERTIES

RICHARD E. SIMS February 4, 1992

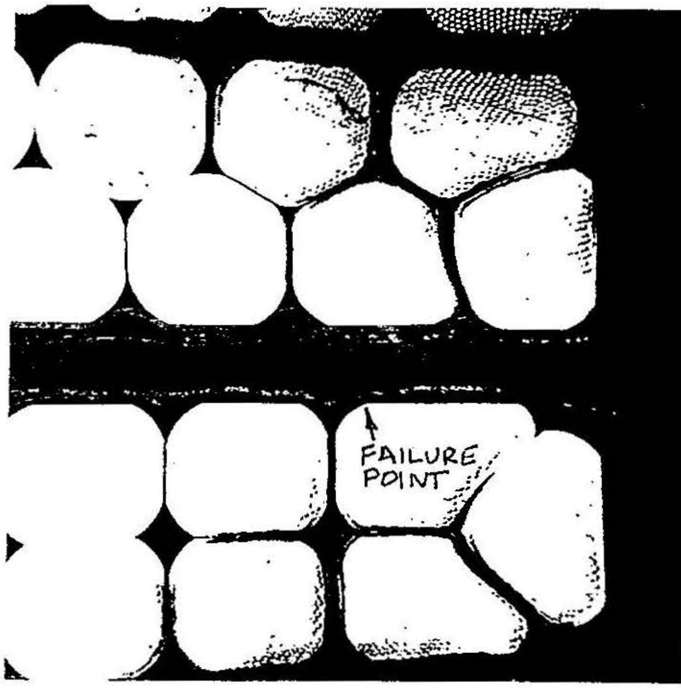
Thermal Properties	Dupont HN		Dupont	Dupont	Dupont	Allied (-Apical)	
	Typical Values	Test Conditions	H	HA	LT	AV	NP
Melting Point	none	none					
Thermal Coefficient of Expansion	20 ppm/°C (11ppm/°F)	-14 to 38°C (7 to 100°F)				2.1 X 10-8 In/In/°C	.8 X 10-50°C
Coefficient of Thermal Conductivity , W/m*K	.12	296°K					
(Cal) (cm)(sec)(°C)	(2.87 X 10-4)	23°C					
Specific Heat	1.09(.261)	°J/ g °K(cal/g/°C)					
Shrinkage, %	.17 1.25	30 min @ 150°C 120 min @ 400°C					
Limiting Oxygen Index, %	37						

NOTE: All information supplied by the Manufacturers.

POSSIBLE SCENARIO LEADING TO DIELECTRIC BREAKDOWN OF POLYIMIDE MIDPLANE INSULATION



R.E.SIMS 2-4-92

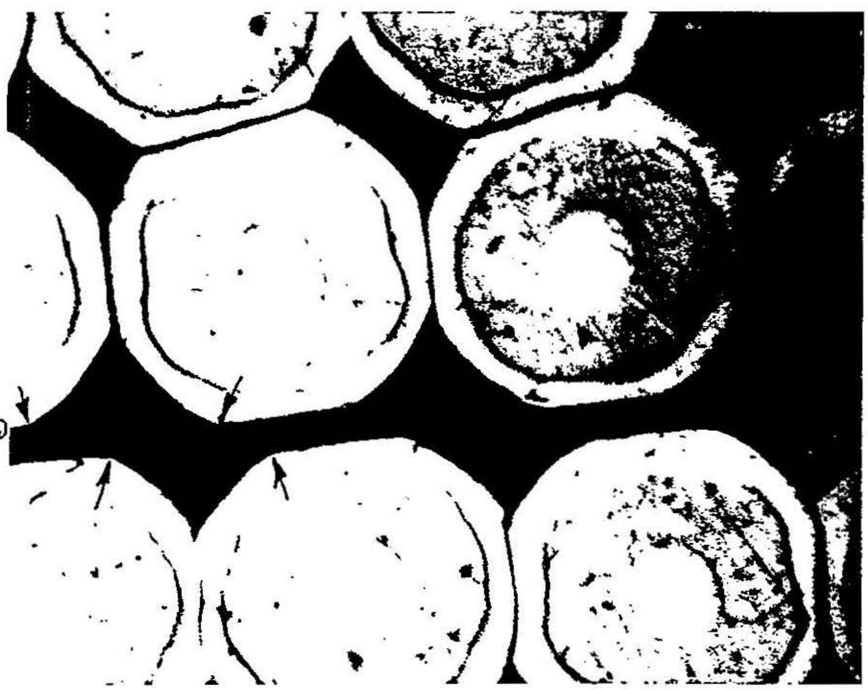


DSA 320

X32

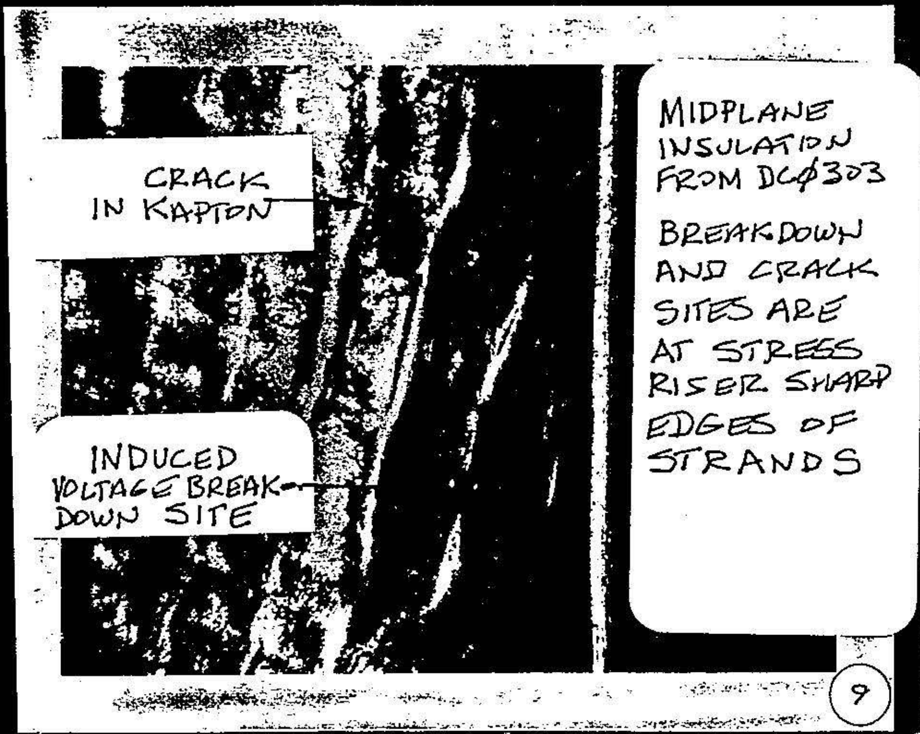
.005" INNER COIL MIDPLANE INSULATION (KAPTON H)

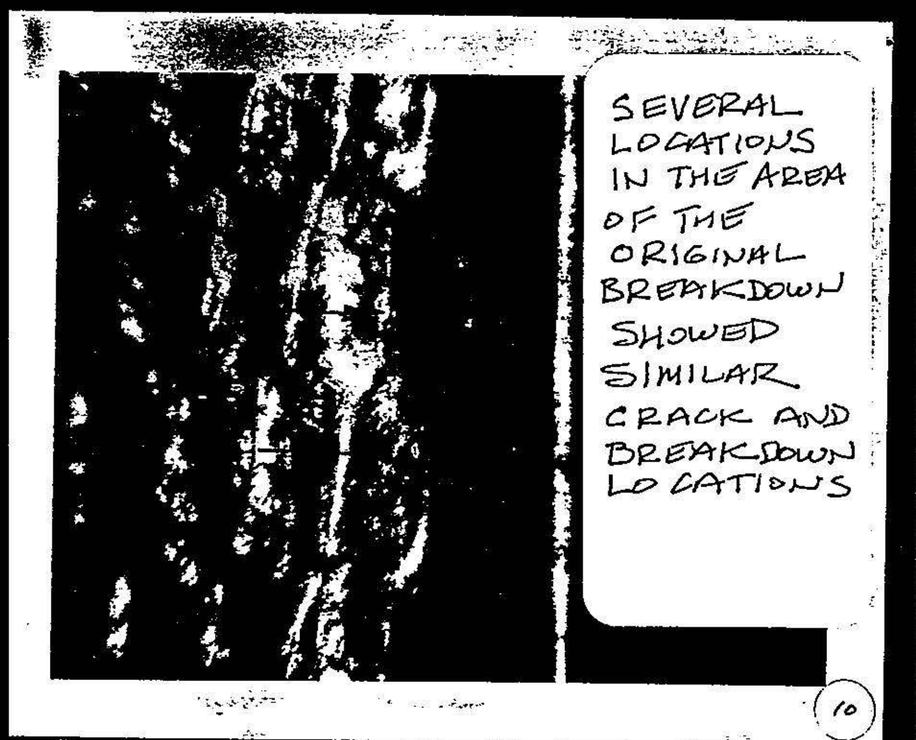
NOTE THAT INSULATION SHOWS BULK MODULUS EFFECTS FROM FLAT STRAND AREAS. THIS FURTHER STRESSES INNER KAPTON AGAINST SHARP EDGE OF STRANDS.



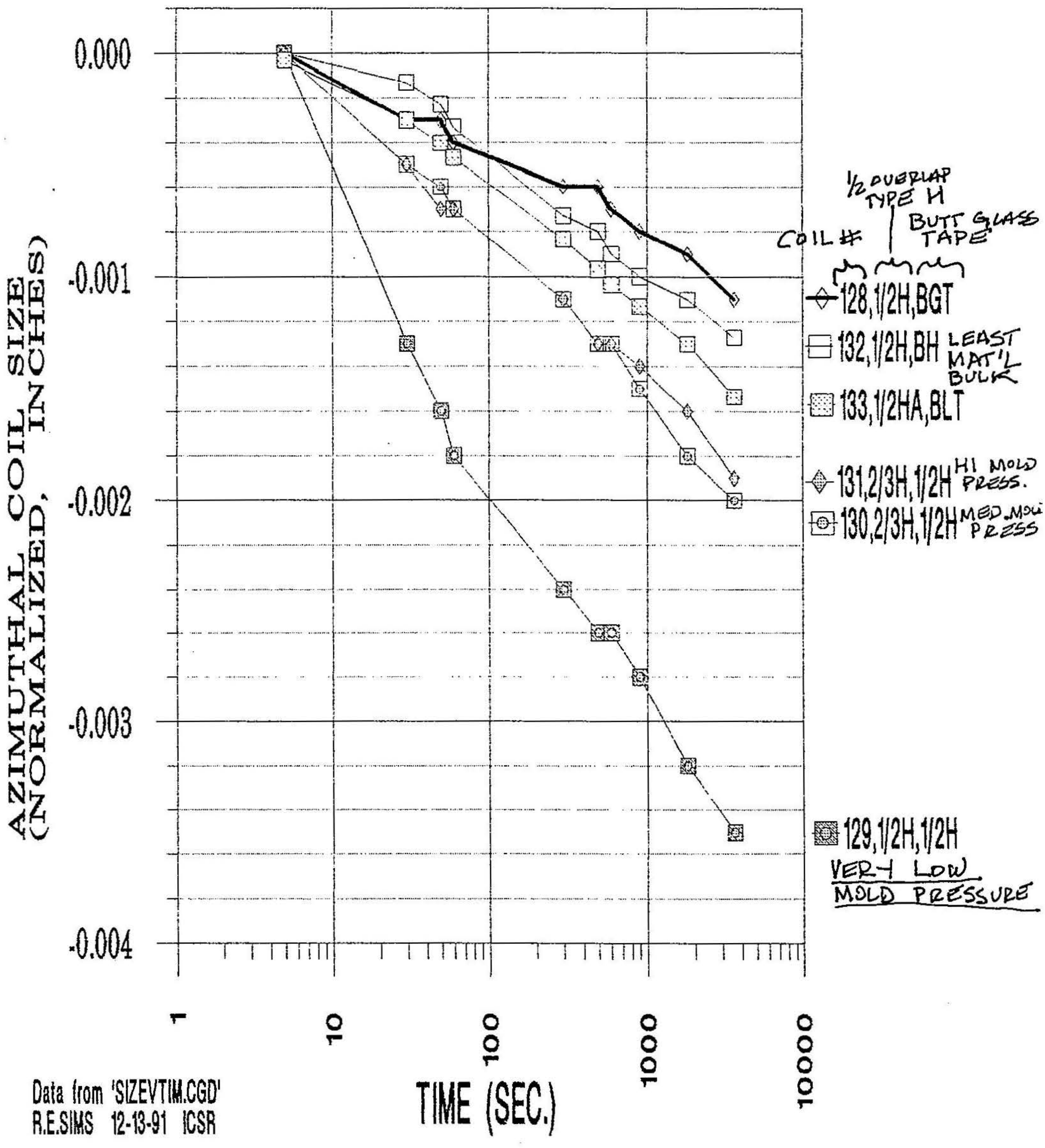
225°
#72
KAP ONLY
X64

WITHOUT GLASS TAPE KAPTON IS NOT STREACHED OVER SHARP EDGES


CRACK IN KAPTON
INDUCED VOLTAGE BREAK-DOWN SITE
MIDPLANE INSULATION FROM DCØ303
BREAKDOWN AND CRACK SITES ARE AT STRESS RISER SHARP EDGES OF STRANDS
9

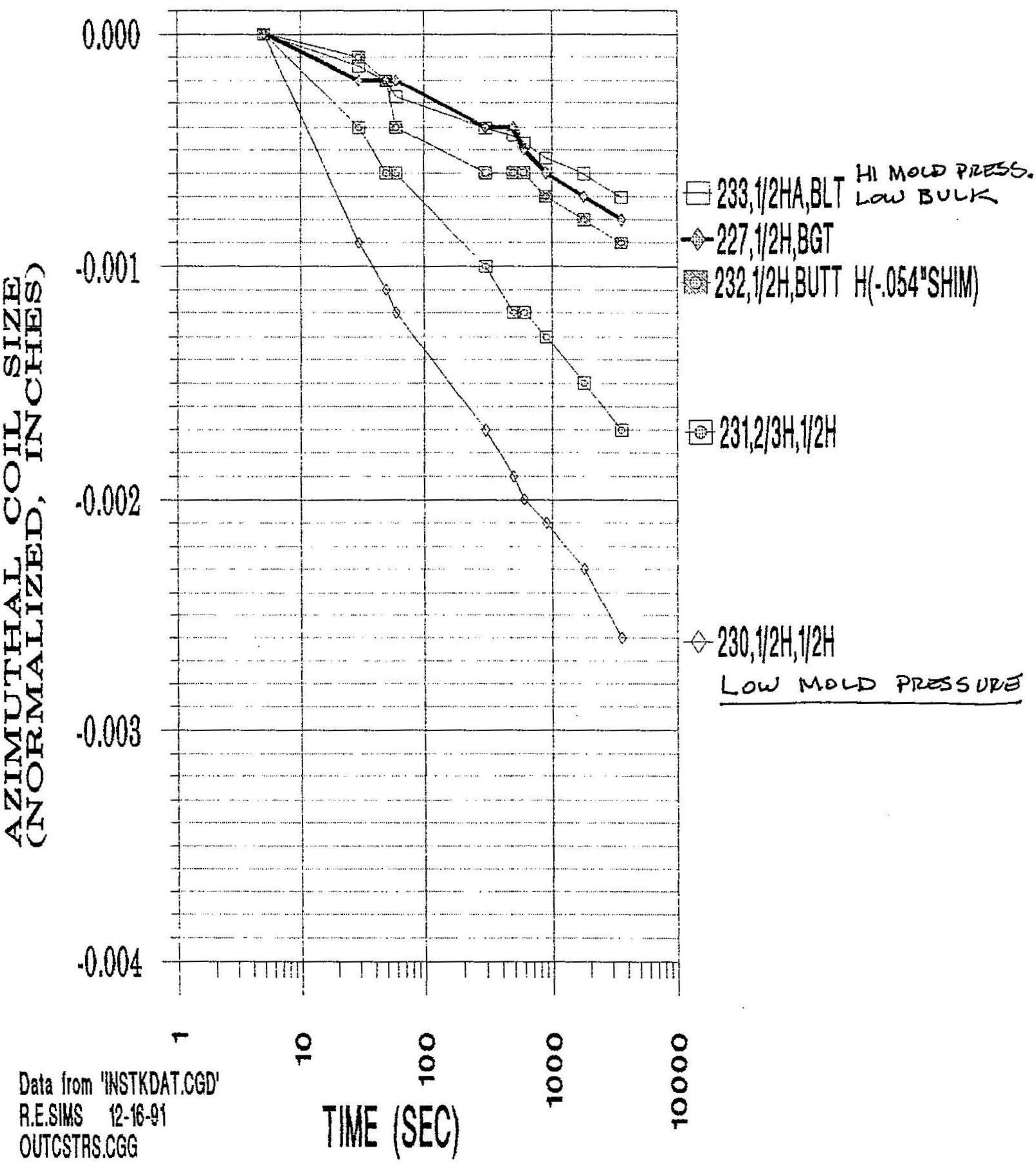

SEVERAL LOCATIONS IN THE AREA OF THE ORIGINAL BREAKDOWN SHOWED SIMILAR CRACK AND BREAKDOWN LOCATIONS
10

SSC 50 mm INNER COIL STRESS RELAXATION AT 12 KPSI WITH VARIOUS INSULATIONS



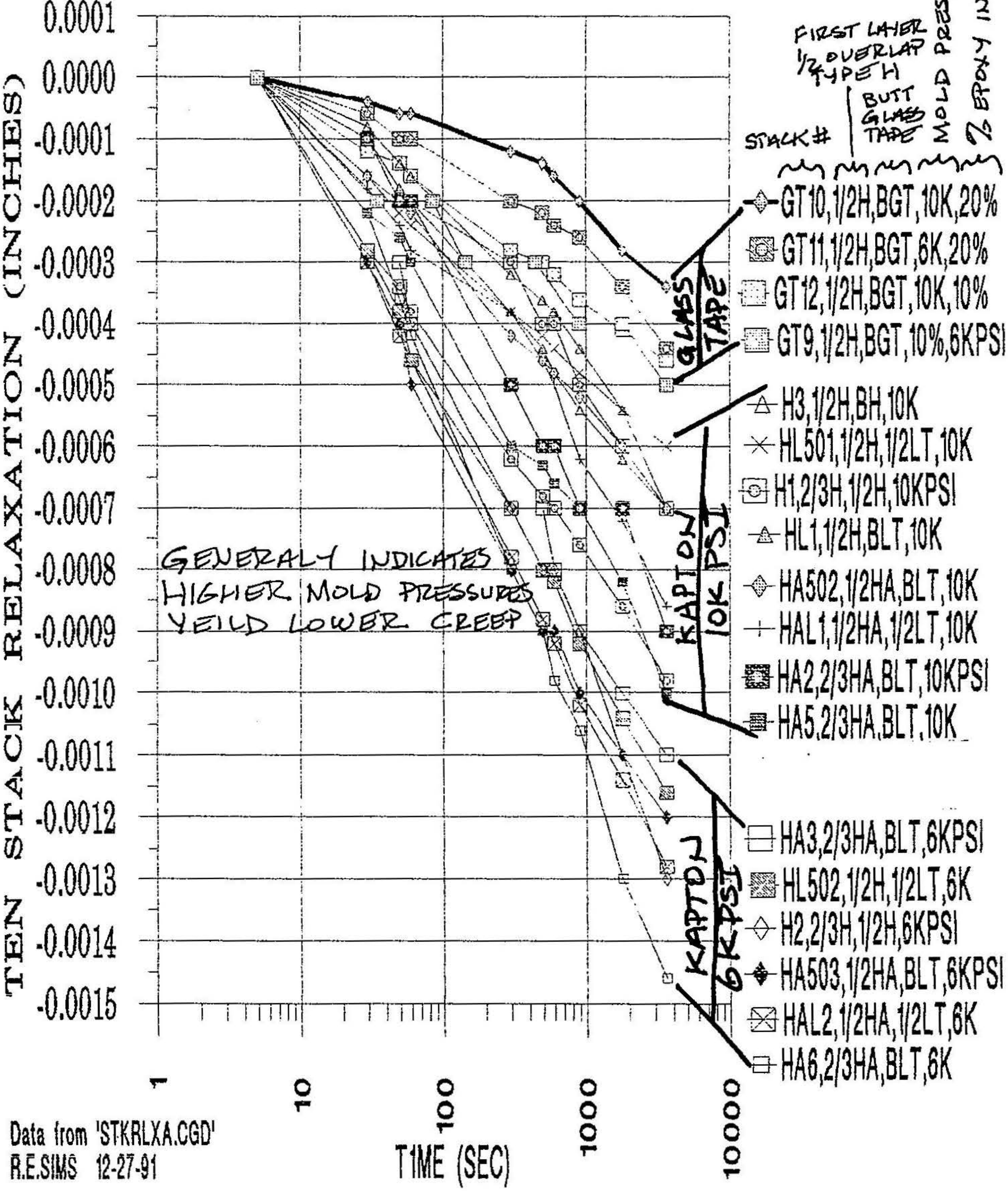
Data from 'SIZEVTIM.CGD'
R.E.SIMS 12-13-91 ICSR

SSC 50 mm OUTER COIL STRESS RELAXATION AT 12 KPSI WITH VARIOUS INSULATIONS

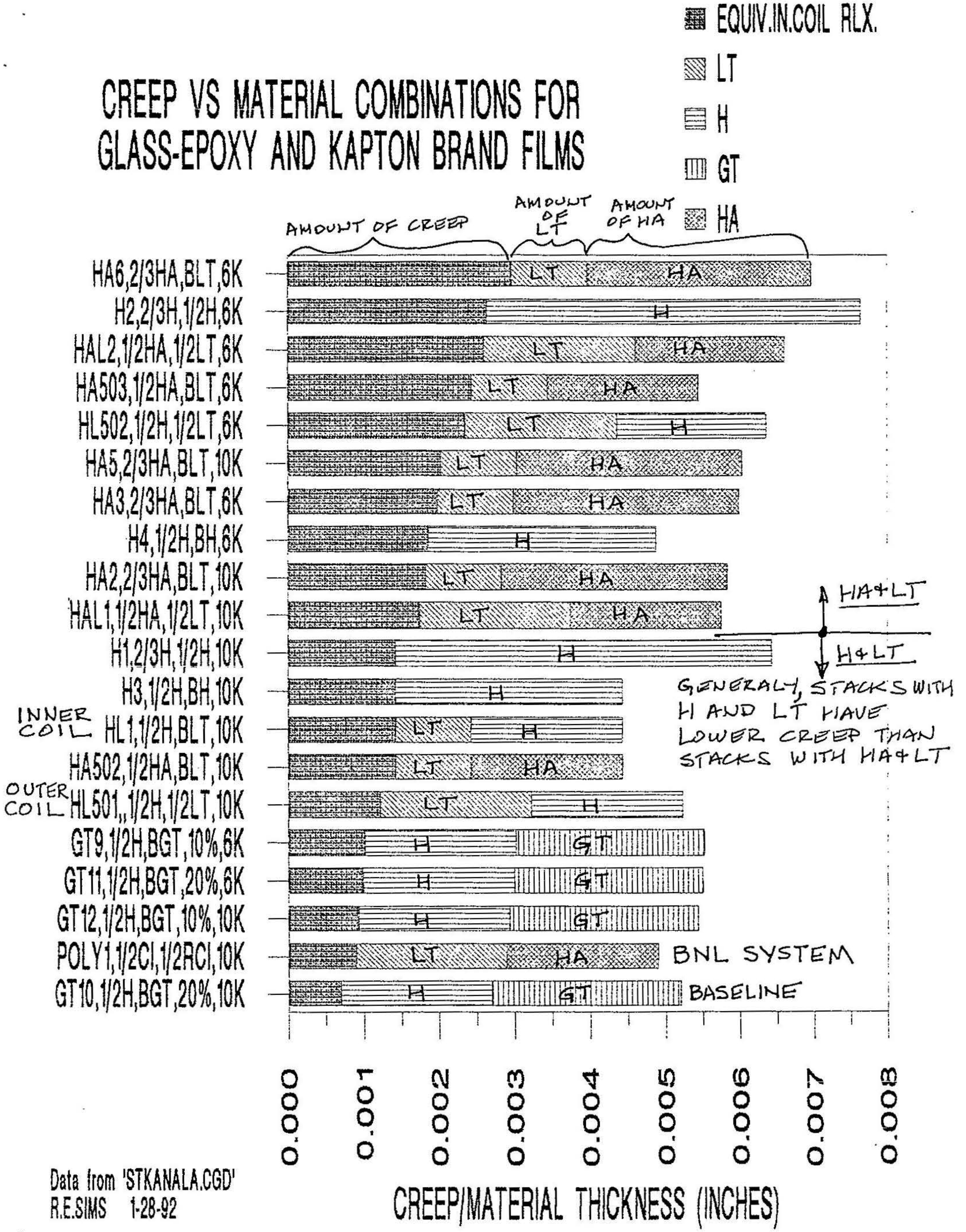


Data from 'INSTKDAT.CGD'
R.E.SIMS 12-16-91
OUTCSTRS.CGG

TEN STACK STRESS RELAXATION WITH 12 KPSI FOR ONE HOUR (SSC 50mm INNER CABLE)

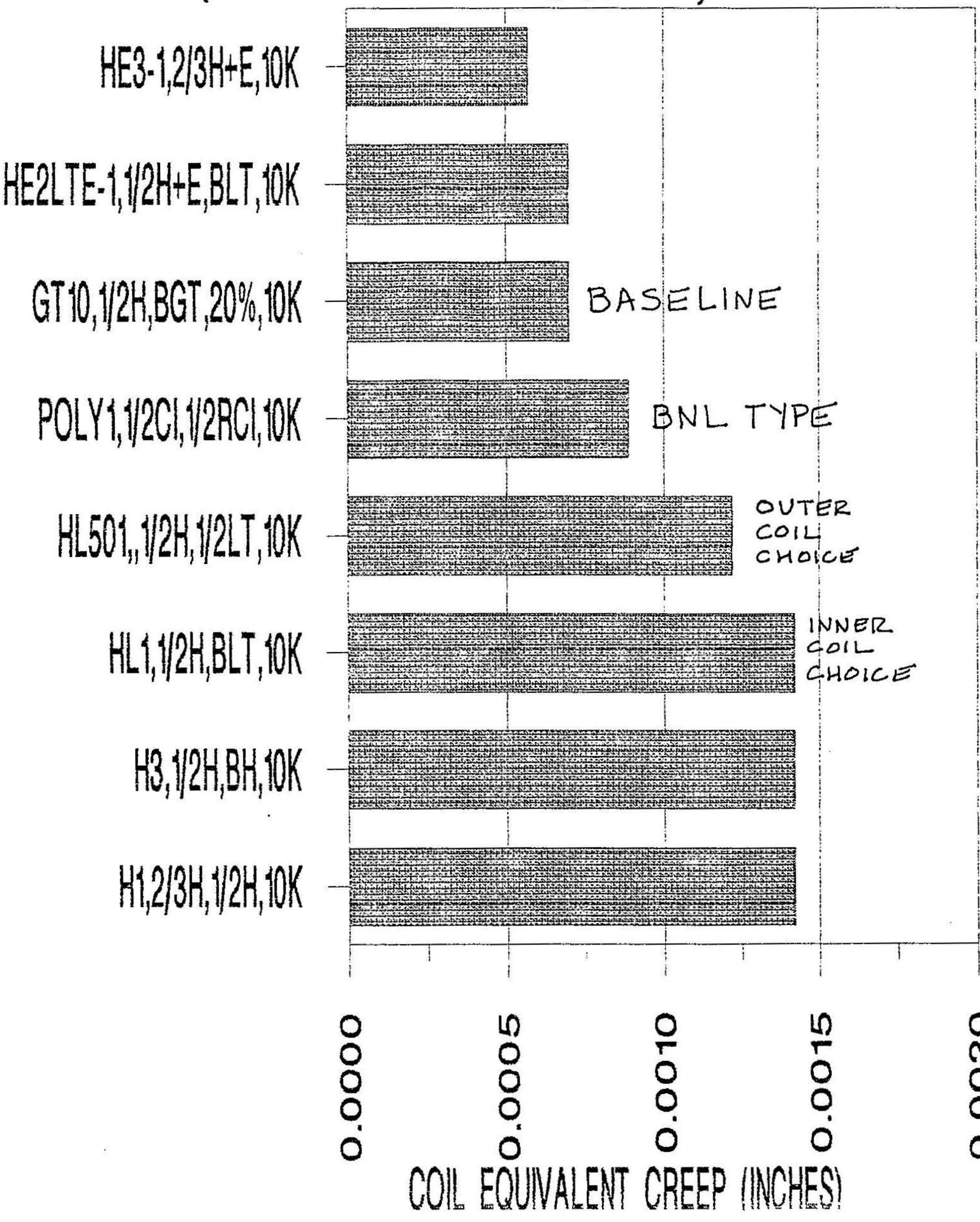


Data from 'STKRLXA.CGD'
R.E.SIMS 12-27-91



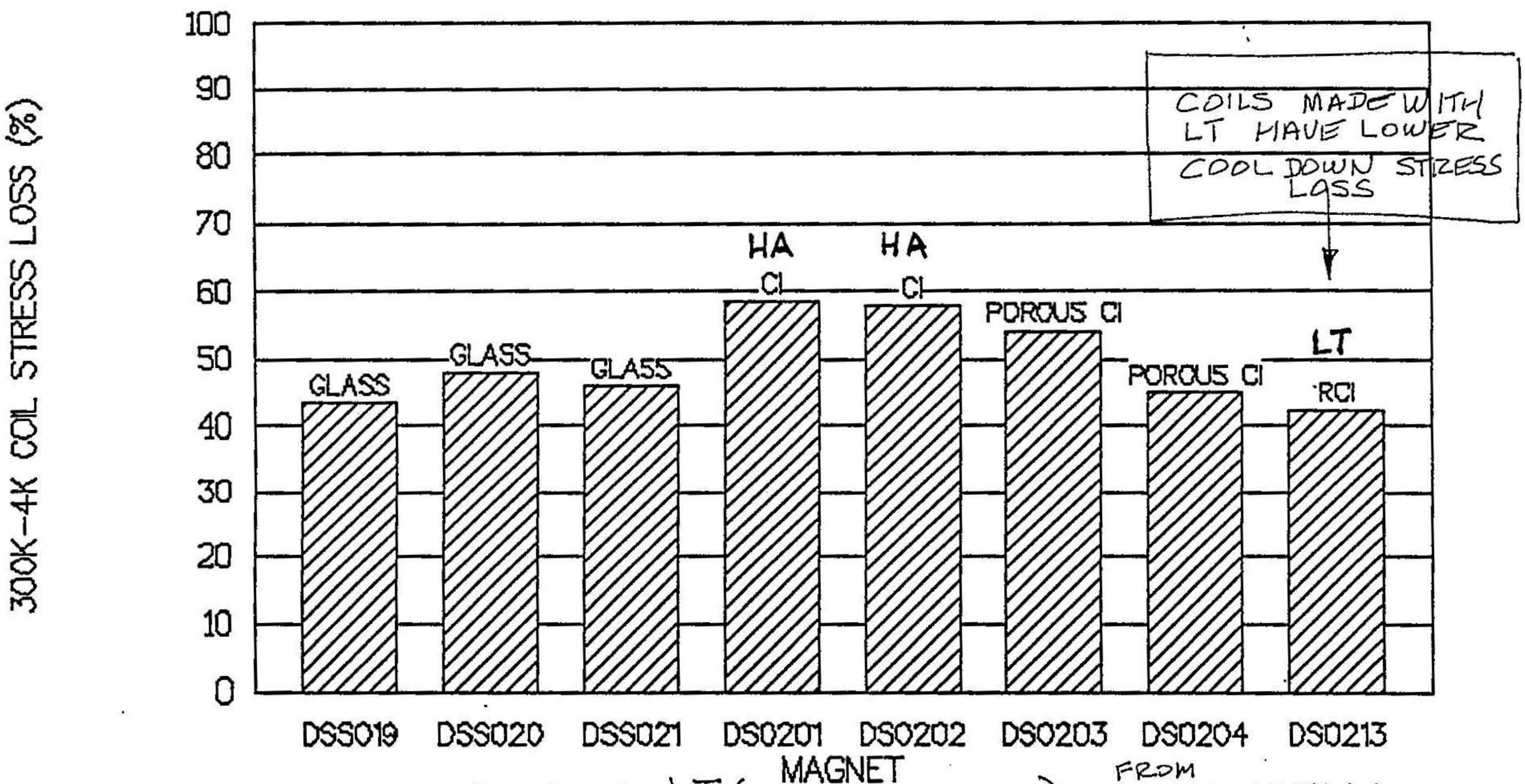
CREEP VS MATERIAL COMBINATIONS FOR
GLASS-EPOXY AND KAPTON BRAND FILMS
EQUIV.IN.COIL RLX.
LT
H
GT
HA
AMOUNT OF CREEP
AMOUNT OF LT
AMOUNT OF HA
HA6,2/3HA,BLT,6K
H2,2/3H,1/2H,6K
HAL2,1/2HA,1/2LT,6K
HA503,1/2HA,BLT,6K
HL502,1/2H,1/2LT,6K
HA5,2/3HA,BLT,10K
HA3,2/3HA,BLT,6K
H4,1/2H,BH,6K
HA2,2/3HA,BLT,10K
HAL1,1/2HA,1/2LT,10K
H1,2/3H,1/2H,10K
H3,1/2H,BH,10K
INNER COIL
HL1,1/2H,BLT,10K
HA502,1/2HA,BLT,10K
OUTER COIL
HL501,,1/2H,1/2LT,10K
GT9,1/2H,BGT,10%,6K
GT11,1/2H,BGT,20%,6K
GT12,1/2H,BGT,10%,10K
POLY1,1/2CI,1/2RCI,10K
GT10,1/2H,BGT,20%,10K
HA+LT
H+LT
GENERALY, STACKS WITH H AND LT HAVE LOWER CREEP THAN STACKS WITH HA+LT
BNL SYSTEM
BASELINE
0.000
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
CREEP/MATERIAL THICKNESS (INCHES)
Data from 'STKANALA.CGD'
R.E.SIMS 1-28-92

VARIOUS KAPTON H AND LT COMBINATIONS VS CREEP
(CHOICES CLOSE TO BASELINE)



1.8m, 4cm SSC MAGNET DATA

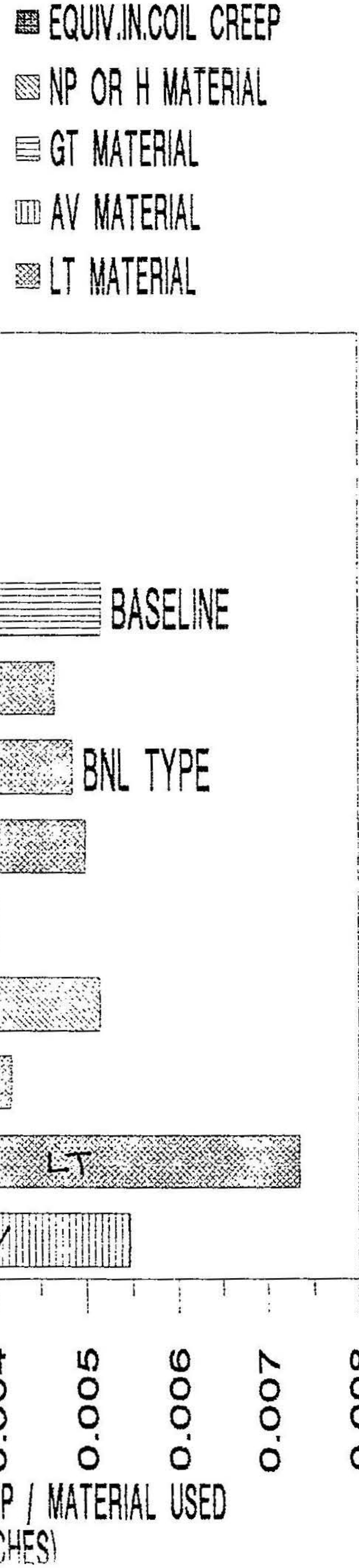
Inner Coil Cooldown Stress Loss



REASON FOR FAVORING LT (LOADED POLYIMIDE) FILM AS THE UPPER LAYER(S) OF INSULATION

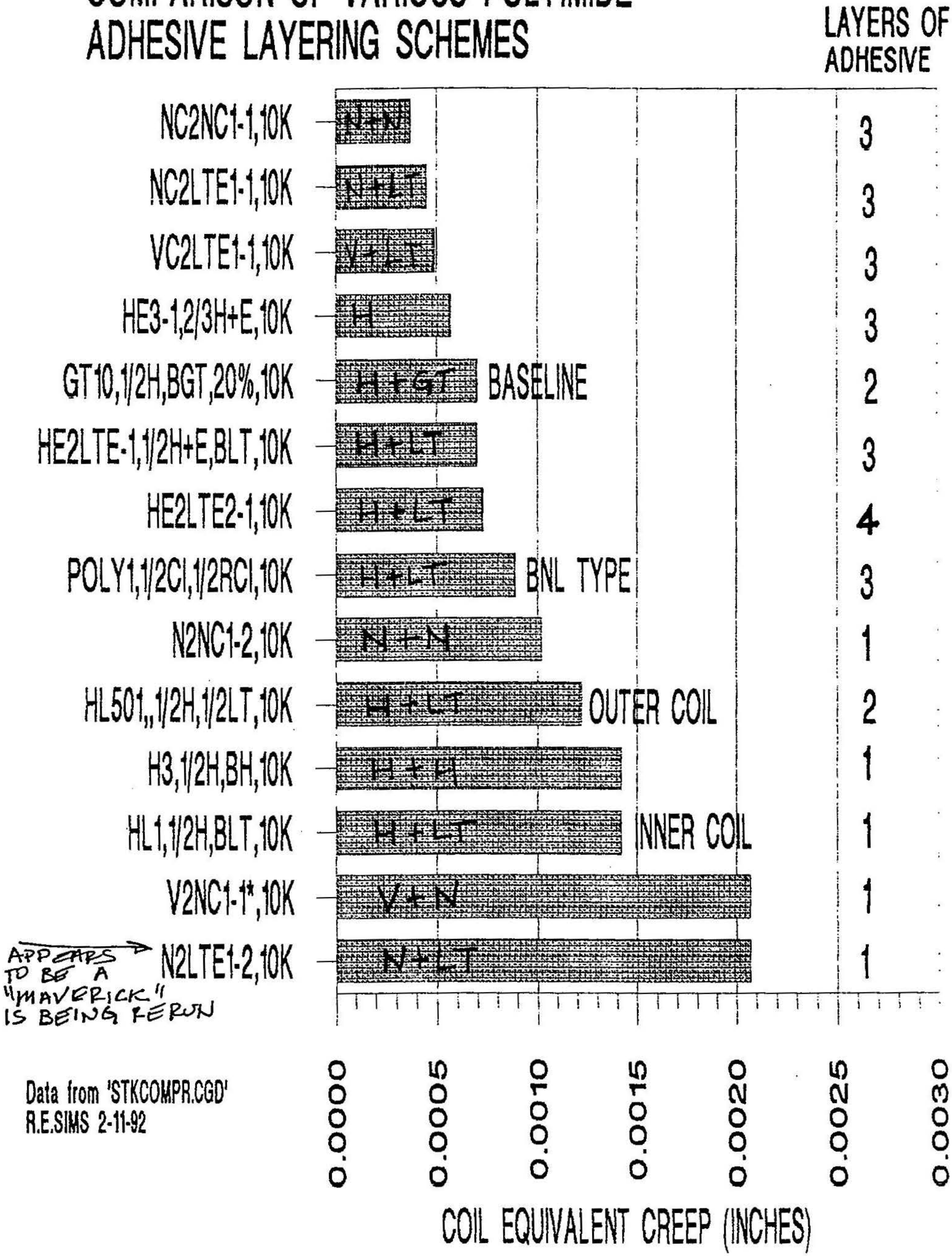
FROM
M. ANERELLA
BNL
8-6-91

CREEP COMPARISON OF VARIOUS COMBINATIONS OF APICAL BRAND FILMS INCLUDING SOME WITH KAPTON BRAND LT FILM



Data from 'STKANAPA.CGD'
R.E.SIMS 2-14-92
APCPMATL.CGG

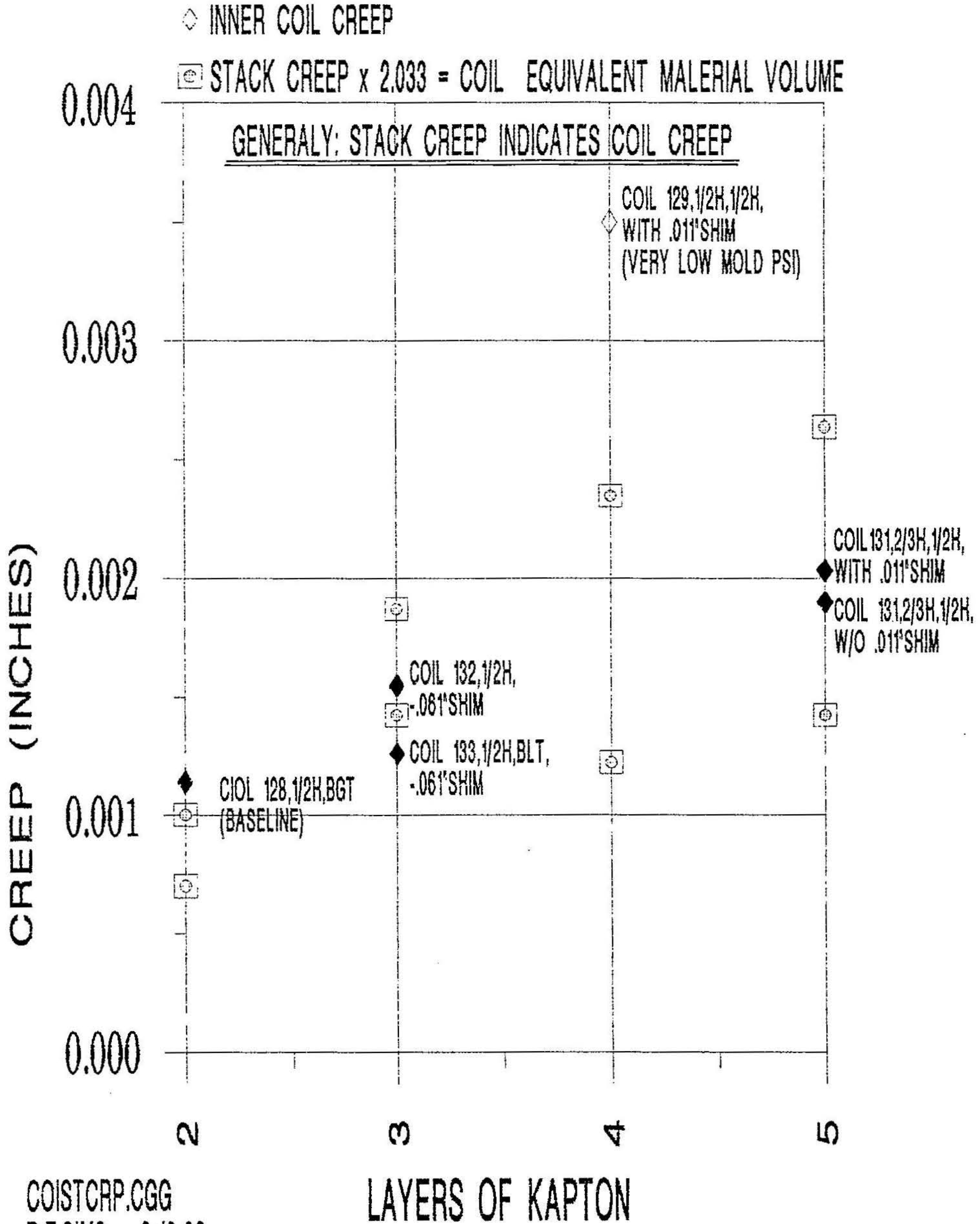
COMPARISON OF VARIOUS POLYIMIDE ADHESIVE LAYERING SCHEMES



Data from 'STKCOMPR.CGD'
R.E.SIMS 2-11-92

COMPARING INNER COIL CREEP TO TEN STACK CREEP

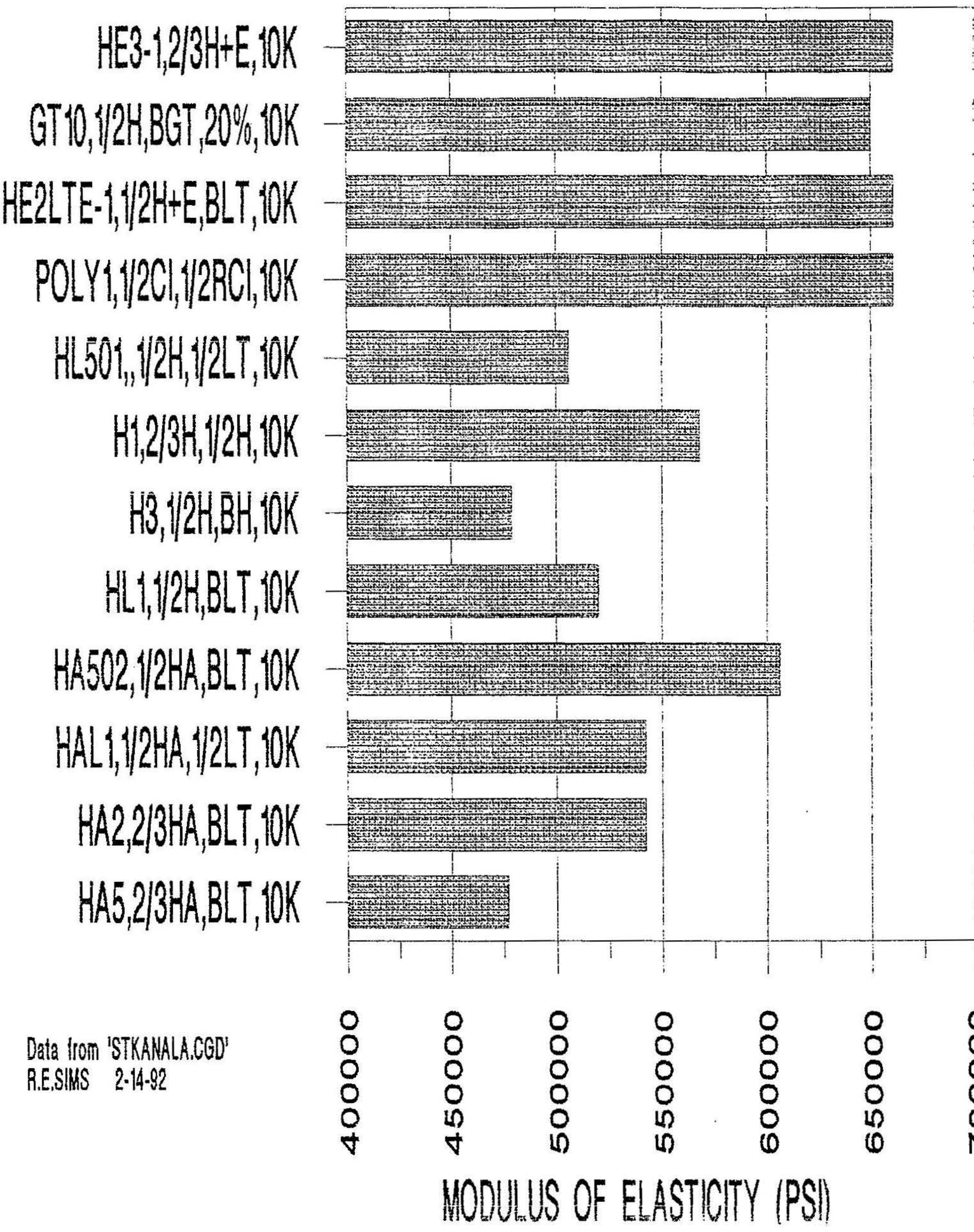
(12 KPSI FOR 60 MINUTES)



COISTCRP.CGG

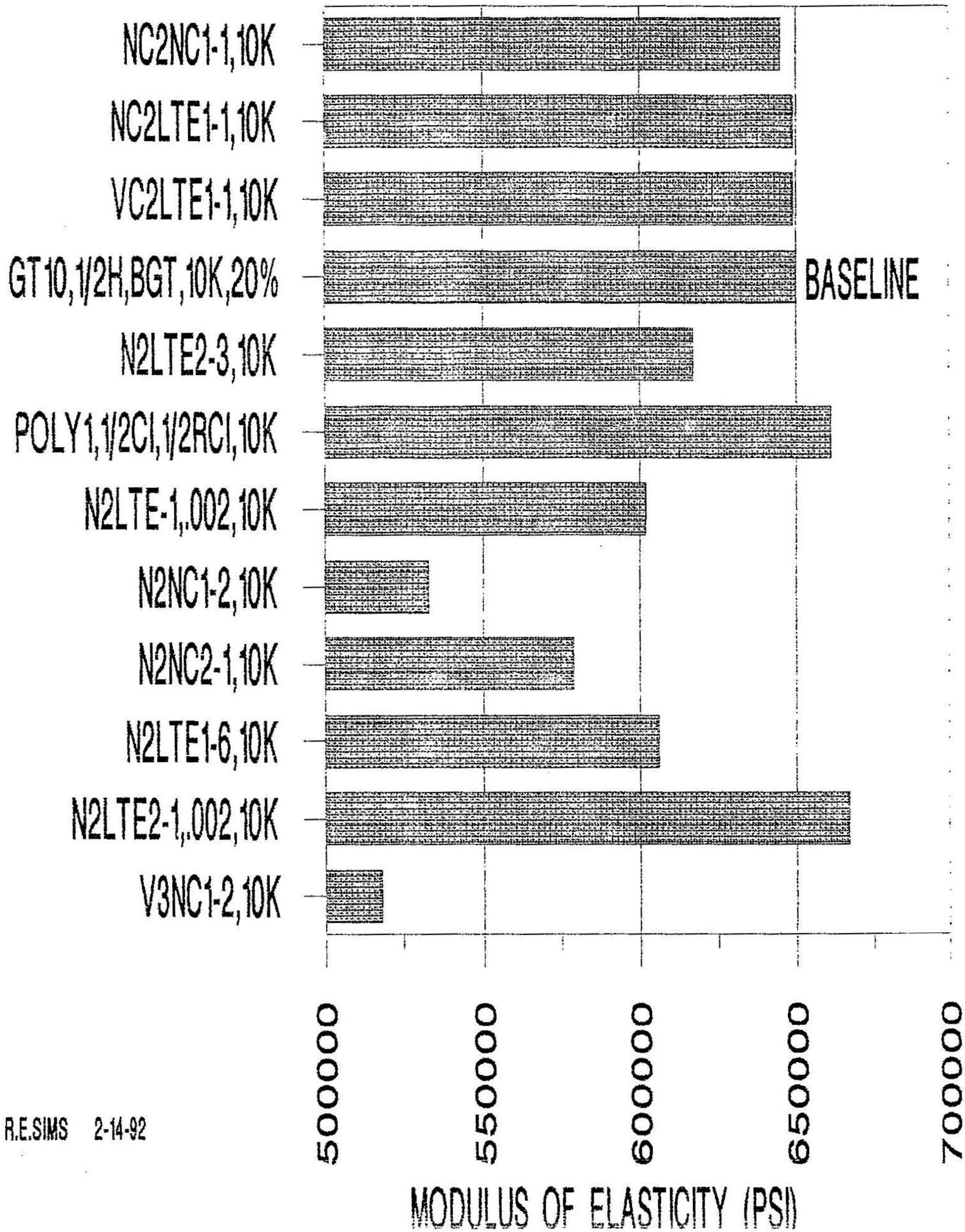
R.E.SIMS 2-13-92

COMPARING MODULII OF ELASTICITY OF STACKS MADE WITH VARIOUS KAPTON BRAND FILMS

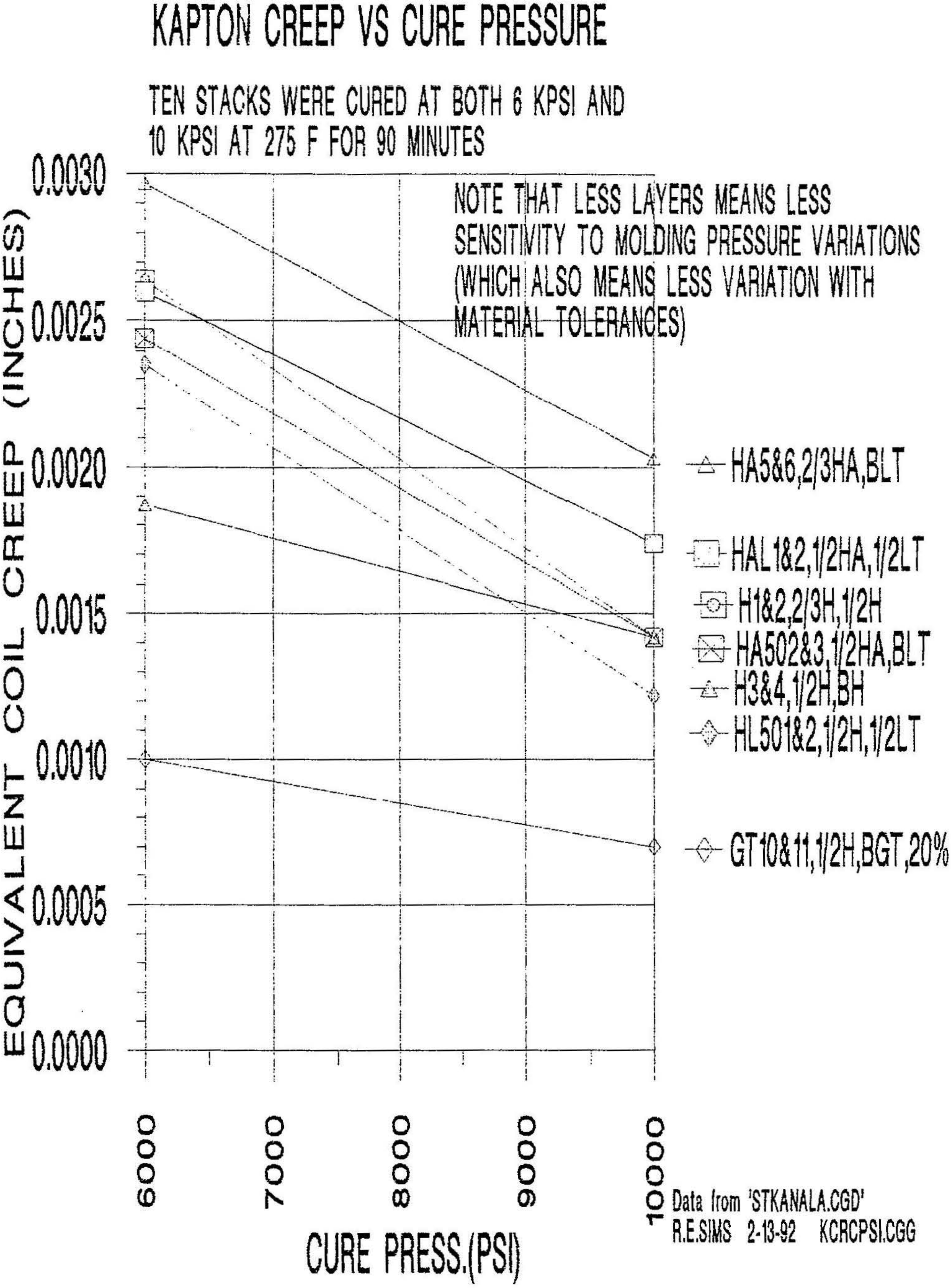


Data from 'STKANALA.CGD'
R.E.SIMS 2-14-92

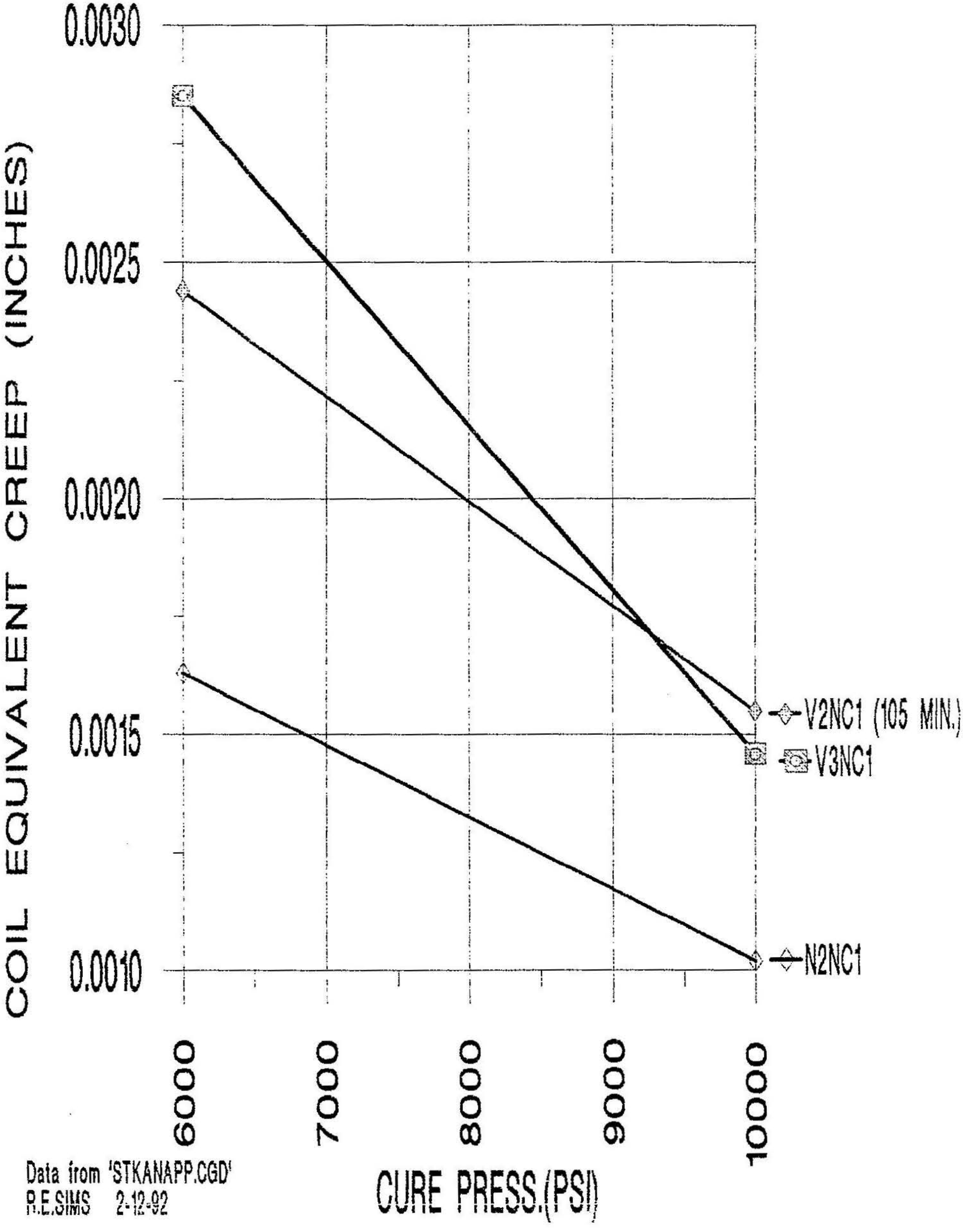
COMPARING MODULI OF ELASTICITY FOR APICAL BRAND FILMS INCLUDING SOME WITH KAPTON BRAND LT FILM



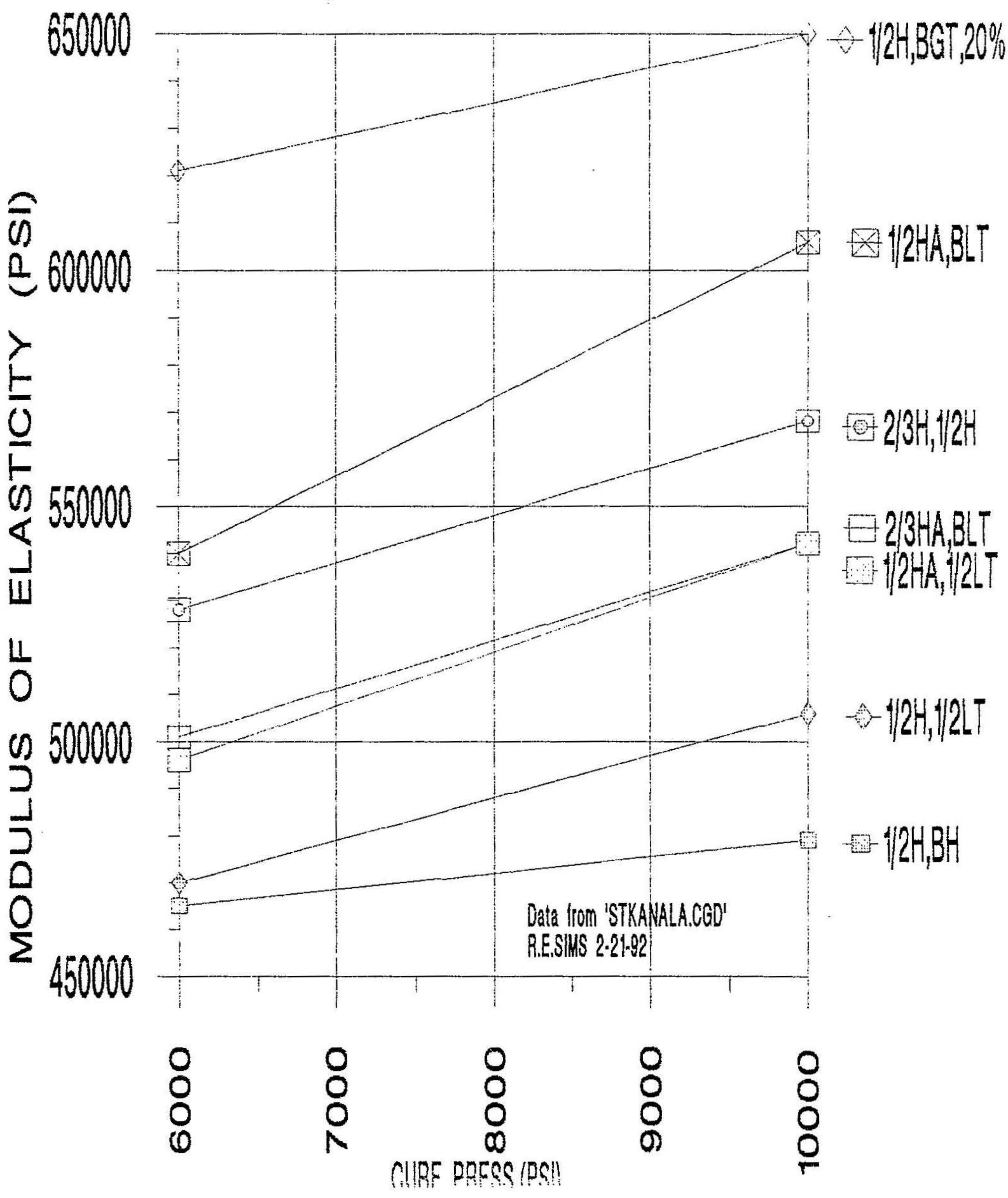
R.E.SIMS 2-14-92


KAPTON CREEP VS CURE PRESSURE
TEN STACKS WERE CURED AT BOTH 6 KPSI AND
10 KPSI AT 275 F FOR 90 MINUTES
NOTE THAT LESS LAYERS MEANS LESS
SENSITIVITY TO MOLDING PRESSURE VARIATIONS
(WHICH ALSO MEANS LESS VARIATION WITH
MATERIAL TOLERANCES)
EQUIVALENT COIL CREEP (INCHES)
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
HA5&6,2/3HA,BLT
HAL1&2,1/2HA,1/2LT
H1&2,2/3H,1/2H
HA502&3,1/2HA,BLT
H3&4,1/2H,BH
HL501&2,1/2H,1/2LT
GT10&11,1/2H,BGT,20%
6000
7000
8000
9000
10000
CURE PRESS.(PSI)
Data from 'STKANALA.CGD'
R.E.SIMS 2-13-92 KCRCPSI.CGG

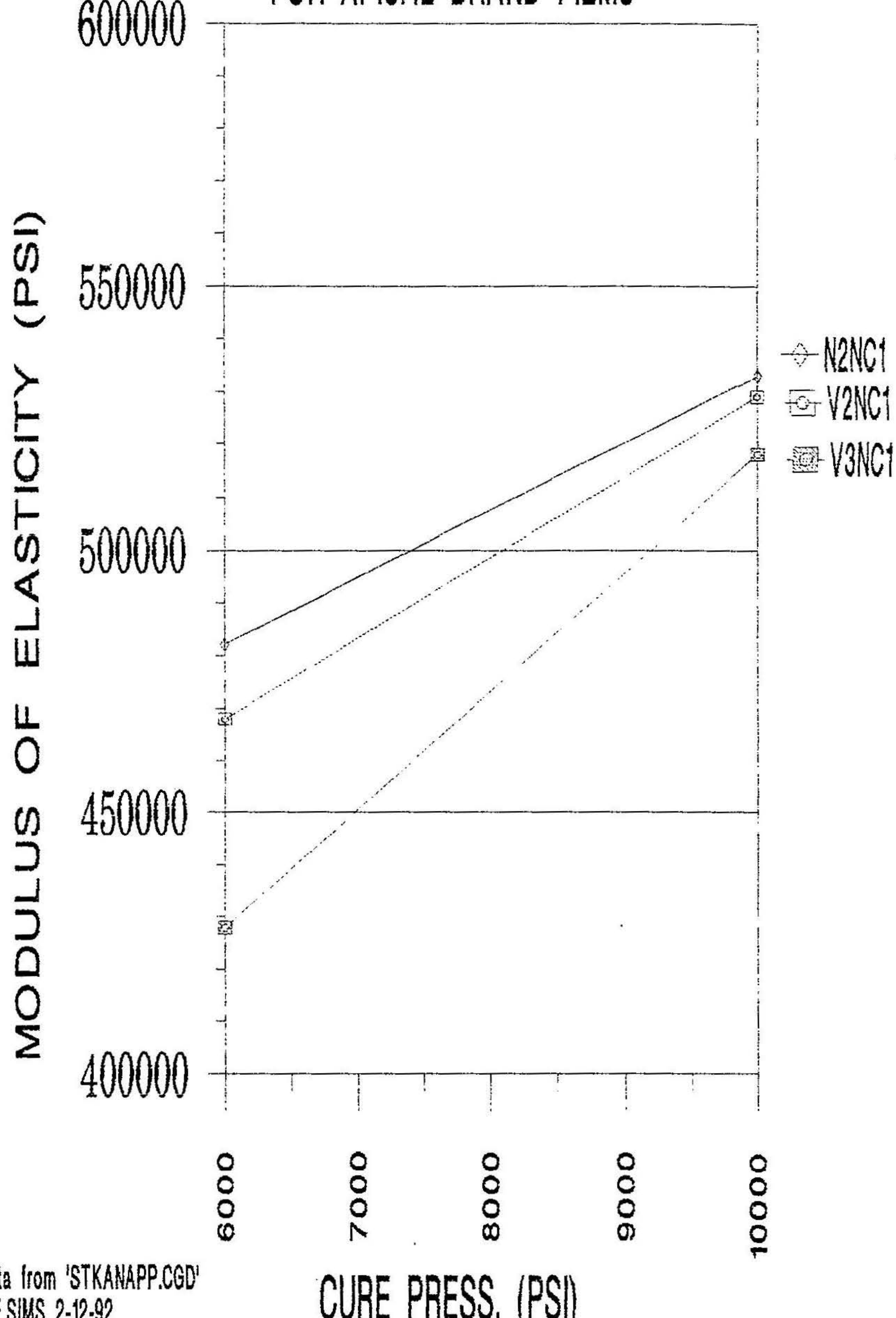
CREEP VS CURING PRESSURE
FOR APICAL BRAND FILMS



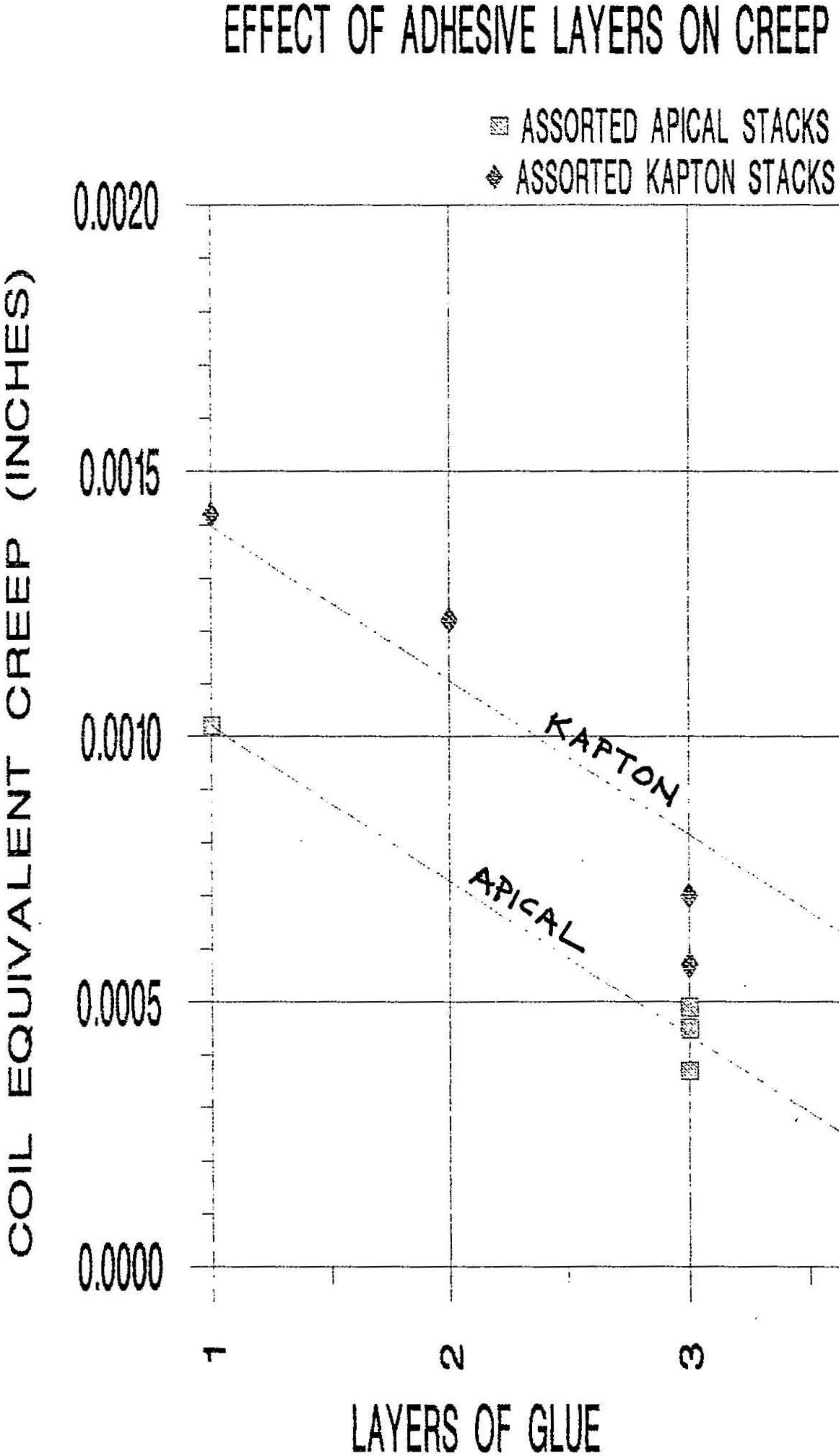
MODULUS OF ELASTICITY VS CURING PRESSURE FOR KAPTON BRAND FILMS

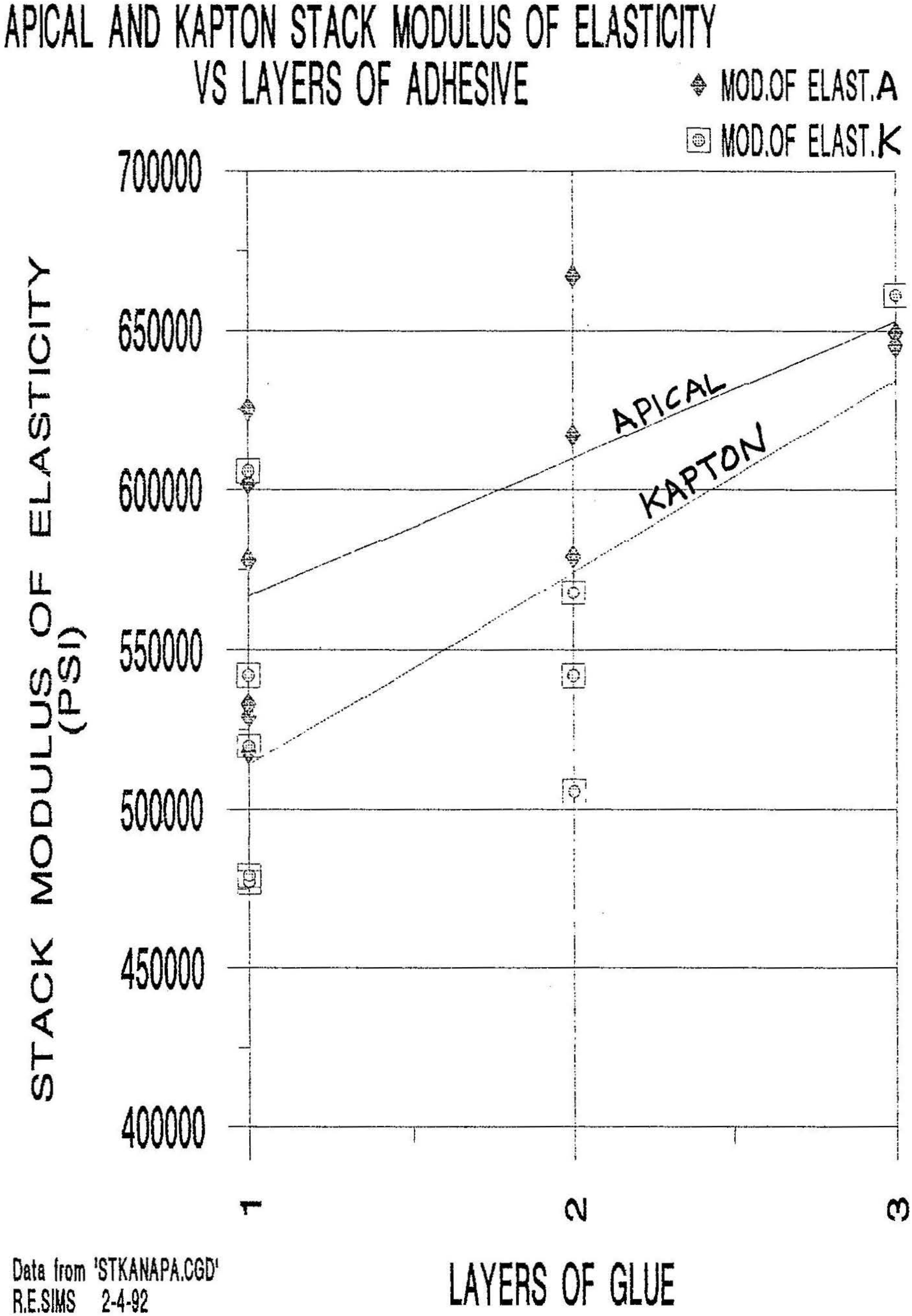


MODULUS OF ELASTICITY VS CURING PRESSURE FOR APICAL BRAND FILMS



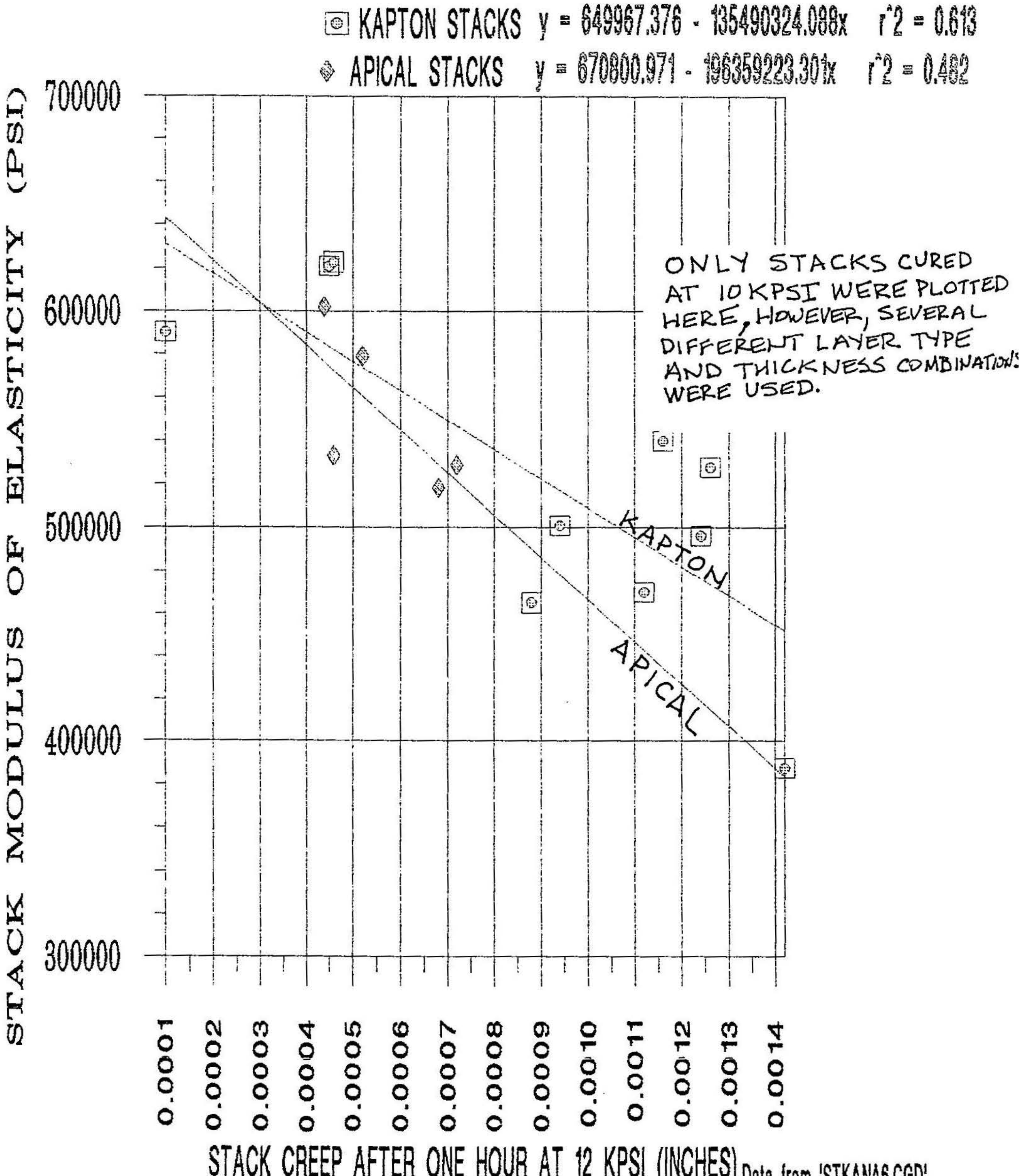
Data from 'STKANAPP.CGD'
R.E.SIMS 2-12-92


EFFECT OF ADHESIVE LAYERS ON CREEP
ASSORTED APICAL STACKS
ASSORTED KAPTON STACKS
COIL EQUIVALENT CREEP (INCHES)
0.0020
0.0015
0.0010
0.0005
0.0000
KAPTON
APICAL
1
2
3
4
LAYERS OF GLUE



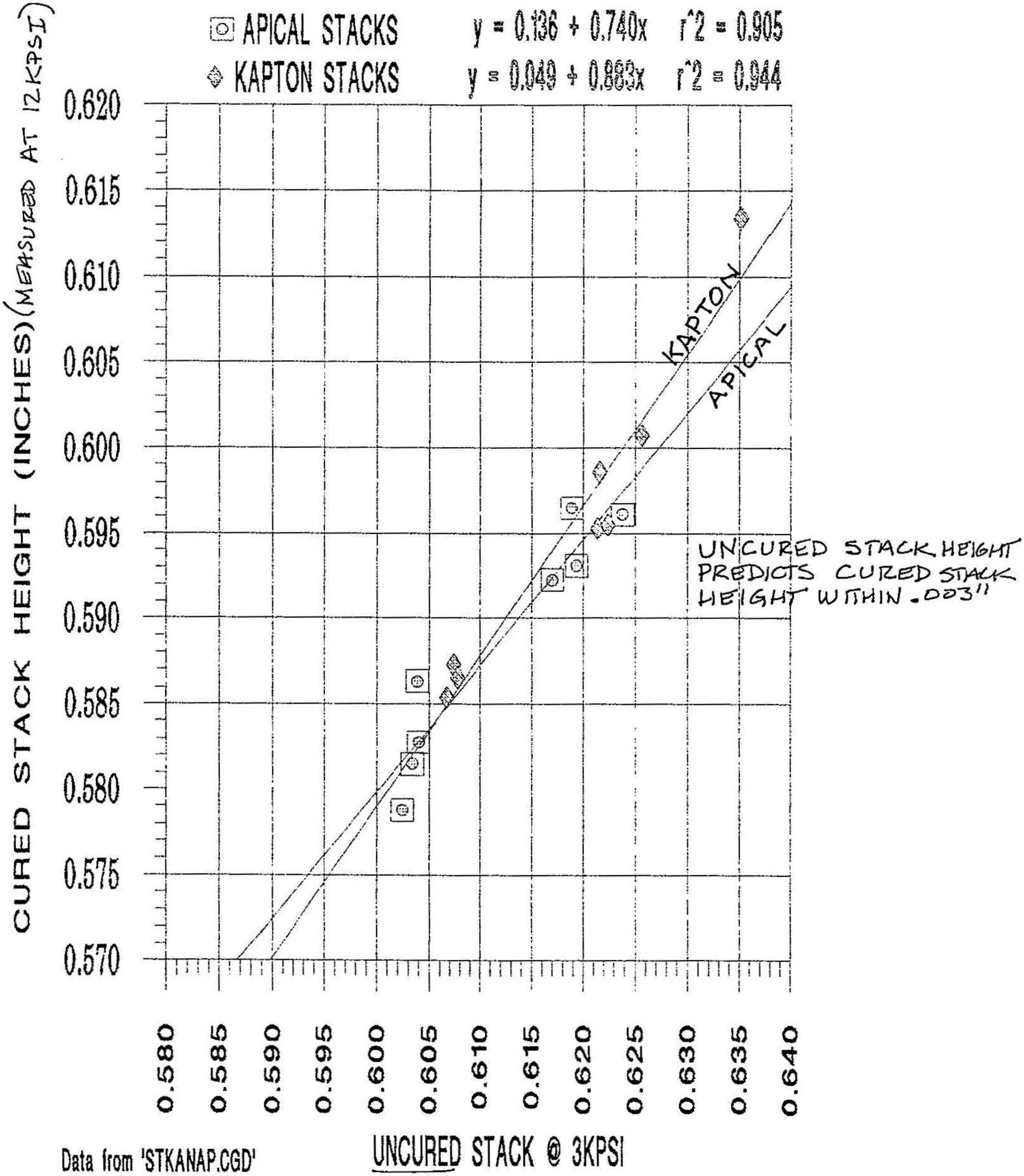
Data from 'STKANAPA.CGD'
R.E.SIMS 2-4-92

KAPTON AND APICAL STACK MODULUS VS CREEP



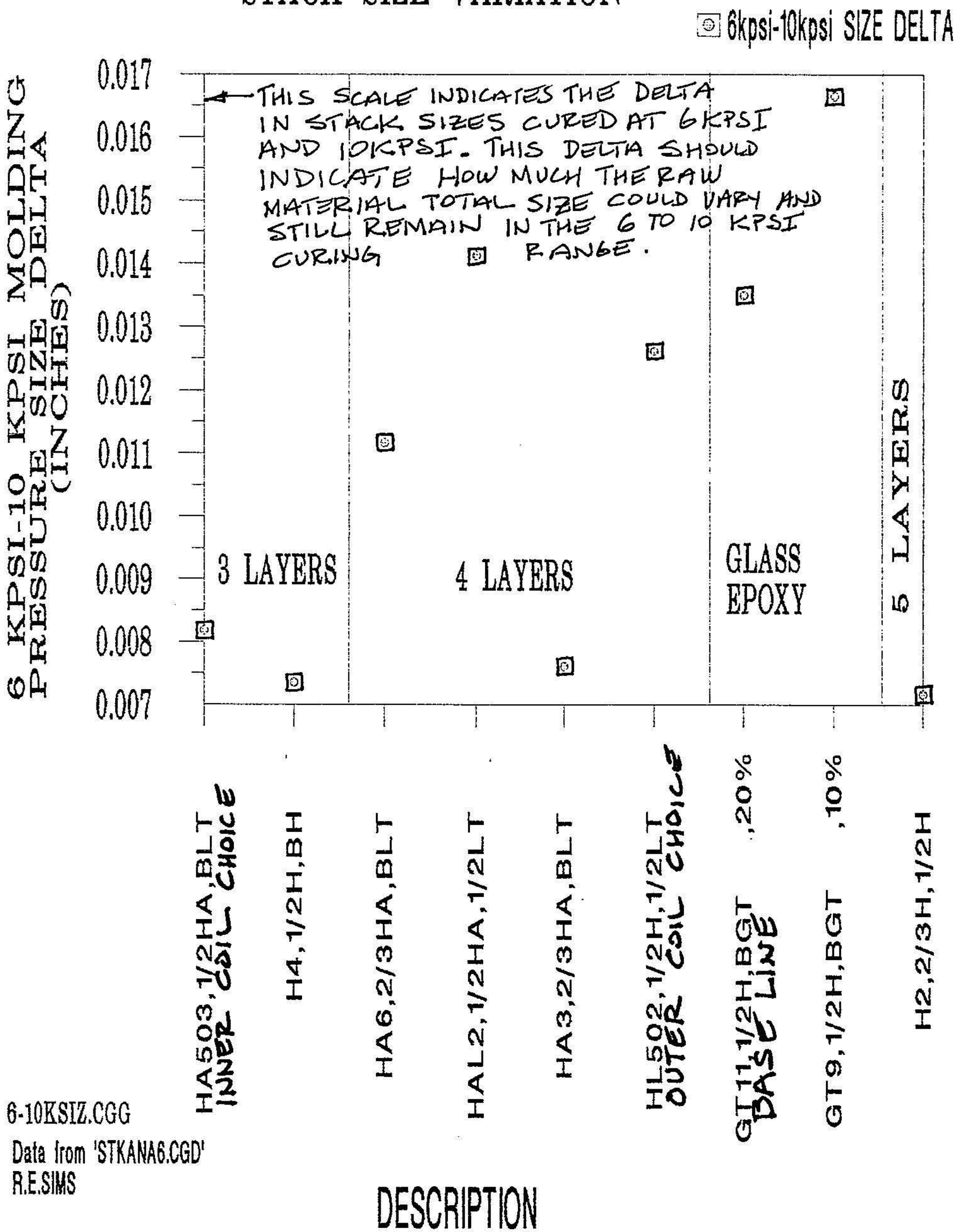
Data from 'STKANA6.CGD'
R.E.SIMS 1-22-92

KAPTON AND APICAL TEN STACKS
BEFORE VS AFTER CURING



Data from 'STKANAP.CGD'
R.E.SIMS 1-22-92

6 KPSI-10 KPSI MOLDING PRESSURE
STACK SIZE VARIATION

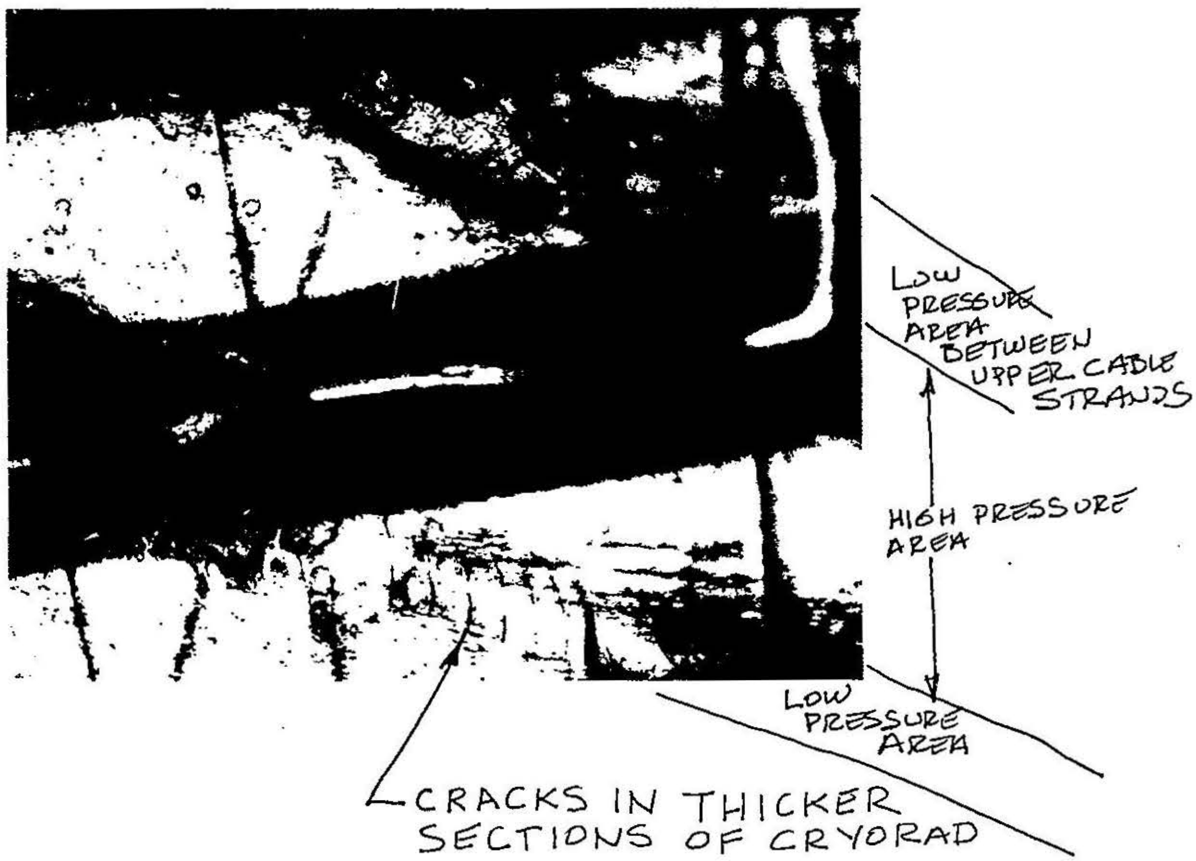


6-10KSIZ.CGG

Data from 'STKANA6.CGD'

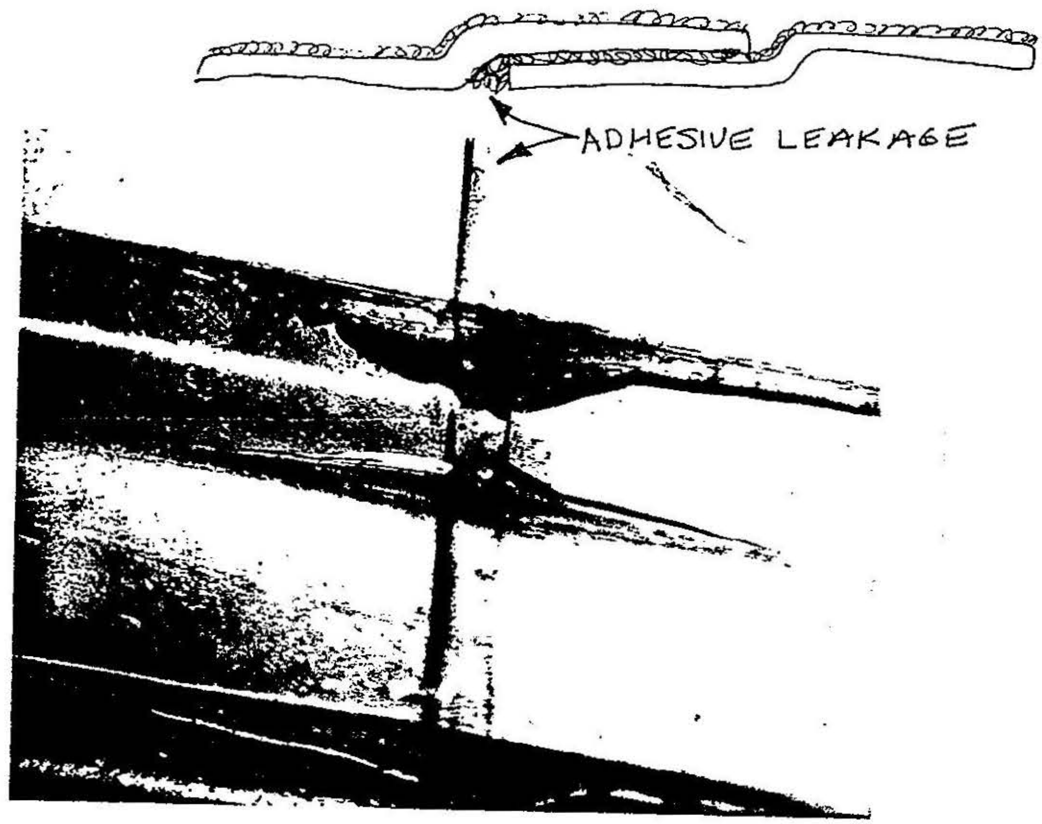
R.E.SIMS

STACK N2CLTE1 (½ OVERLAPPED NP WITH CRYORAD, BUTT WRAP LT WITH 2290 EPOXY ON TOP SIDE) WAS PARTIALY CUT APPART TO EXAMINE HOW THE CRYORAD ADHESIVE FLOWED AND IF IT LEAKED ONTO THE CABLE. (NEXT 3 PAGES)



VIEW OF BOTTOM LAYER OF 50% OVERLAP WRAPPED .001" THICK APICAL TYPE NP WHICH HAS APROX. .00025" CRYORAD TOP COAT BEFORE IT WAS CURED. HERE THE STACK WAS CURED AT ~275°F AND THE TOP LAYER OF KAPTON TYPE LT (BUTT WRAPPED) WAS PEALED OFF.

R.E. SIMS 2-4-92



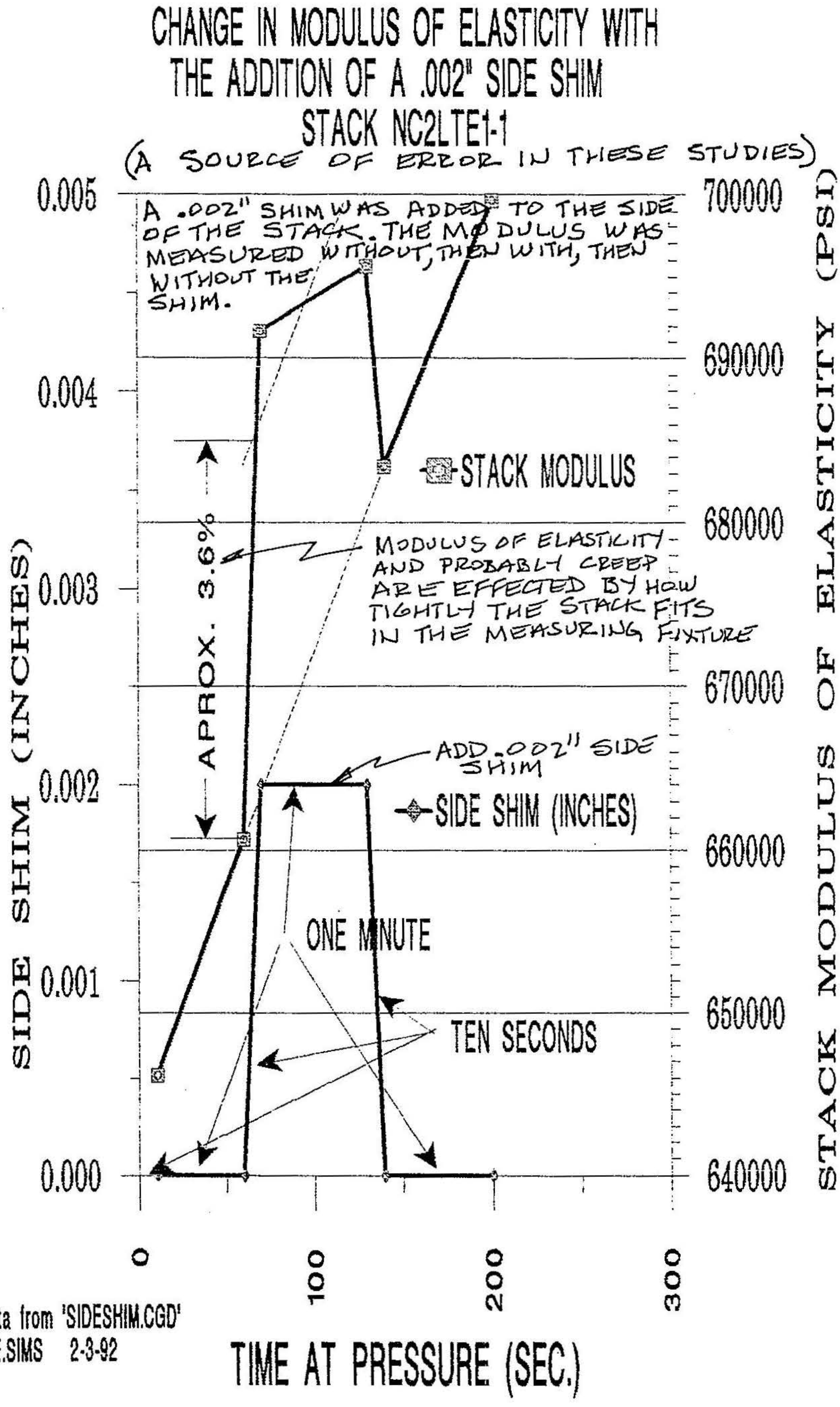
SEAM OF 50% OVERLAPPED APICAL TYPE NP WITH CRYORAD ADHESIVE ON TOP SIDE OF FILM. SOME CRYORAD ADHESIVE HAS FLOWED TO THE LOW PRESSURE AREAS.

SMALL PATCHES OF CRYORAD HAVE "LEAKED" ON TO THE SURFACE OF THE STRANDS.

R.E. SIMS 2-4-92

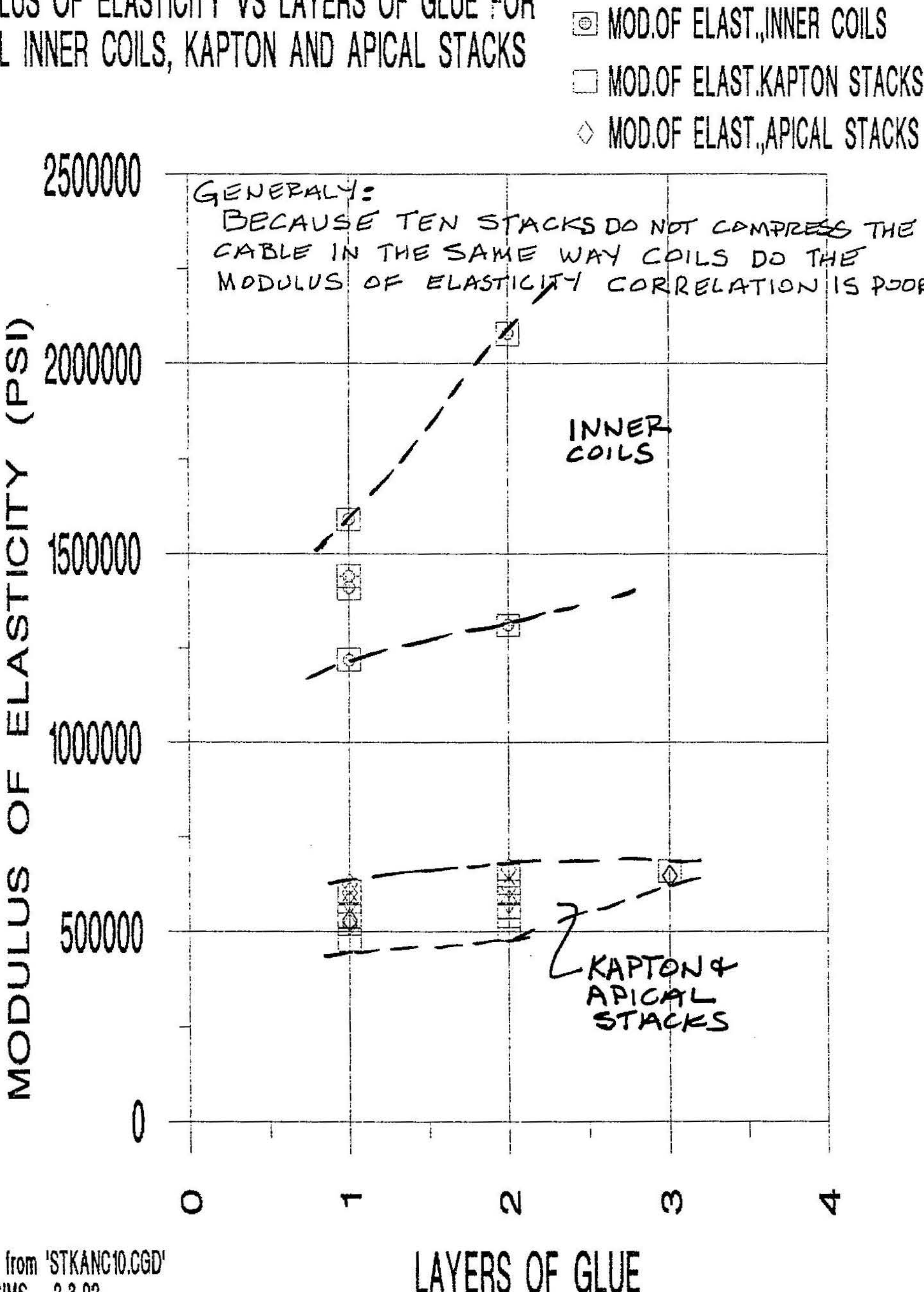
CRYORAD DROPLET BETWEEN STRANDS

R.E. SIMS 2-4-92

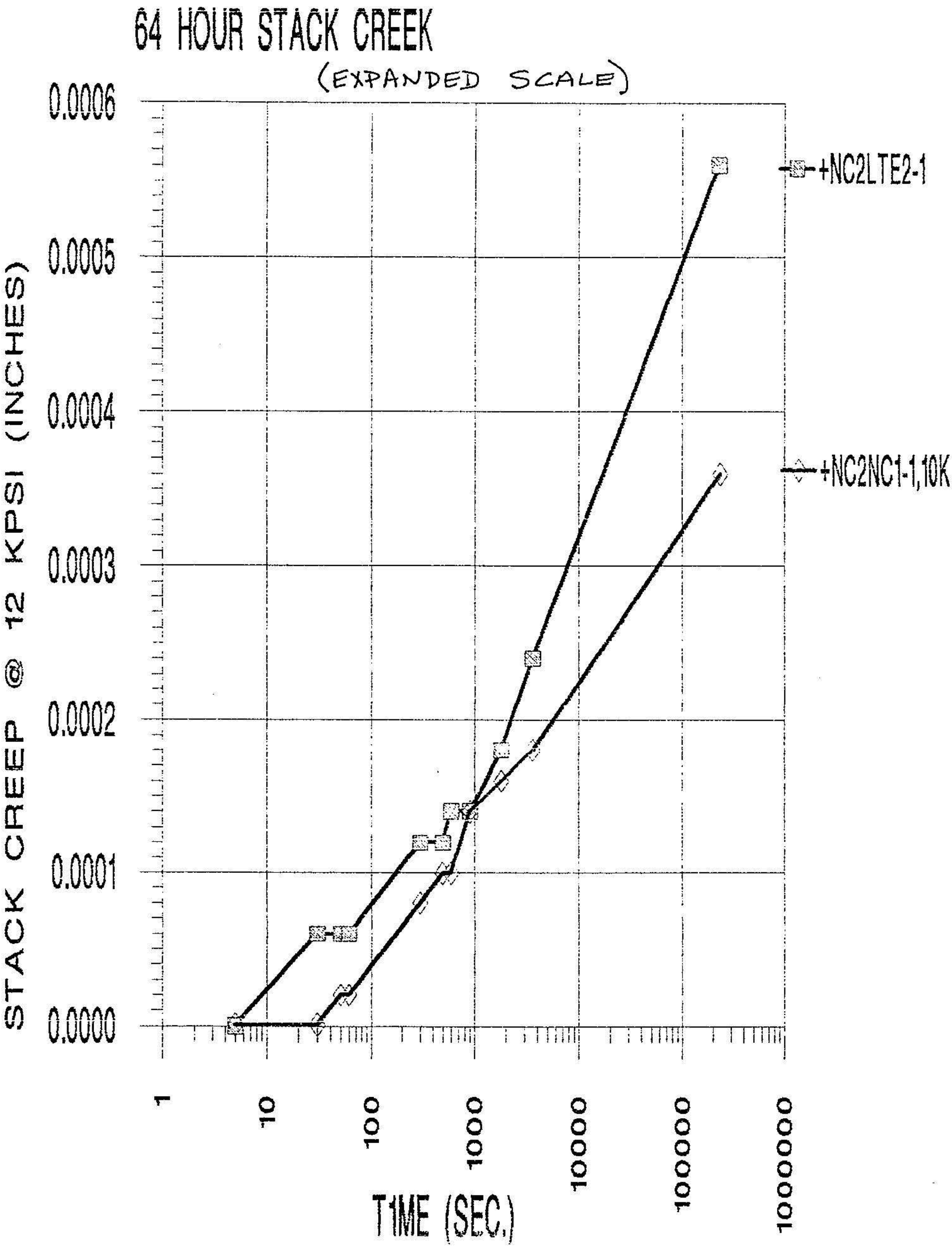


Data from 'SIDESHIM.CGD'
R.E.SIMS 2-3-92

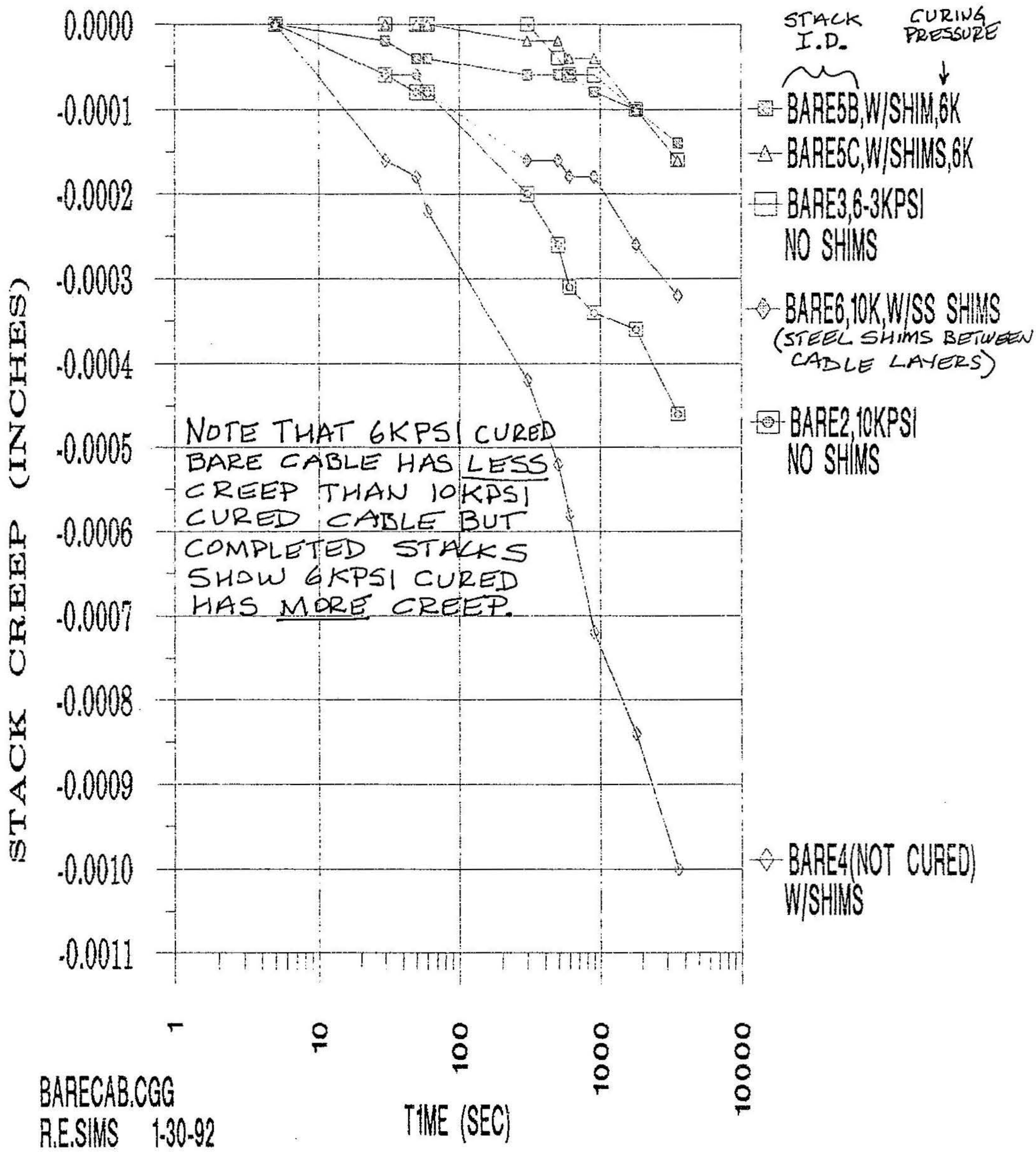
MODULUS OF ELASTICITY VS LAYERS OF GLUE FOR MODEL INNER COILS, KAPTON AND APICAL STACKS



Data from 'STKANC10.CGD'
R.E.SIMS 2-3-92


64 HOUR STACK CREEK
(EXPANDED SCALE)
STACK CREEP @ 12 KPSI (INCHES)
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
+NC2LTE2-1
+NC2NC1-1,10K
1
10
100
1000
10000
100000
1000000
TIME (SEC.)

50 mm INNER CABLE WITH NO INSULATION WRAP AFTER CREEPING FOR ONE HOUR AT 12 KPSI



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PREDICTING COIL SIZE FROM STACK SIZE