Volume IV
Appendix F.4
ET Cryoinsulation

ET cryoinsulation Power Point Slides presented 7 April 2003 at the CAIB Public Hearing: ET cryoinsulation, by Lee Foster and Scotty Sparks, MSFC.

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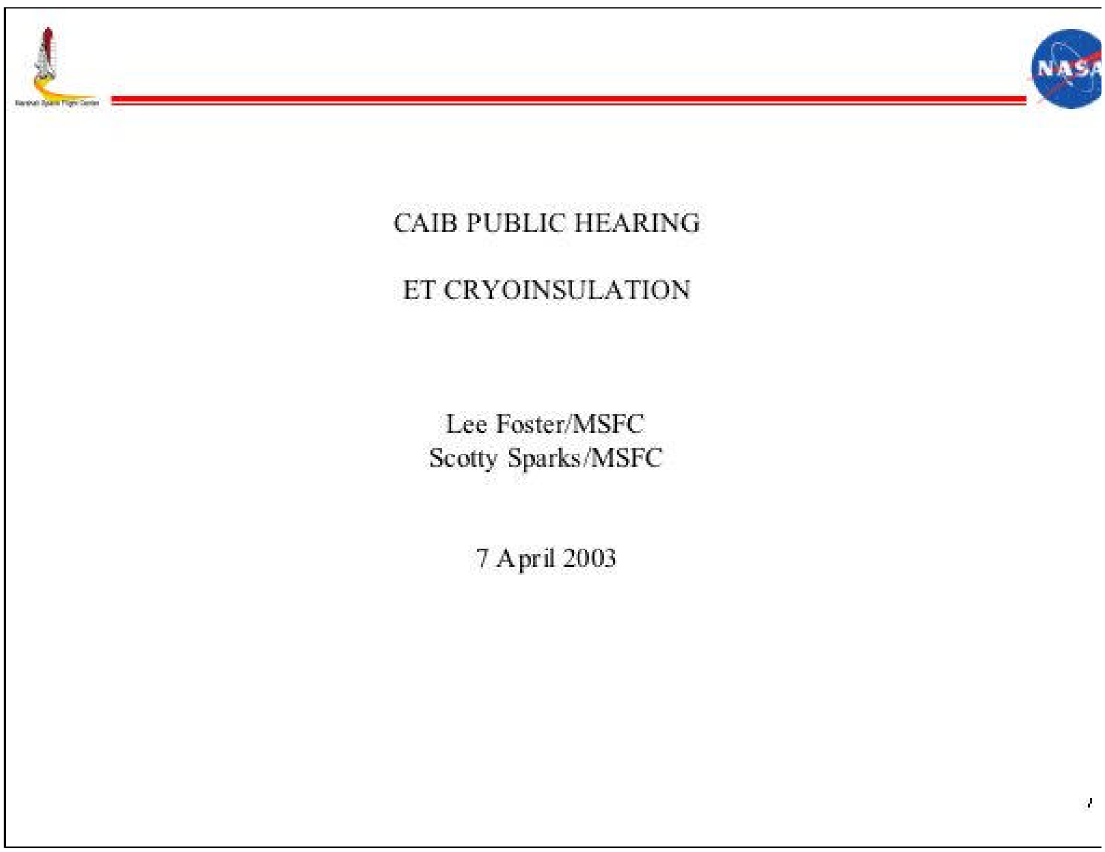
CAIB Public Hearing: ET Cryoinsulation
Lee Foster / MSFC
Scotty Sparks / MSFC
April 7, 2003



CAIB PUBLIC HEARING: Cryoinsulation

Objectives

Inform the CAIB and the Public of:

Cryoinsulation Purpose & Characteristics

Material Development & Qualification

Flight Environments

Debris History & Past Issues

Efforts to Reduce Debris

Recent Observances

CAIB PUBLIC HEARING: Cryoinsulation Characteristics

Purpose of Cryoinsulation

Prelaunch

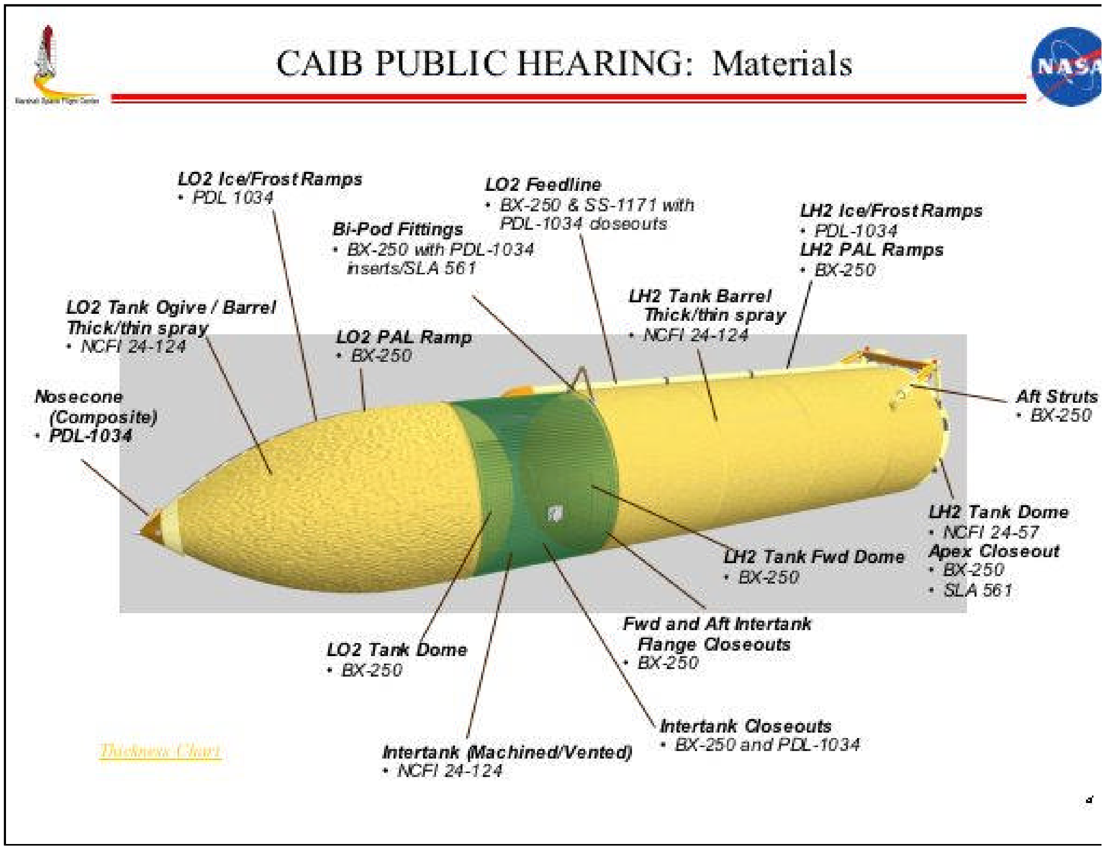
- Minimizes ice formation
- Maintain LO_2 and LH_2 boil-off rates at acceptable levels
- Eliminates air liquefaction (cryopumping)
- Contributes to propellant loading accuracy and increased propellant densities

Ascent

- Provide protection from flight heating environments (Foam materials in low heating regions and ablators/composites in high heating regions)
  - Aerodynamic heating
  - Plume-induced heating
- Minimize effects on structure of aerodynamic loading
  - Static airloads
  - Unsteady aerodynamic effects

Reentry

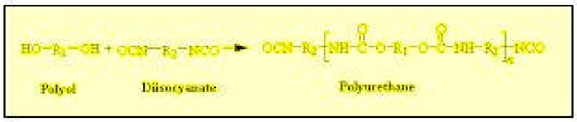
- Assure safe separation distance from Orbiter and proper breakup altitude

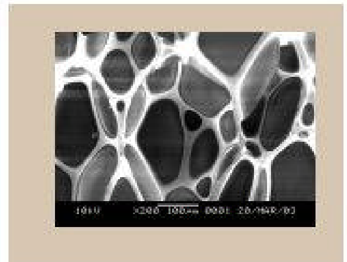

CAIB PUBLIC HEARING: Materials
LO2 Ice/Frost Ramps
• PDL 1034
LO2 Feedline
• BX-250 & SS-1171 with PDL-1034 closeouts
Bi-Pod Fittings
• BX-250 with PDL-1034 inserts/SLA 561
LH2 Ice/Frost Ramps
• PDL-1034
LH2 PAL Ramps
• BX-250
LH2 Tank Barrel Thick/thin spray
• NCFI 24-124
LO2 Tank Ogive / Barrel Thick/thin spray
• NCFI 24-124
LO2 PAL Ramp
• BX-250
Nosecone (Composite)
• PDL-1034
Aft Struts
• BX-250
LH2 Tank Dome
• NCFI 24-57
Apex Closeout
• BX-250
• SLA 561
LH2 Tank Fwd Dome
• BX-250
Fwd and Aft Intertank Flange Closeouts
• BX-250
LO2 Tank Dome
• BX-250
Intertank Closeouts
• BX-250 and PDL-1034
Thickness Chart
Intertank (Machined/Vented)
• NCFI 24-124

CAIB PUBLIC HEARING: Cryoinsulation Characteristics

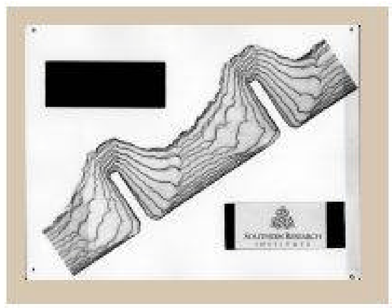
Levels of Structure

1. Polymeric Structure

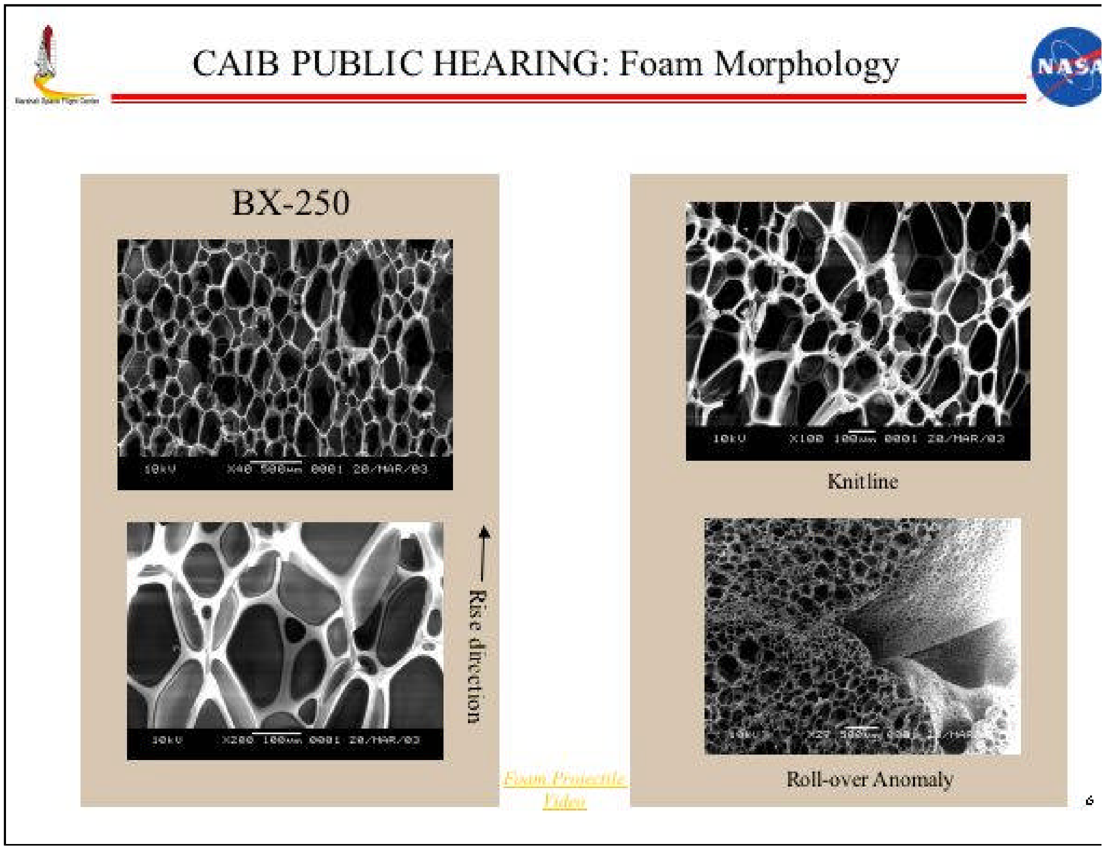


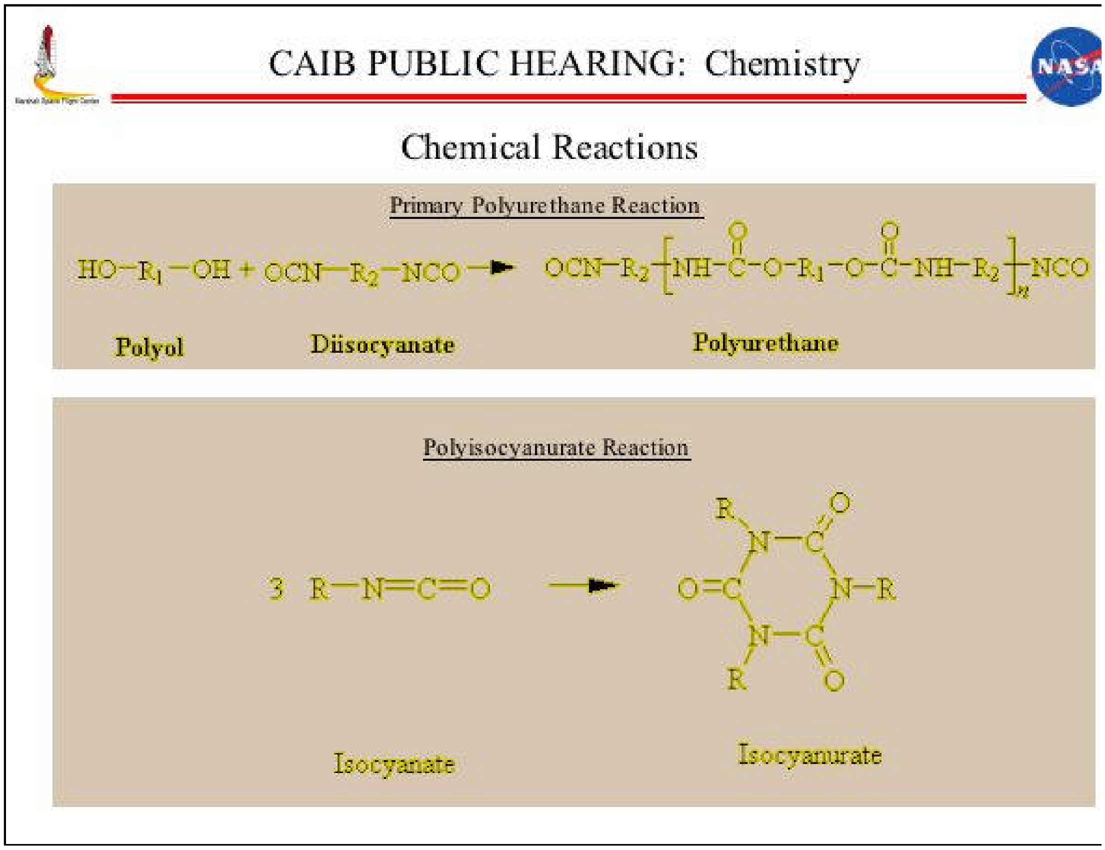


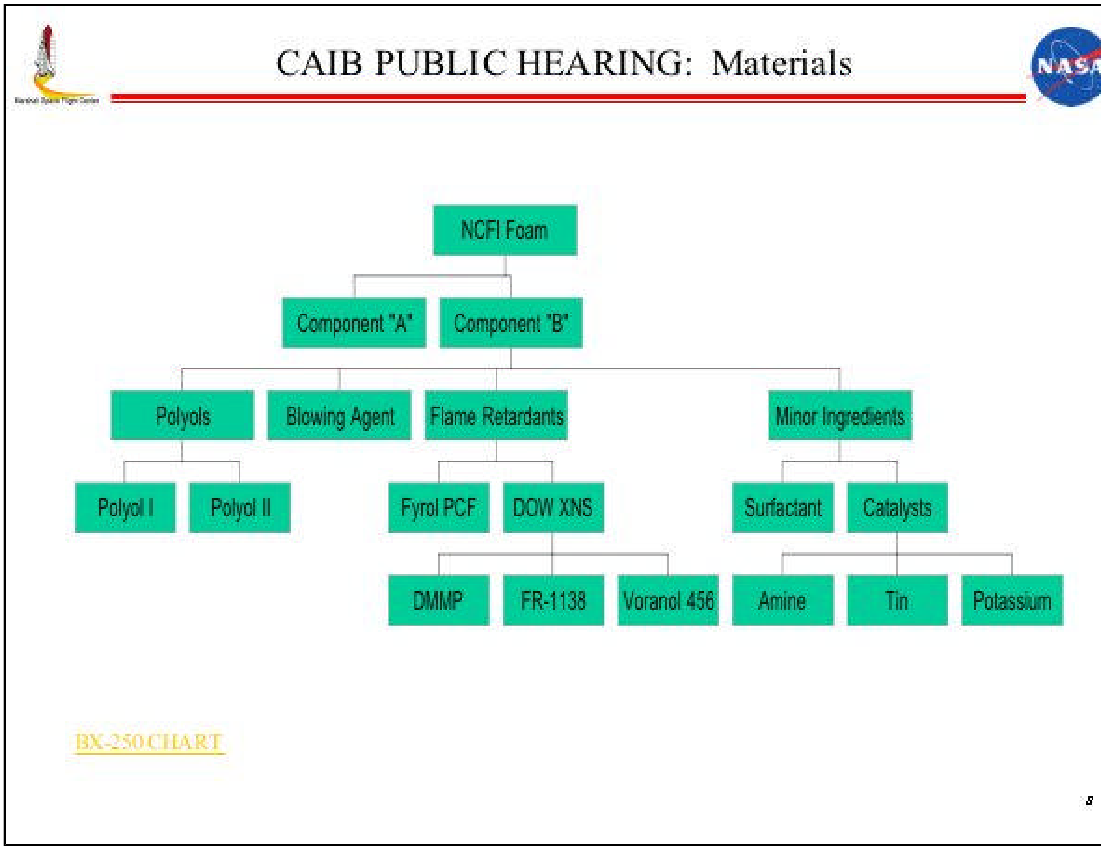
2. Cellular Structure



3. Knitline Geometry
4. Substrate Geometry


CAIB PUBLIC HEARING: Foam Morphology
BX-250
Rise direction
Knitline
Roll-over Anomaly
Foam Projectile Video


CAIB PUBLIC HEARING: Chemistry
Chemical Reactions
Primary Polyurethane Reaction
HO−R1−OH + OCN−R2−NCO
OCN−R2−[NH−C(=O)−O−R1−O−C(=O)−NH−R2]n−NCO
Polyol
Diisocyanate
Polyurethane
Polyisocyanurate Reaction
3 R−N=C=O
Isocyanate
Isocyanurate


CAIB PUBLIC HEARING: Materials
NASA
NCFI Foam
Component "A"
Component "B"
Polyols
Blowing Agent
Flame Retardants
Minor Ingredients
Polyol I
Polyol II
Fyrol PCF
DOW XNS
Surfactant
Catalysts
DMMP
FR-1138
Voranol 456
Amine
Tin
Potassium
BX-250 CHART
8

CAIB PUBLIC HEARING: Properties

Foam / Property	(BCFC) NCFI 24-124 (CFC) CPR 488			(BCFC) NCFI 24-57 (CFC) NCFI 22-65			(BCFC) PDL 1034 (CFC) PDL 4034			(BCFC) BX265 (BCFC)SS 1171 (CFC) BX250		
(% of total foam)	(77%)			(7%)			(1%)			(14%)		
Application	LH2, LO2, I/T side wall			LH2 aft dome			Closeouts and repairs			LH2 forward dome, LO2 aft dome, closeouts		
Process	Spray			Spray			Pour/Mold			Spray		
Description	Isocyanurate			Isocyanurate			Urethane			Urethane		
Requirements	Spec Req	Typ Prop	Fll Pred	Spec Req	Typ Prop	Fll Pred	Spec Req	Typ Prop	Fll Pred	Spec Req	Typ Prop	Fll Pred
Density PCF	2.0-2.5 2.1-2.6	2.25 2.4	lighter[4]	2.6-3.1 2.6-3.1	2.97 2.90	heavier[4]	2.3-3.1 2.3-3.1	2.6 2.6	same[4]	1.8-2.6 1.8-2.6 1.8-2.6	2.4 2.4 2.4	same[4]
Tensile RT (psi)	30 min 35 min	44 54	19	40 min 40 min	66 71	19	60 60	113 104	19	35 min 35 min 35 min	30 53 75	19
Tensile -423°F (psi)	N/A[1]	34 41	19	N/A	49 47	19	N/A	50 49	19	N/A	73 62 53	19
Tensile +200°F (psi)	N/A	32 37	19	N/A	36 45	19	N/A	71.2 53	19	N/A	53 36.1 47	19
Compression (psi)	25 min 24 min	33 40	20	35 min 35 min	49 51	20	30 30	61 42	20	24 min 24 min 24 min	43 30 42	20
Erosion Rate @ 7 BTU/ft sq sec (in/sec)	N/A	0.0094 0.0168	lower[6]	N/A	0.00992 0.00997	same[6]	N/A	0.0303 0.0235	higher[6]	N/A	0.031 0.0172 0.024	lower[6]
Thermal Cond @ RT BTU/hr ft °F)	0.0125	0.017 0.017	same[6]	0.0125 0.0153	0.0130 0.0156	higher[6]	0.016 0.016	0.015 0.012	higher[6]	0.015 0.015	0.015 0.013 0.0111	higher[6]
Cryoflex (psi)	41@423	48@423 48@423	pass	53@423	48@423 48@423	pass	N/A	40@320 40@320	pass	N/A	48@423 48@423	pass

[1]N/A- Not Applicable [2]+200°F Values [3]@ 4 BTU/ft sq sec [4]Max density 3.0 in dome area allowed
[5]@ + 200°F [6]Means new vs. old [7]Radiant heating [8]2.4 – 2.8 PCF for thickness

9

CAIB PUBLIC HEARING: Properties

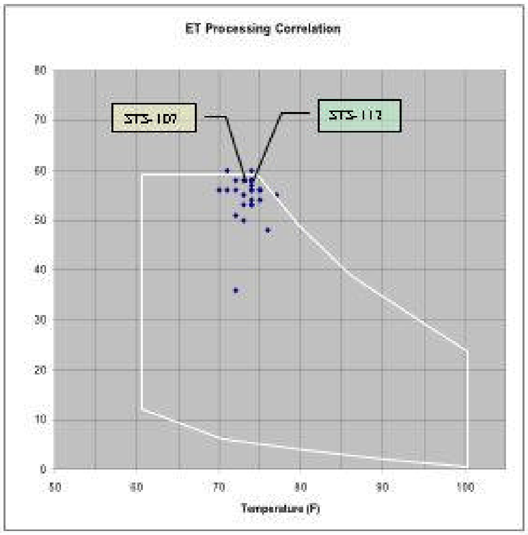
ET CRYOINSULATIONS	ACCELERATED EXPOSURE
NCFI 24-124 (HCFC-141B)	0.12% Weight Gain of Machined Foam (7 Days @125 F & 95% RH)
BX-250 (CFC-11)	0.16% Weight Gain of Machined Foam (7 Days @125 F & 95% RH)
SS-1171 (HCFC-141B)	0.42% Weight Gain of Machined Foam (7 Days @125 F & 95% RH)
PDL-1034 (HCFC-141B)	0.83% Weight Gain of Machined Foam (7 Days @125 F & 95% RH)

* Materials on metal substrates (1' X 1') during accelerated exposure

10


CAIB PUBLIC HEARING: Qualification Activities
NASA
Testing Performed Throughout Qualification Activities
Several lots of material were tested to characterize the material variability and process repeatability.
Physical Properties
Bond Tension (-423 to 300 °F)
Flatwise Tension (-423 to 300 °F)
Plug Pulls
Density
Compression
Mechanical Properties
Cryoflex (-423 & -320 °F)
Monostrain (-423 to 400 °F)
Torsion Shear
Poisson Ratio
Thermal Properties
Thermal Conductivity (-423 to 200 °F)
Oxygen Index
Flammability
Specific Heat & TGA
Aero-recession (Hot Gas)
Thermal-Vac
Major Flight Acceptance Tests:
Wind Tunnel (aero-recession for ascent)
Plasma Arc (Entry recession)
PAL Ramps
Aft Dome Test (Stop Sign)
Combined Environments (combined lift-off environments)
Chart presented on
11

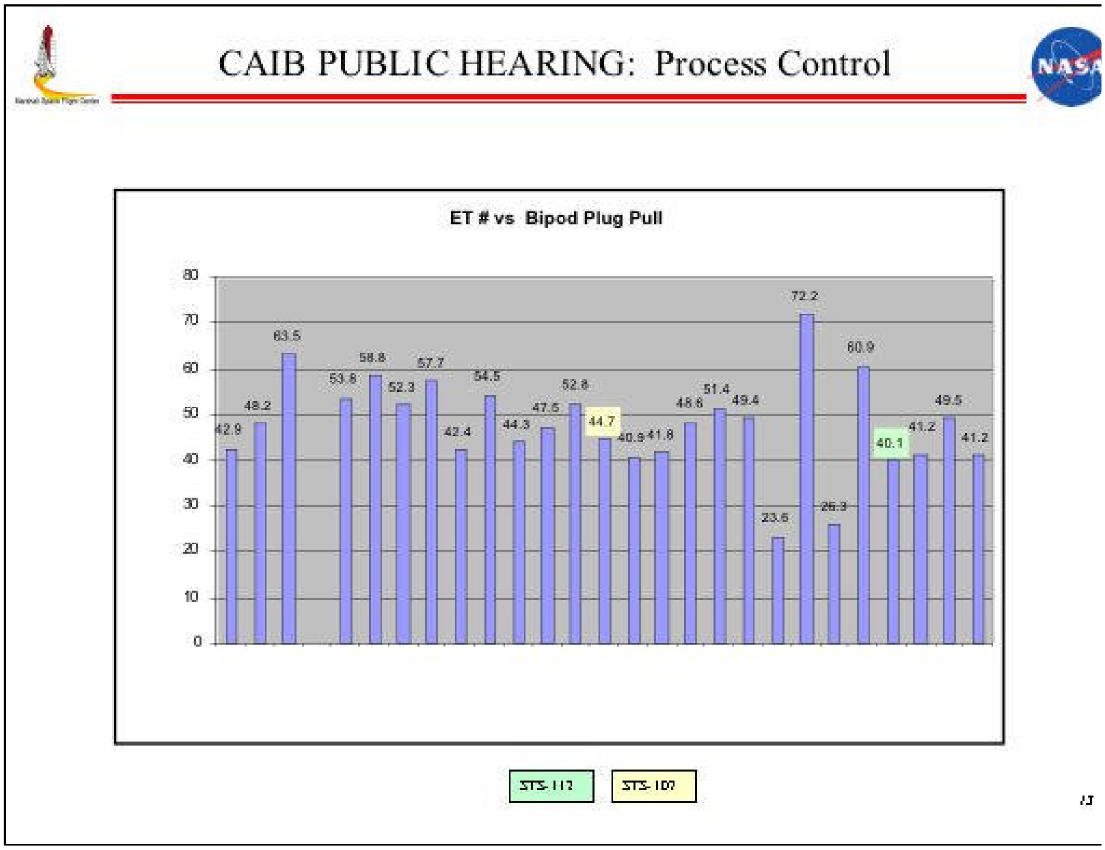
CAIB PUBLIC HEARING: Process Control



BX-250 Bipod Application	Work Area Temperature (F)	Work Area Relative Humidity (%)
ET-106 -Y	72	56
ET-106 +Y	72	58
ET-107 -Y	75	56
ET-107 +Y	74	57
ET-108 -Y	73	50
ET-108 +Y	75	54
ET-109 -Y	74	54
ET-109 +Y	76	48
ET-110 -Y	74	56
ET-110 +Y	77	55
ET-111 -Y	74	58
ET-111 +Y	74	60
ET-93 -Y	73	58
ET-93 +Y	74	58
ET-94 -Y	74	56
ET-94 +Y	72	51
ET-112 -Y	72	36
ET-112 +Y	71	56
ET-113 -Y	70	56
ET-113 +Y	75	56
ET-114 -Y	73	53
ET-114 +Y	74	53
ET-115 -Y	74	58
ET-115 +Y	74	53
ET-116 -Y	73	55
ET-116 +Y	71	60

STS-112 STS-107

12


CAIB PUBLIC HEARING: Process Control
ET # vs Bipod Plug Pull
80
70
60
50
40
30
20
10
0
42.9
48.2
63.5
53.6
58.8
52.3
57.7
42.4
54.5
44.3
47.5
52.8
44.7
40.9
41.8
48.6
51.4
49.4
23.6
72.2
26.3
60.9
40.1
41.2
49.5
41.2
STS-112
STS-107

CAIB PUBLIC HEARING: Material Changes

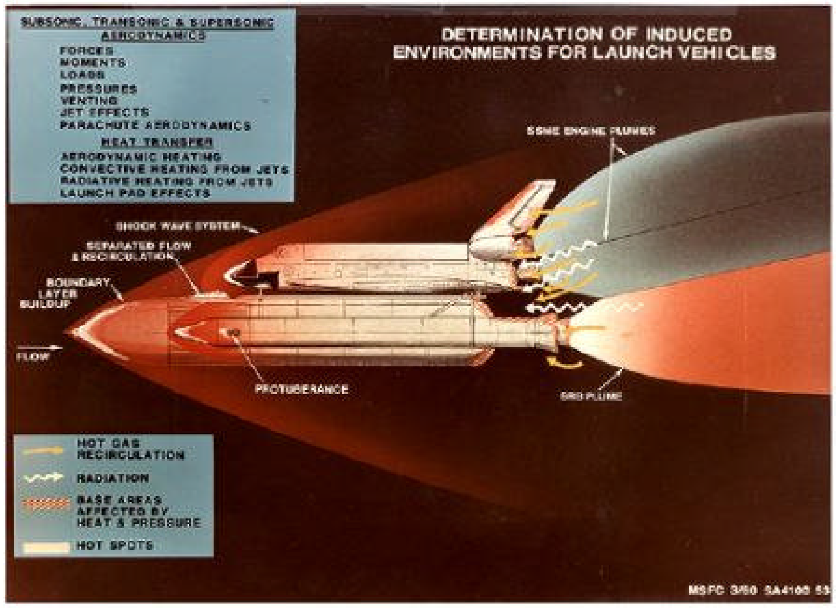
BX-250 to SS 1171 to BX-265

- Original ET material, BX-250, Chosen for Ramp/Closeout Applications
- 1993 - CFC 11 blowing agent manufacture discontinued (accelerated EPA date)
- 1995 - SS-1171 (w/HCFC 141b) chosen to replace BX 250
- 1995 - Secured available stock of CFC 11 for use with remaining BX 250
- 1995 - FR 1138 Flame Retardant discontinued in SS-1171 foam – acquired Dead Sea Bromide as replacement
- 1998 - Production issues identified with use of SS 1171 in F/A & Bldg 420, decision made to continue BX 250 usage
- 1999 - SS 1171 low strength failure analysis and subsequent acquisition by BASF; usage on ET discontinued
- 2000 - Mondur Dark Isocyanate used in BX 250 phased out of production (secured supply till BX 265 implemented)
- 2001 - BX-265 qualified to replace BX-250
- 2002 - BX-265 Foam Implementation on ET-117 (subsequent repair on ET-116 at KSC)
- 2003 - EPA phase out of HCFC 141b initiated (Waiver Required for Procurement in US)
- 2003 - Waiver approving NASA's HCFC 141b exemption allowance granted on March 5, 2003.

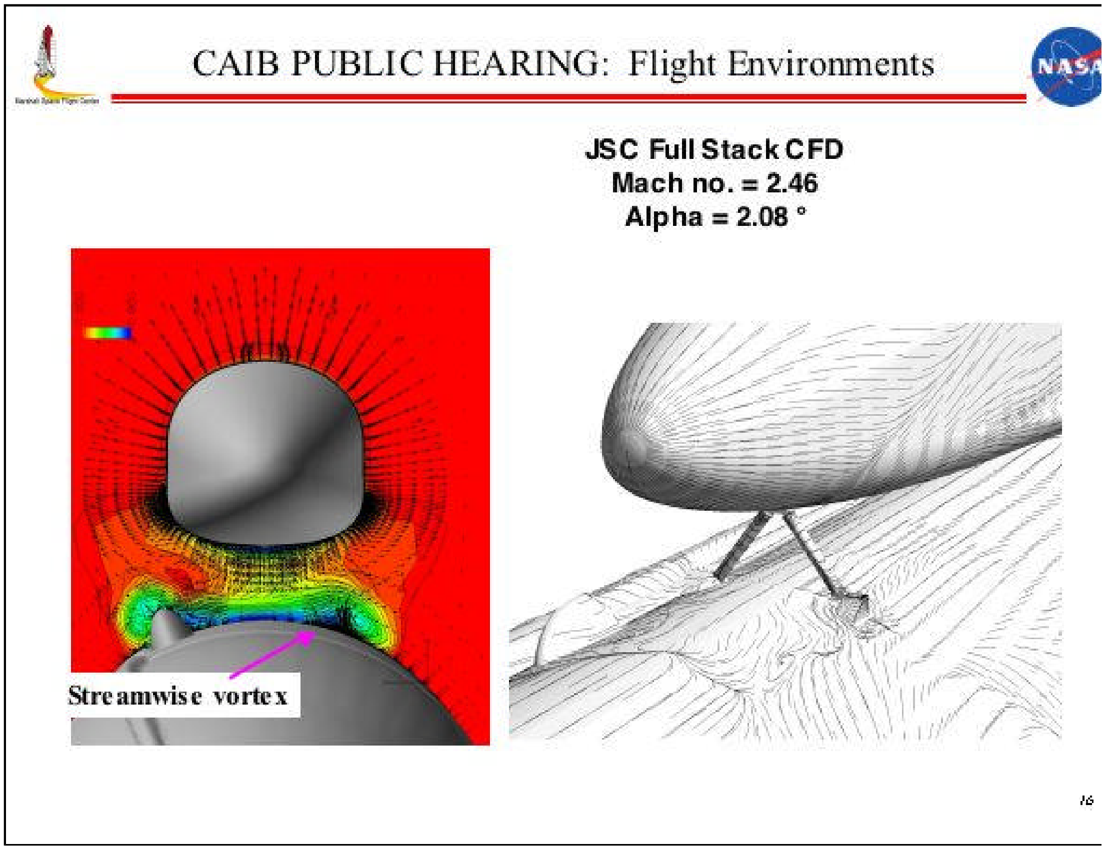
1996 CFC to HCFC Presentation

14

CAIB PUBLIC HEARING: Flight Environments



Synchronized Flight Environments


CAIB PUBLIC HEARING: Flight Environments
JSC Full Stack CFD
Mach no. = 2.46
Alpha = 2.08 °
Streamwise vortex
16

CAIB PUBLIC HEARING: History of Foam Loss

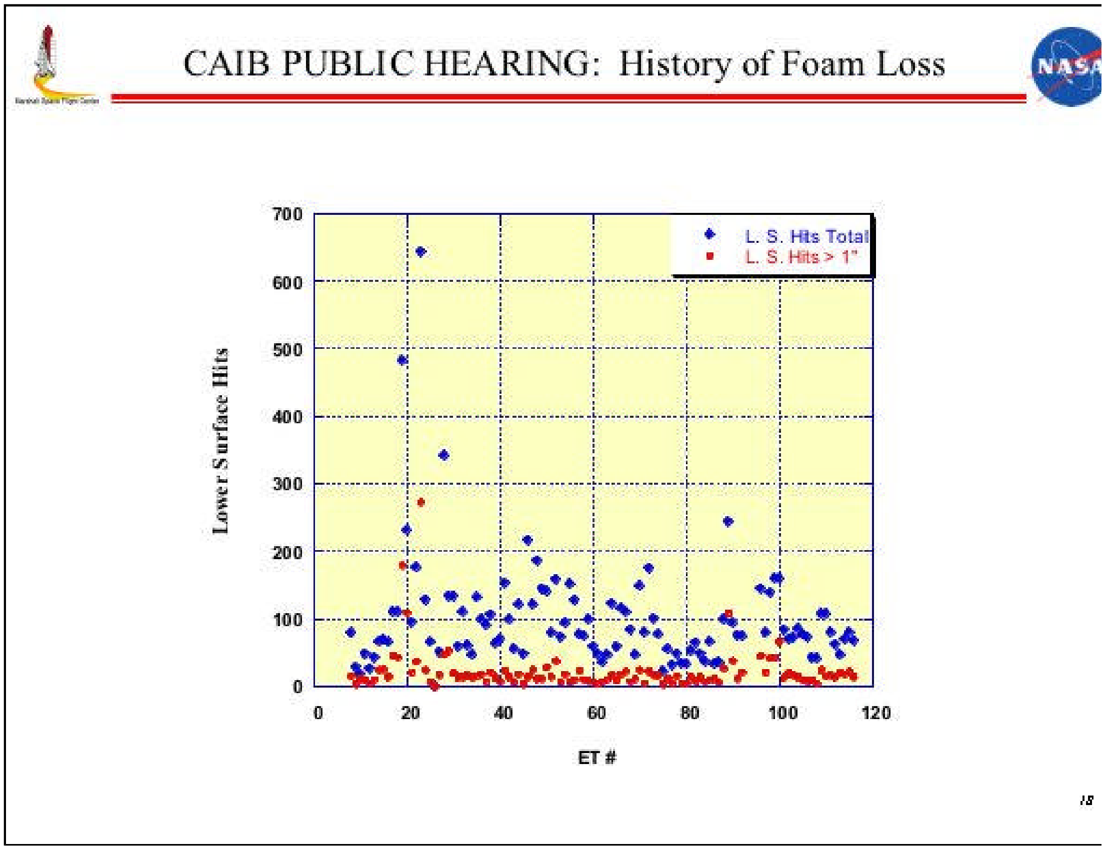
Data Commonly Available for Assessment of ET Debris Production

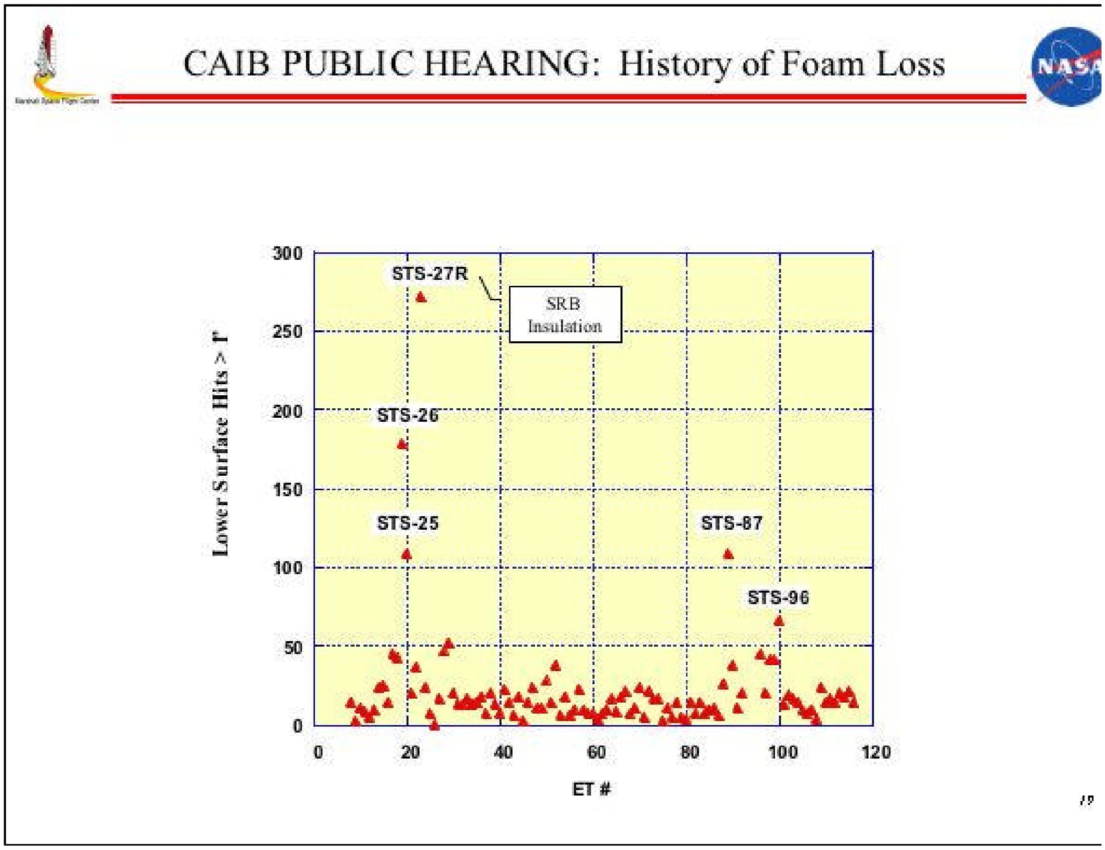
1. Ascent photographic coverage
2. ET-Orbiter separation photographic coverage
    1. Umbilical well cameras
    2. Crew hand held cameras
3. Post-flight Orbiter tile damage

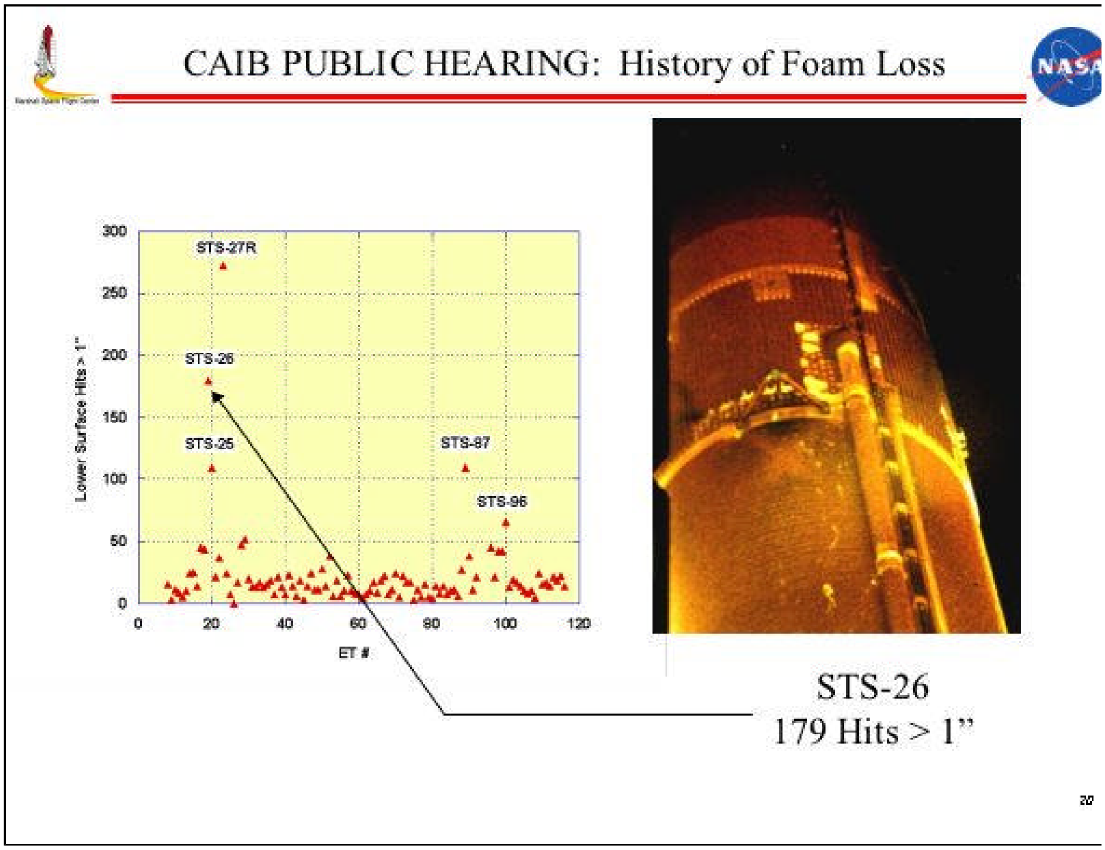
Additional Data Collection for Assessment of ET Debris Production

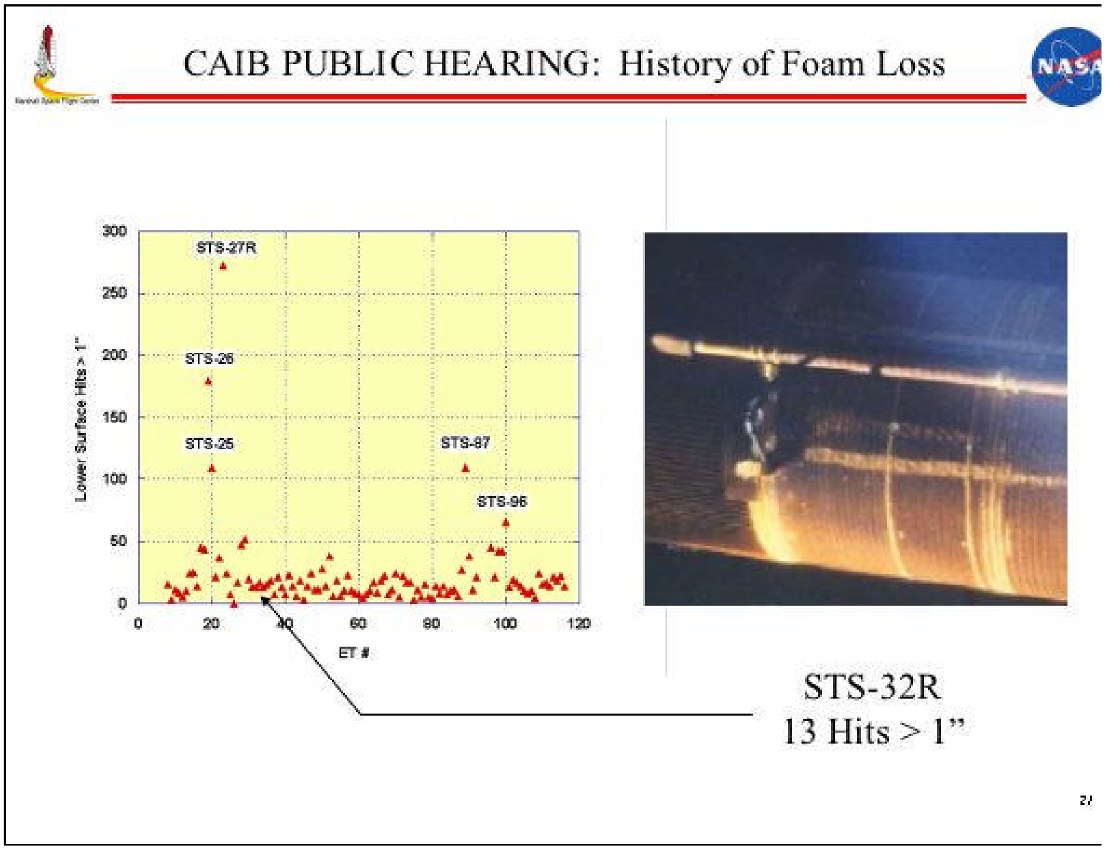
1. SRB ascent camera coverage (intertank thrust panel)
2. ET ascent camera (general view aft)

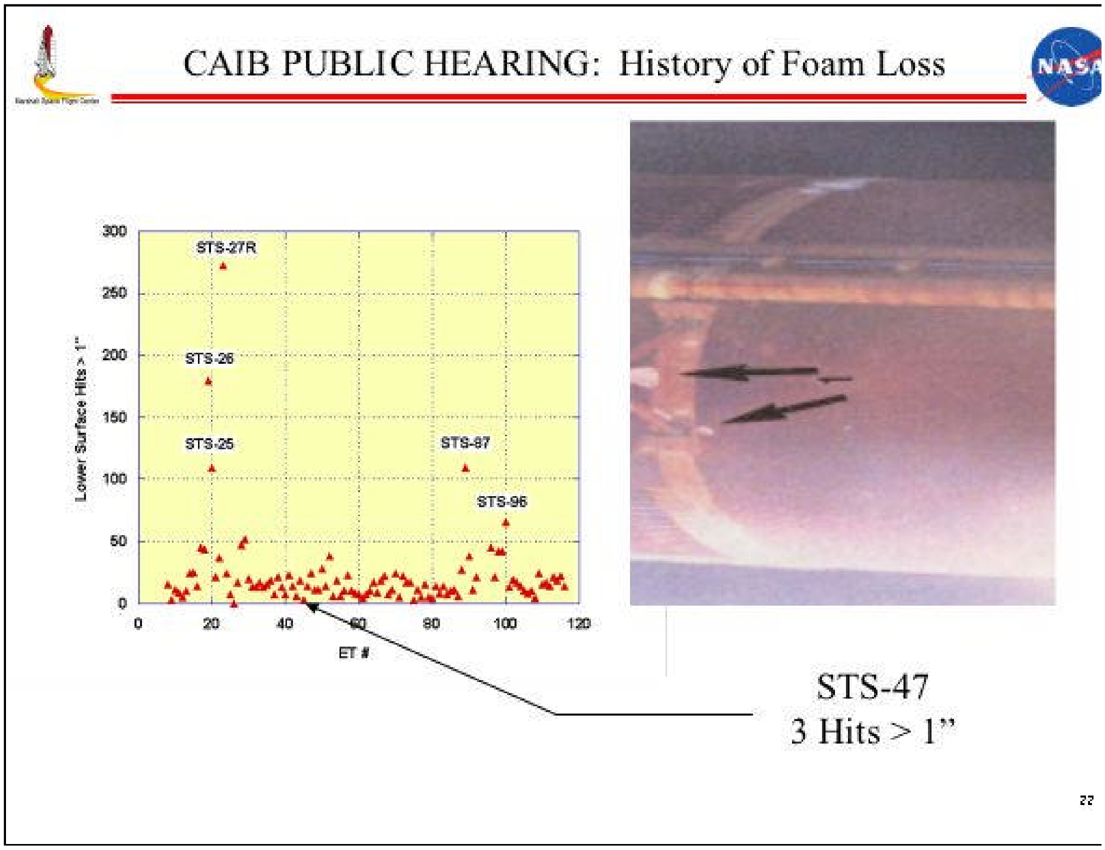
17

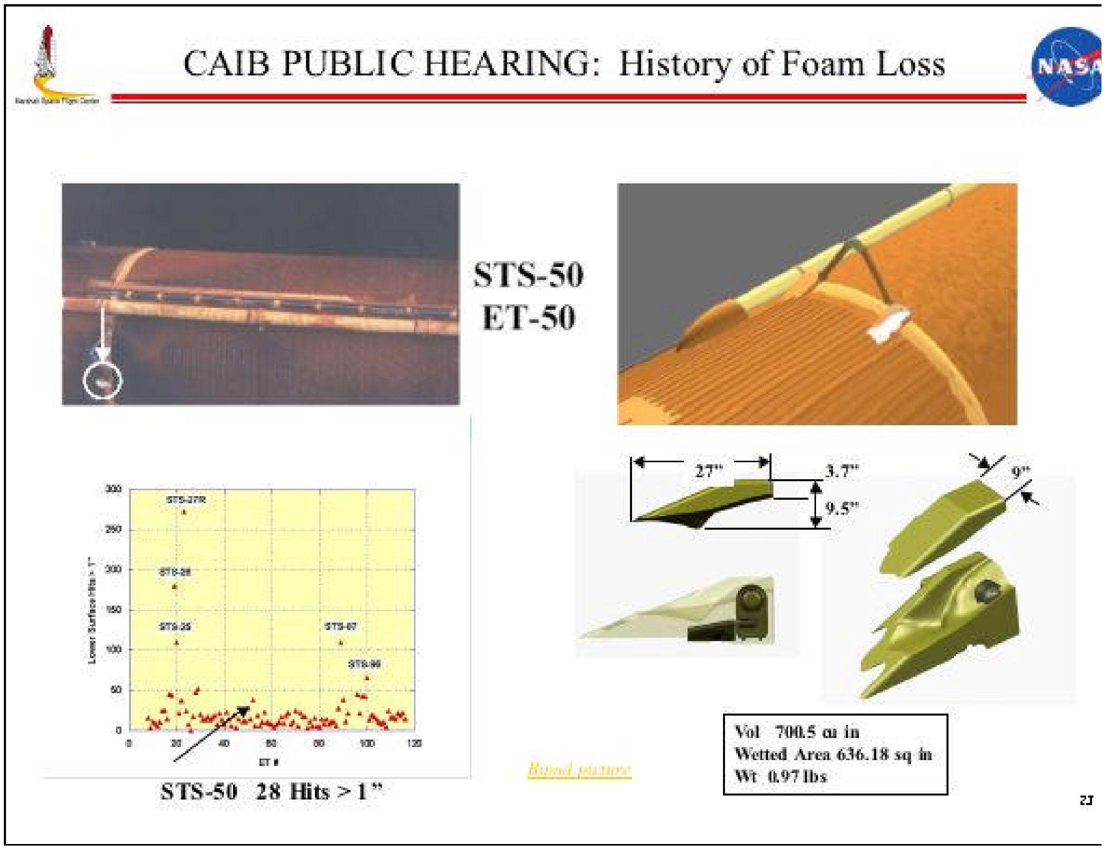

CAIB PUBLIC HEARING: History of Foam Loss
NASA
Lower Surface Hits
ET #
L. S. Hits Total
L. S. Hits > 1"
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
18

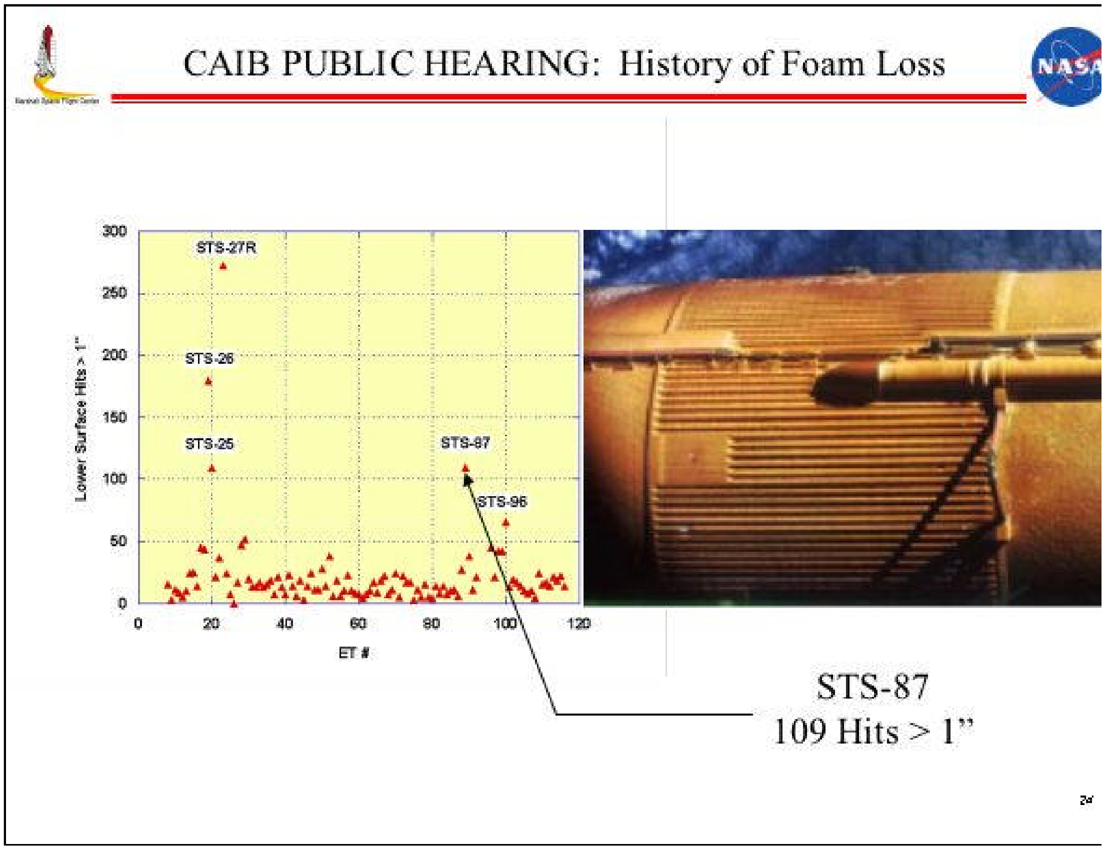

CAIB PUBLIC HEARING: History of Foam Loss
NASA
Lower Surface Hits > 1"
ET #
STS-27R
SRB Insulation
STS-26
STS-25
STS-87
STS-96
300
250
200
150
100
50
0
0
20
40
60
80
100
120


CAIB PUBLIC HEARING: History of Foam Loss
NASA
Lower Surface Hits > 1"
ET #
STS-27R
STS-26
STS-25
STS-87
STS-96
300
250
200
150
100
50
0
0
20
40
60
80
100
120
STS-26
179 Hits > 1"
20


CAIB PUBLIC HEARING: History of Foam Loss
NASA
300
250
200
150
100
50
0
Lower Surface Hits > 1"
0
20
40
60
80
100
120
ET #
STS-27R
STS-26
STS-25
STS-87
STS-96
STS-32R
13 Hits > 1"


CAIB PUBLIC HEARING: History of Foam Loss
NASA
Lower Surface Hits > 1"
300
250
200
150
100
50
0
STS-27R
STS-26
STS-25
STS-87
STS-96
0
20
40
60
80
100
120
ET #
STS-47
3 Hits > 1"
22

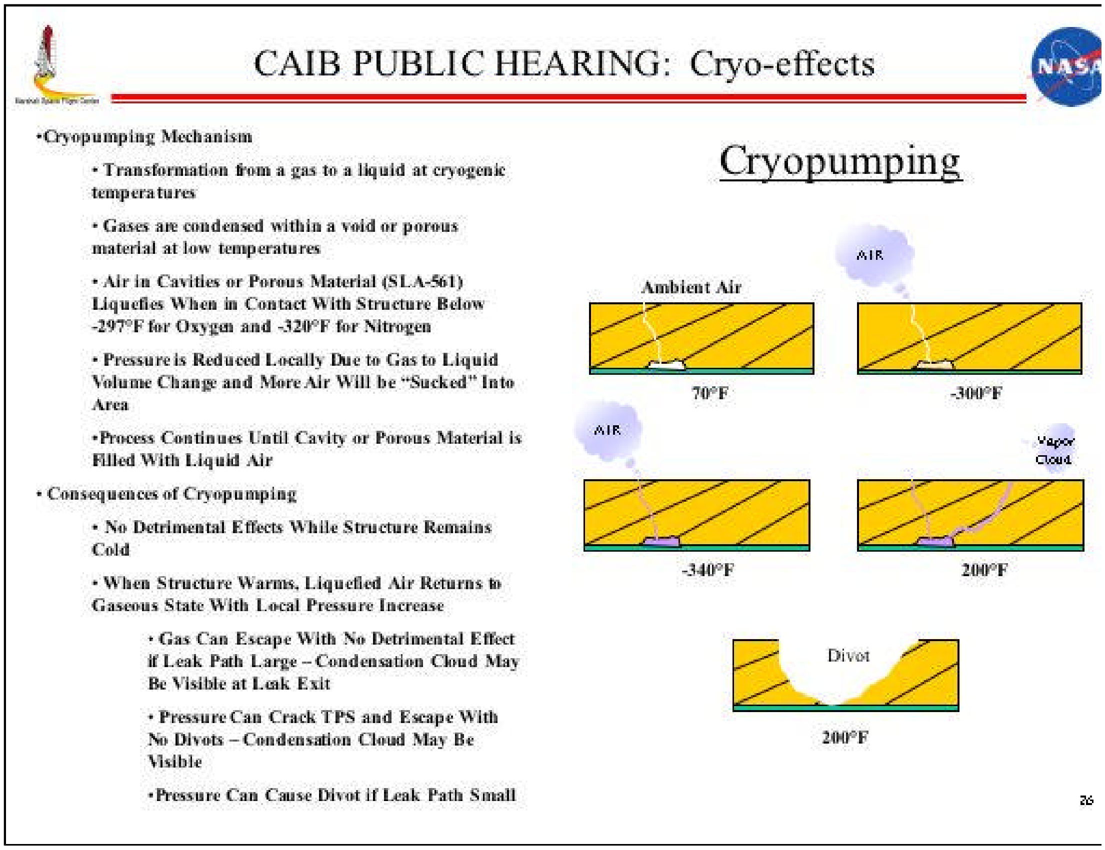

CAIB PUBLIC HEARING: History of Foam Loss
STS-50
ET-50
27"
3.7"
9.5"
9"
STS-27R
STS-28
STS-35
STS-87
STS-98
Lower Surface Hits > 1"
ET #
STS-50 28 Hits > 1"
Bipod picture
Vol 700.5 cu in
Wetted Area 636.18 sq in
Wt 0.97 lbs
23


CAIB PUBLIC HEARING: History of Foam Loss
NASA
Lower Surface Hits > 1"
ET #
STS-27R
STS-26
STS-25
STS-87
STS-96
0
50
100
150
200
250
300
0
20
40
60
80
100
120
STS-87
109 Hits > 1"

CAIB PUBLIC HEARING: Efforts to Reduce Debris

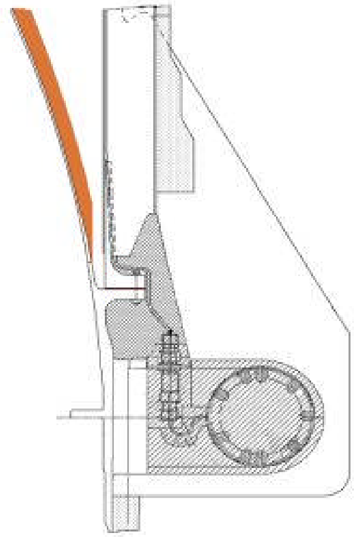
STS	ET	Launch Date	Precipitating Event / Concern	Efforts to Reduce Debris
1	1	4/12/1981	Ice may form on instrumentation islands and become debris	Removed instrumentation islands on LO2 Tank to insure no ice debris
6	8 (LWT 1)	4/1/83	Block change to Lightweight Tank enabled design changes	Redesign of Bipod Ramp angle from 45° to 30° on LWT-7
				Incorporated maximum repairable defect limits on Bipod ramp
				Incorporated improved fabrication procedures for LH2 tank cable tray ice frost ramps (two-step single-pour application versus one-step multi-pour process)
				Reduced SLA areas
				Deleted anti-geyser line
				Incorporated "two-tone" foam configuration on areas of the Intertank
27	21	8/14/1988	Large Intertank divots observed on STS-25 & STS-26	Corrective action (drilled holes) applied in two-tone areas to preclude debris due to Isochem bondlayer issues
32R	32	1/9/1990	Intertank / Bipod divot observed on STS-32R	Added inspection to verify vent hole depth in two-tone areas
35	35	12/2/1990	Ten flange area divots observed on STS-35	Incorporated process improvements to reduce potential for void formation around the flange bolts
50	50	6/25/1992	Jack-pad area divot observed on STS-50	Changed jack-pad closeout method
46	48	7/31/1992	Intertank / Bipod divot observed on STS-50	Added more vent holes around bipod ramps in two-tone areas
54	51	1/13/1993	Previous problems with two-tone Intertank foam	Incorporated two-gun spray foam application on Intertank to replace two-tone foam
56	54	4/8/1993	Ten large, shallow divots on -Z Intertank Acreage	Enhancement of Process to reduce roll-over and crevicing
87	89	11/19/1997	Increased number of Orbiter tile hits	Reduced foam thickness
				Incorporated "vent" holes
112	115	10/7/2002	Bipod foam loss on STS-112	Proposed corrective action (to be presented 2/6/03): remove SLA from under the foam application

23


CAIB PUBLIC HEARING: Cryo-effects
•Cryopumping Mechanism
• Transformation from a gas to a liquid at cryogenic temperatures
• Gases are condensed within a void or porous material at low temperatures
• Air in Cavities or Porous Material (SLA-561) Liquefies When in Contact With Structure Below -297°F for Oxygen and -320°F for Nitrogen
• Pressure is Reduced Locally Due to Gas to Liquid Volume Change and More Air Will be "Sucked" Into Area
•Process Continues Until Cavity or Porous Material is Filled With Liquid Air
• Consequences of Cryopumping
• No Detrimental Effects While Structure Remains Cold
• When Structure Warms, Liquefied Air Returns to Gaseous State With Local Pressure Increase
• Gas Can Escape With No Detrimental Effect if Leak Path Large – Condensation Cloud May Be Visible at Leak Exit
• Pressure Can Crack TPS and Escape With No Divots – Condensation Cloud May Be Visible
•Pressure Can Cause Divot if Leak Path Small
Cryopumping
AIR
Ambient Air
70°F
-300°F
AIR
Vapor Cloud
-340°F
200°F
Divot
200°F
26

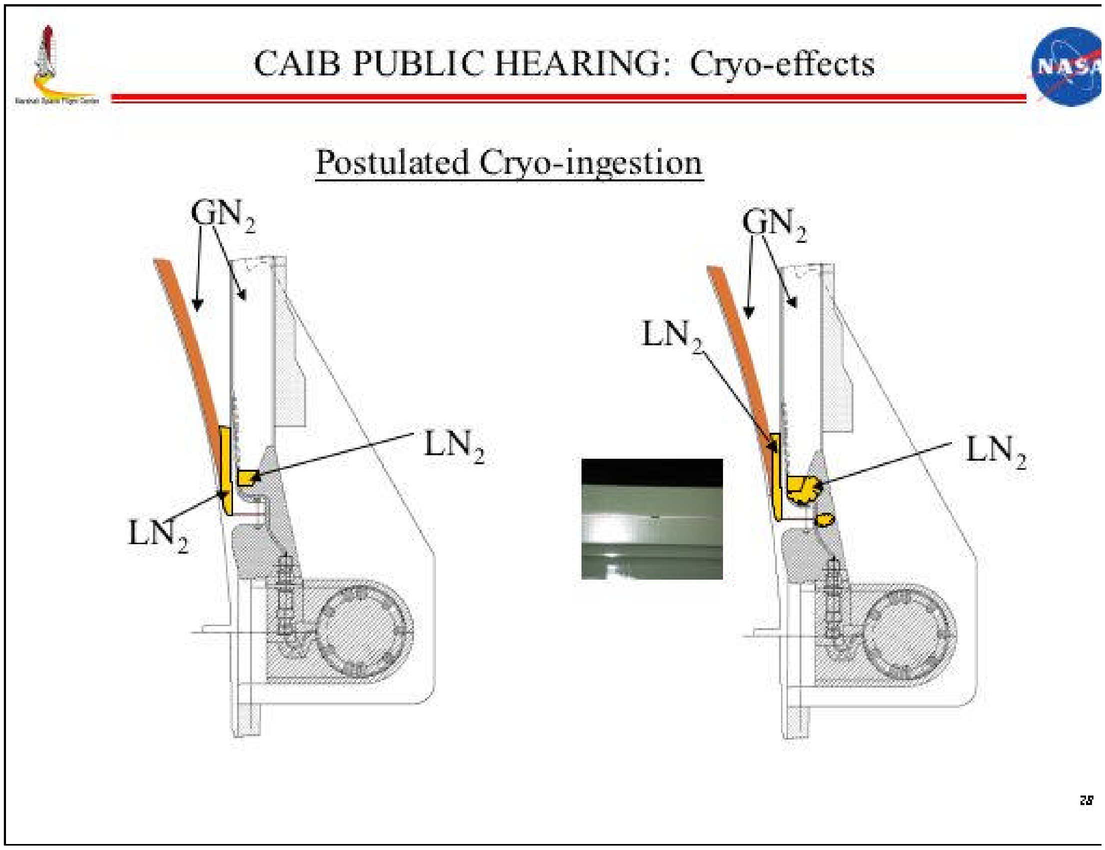
CAIB PUBLIC HEARING: Cryo-effects

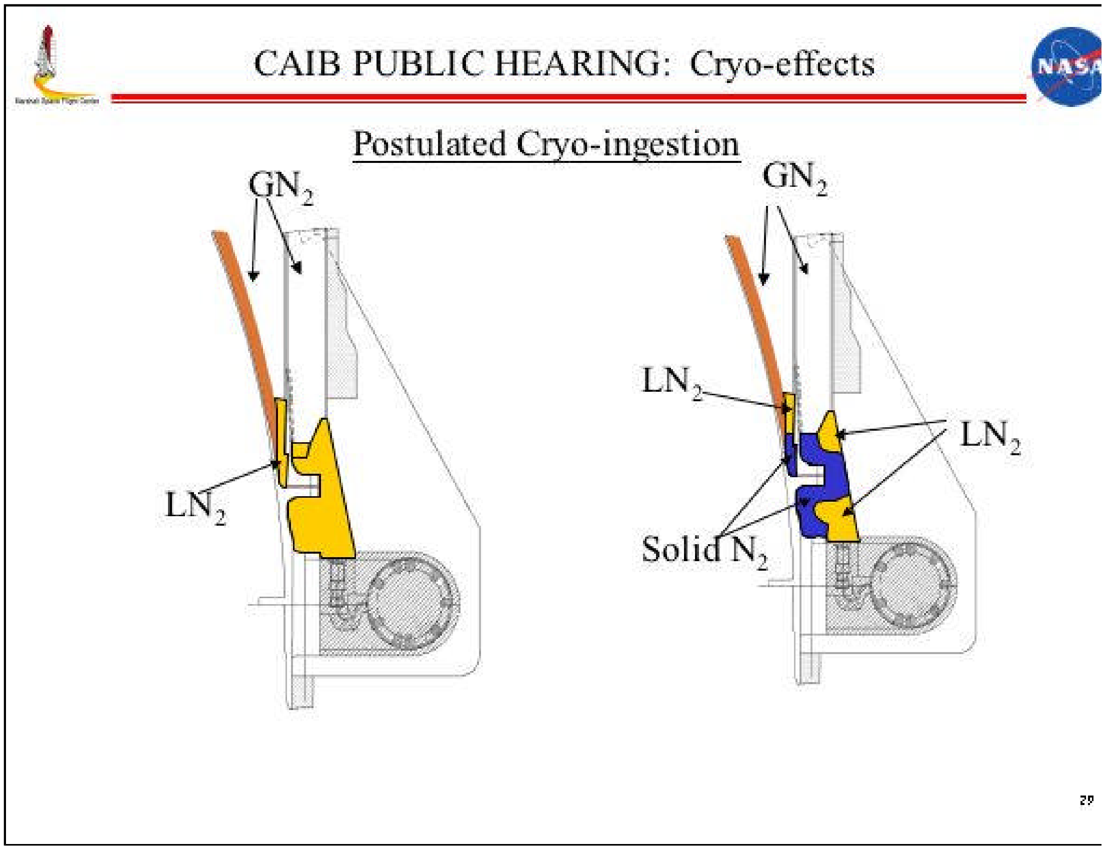
Postulated Cryo-ingestion

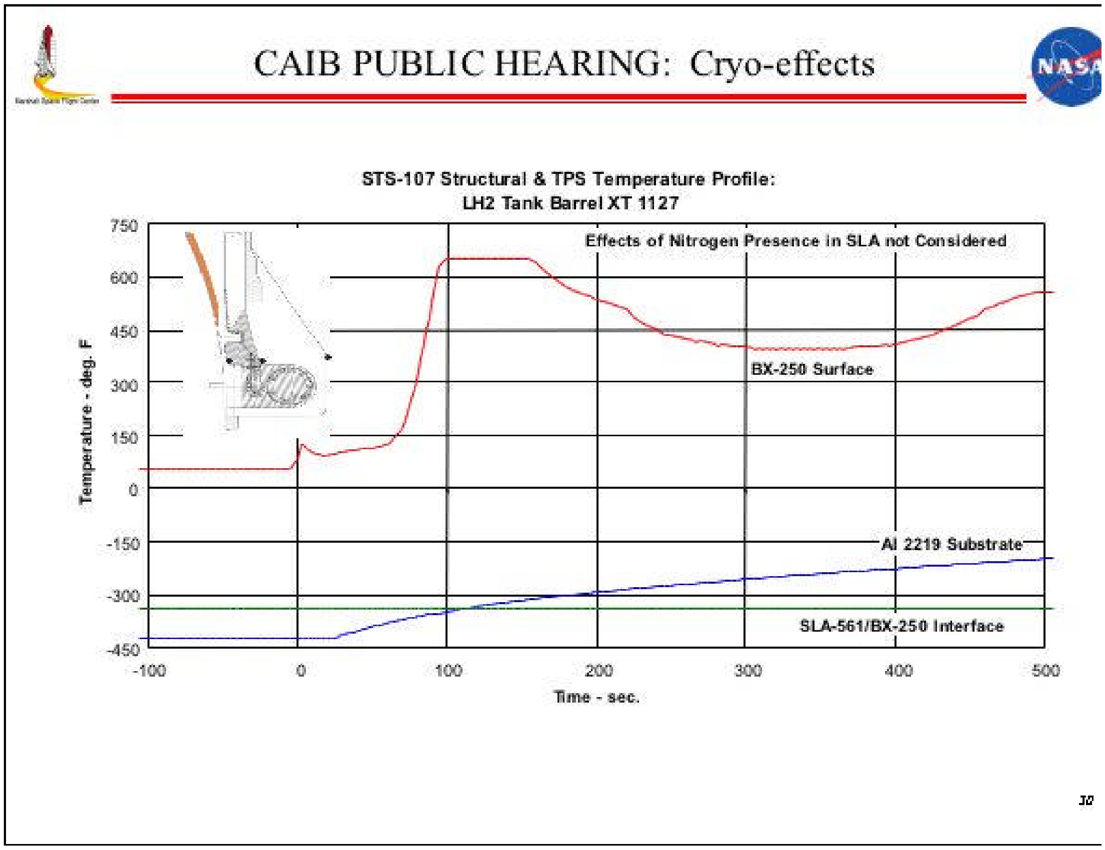


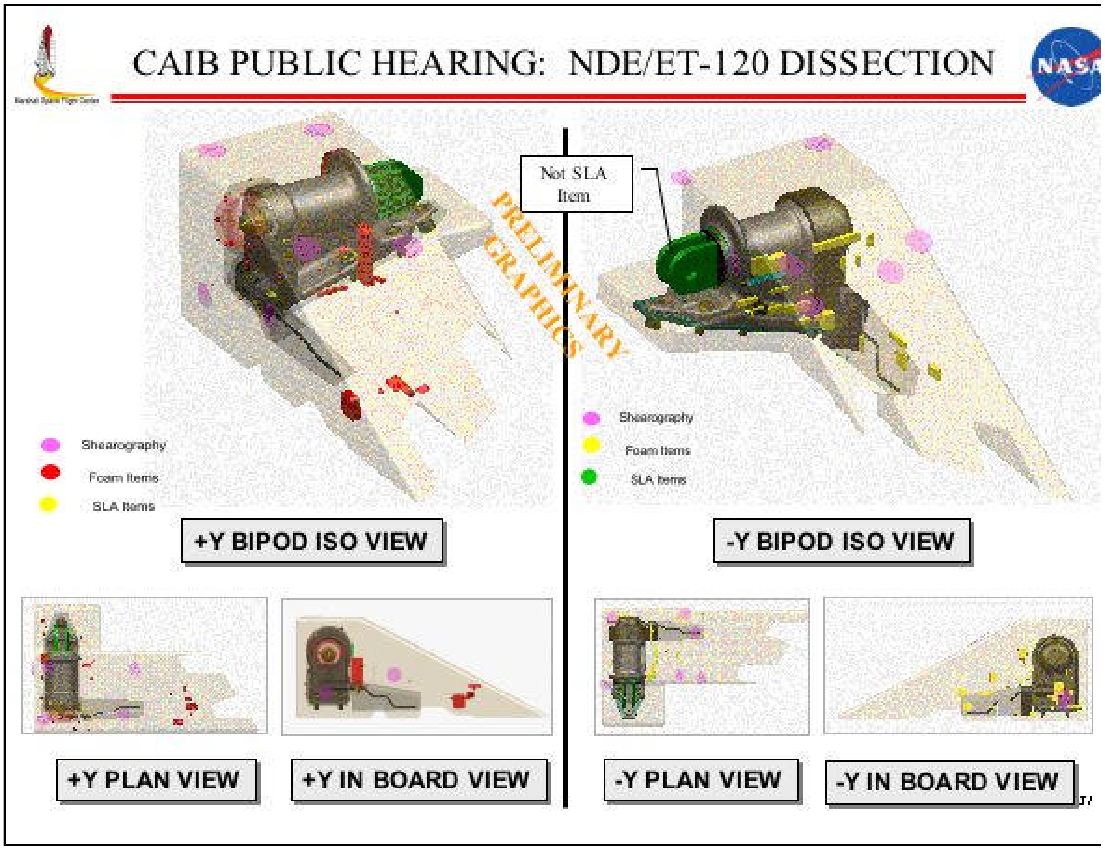
Bipod Schematic

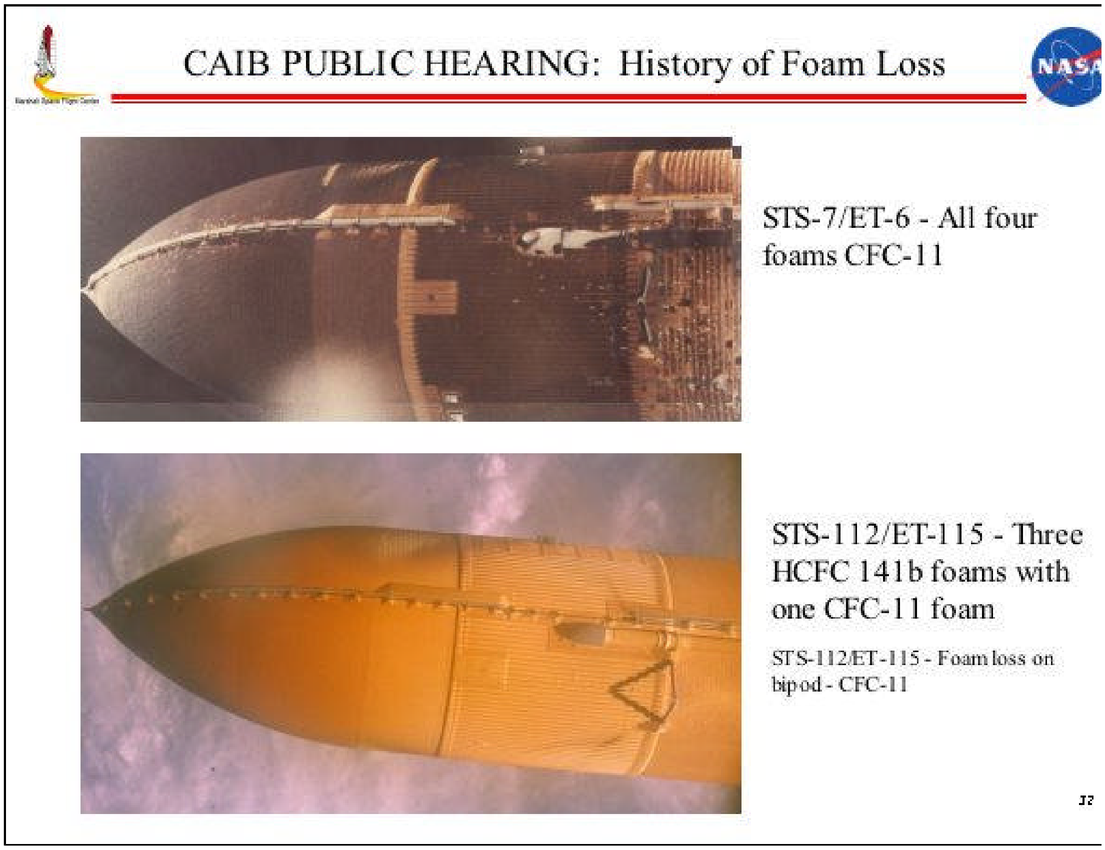
27

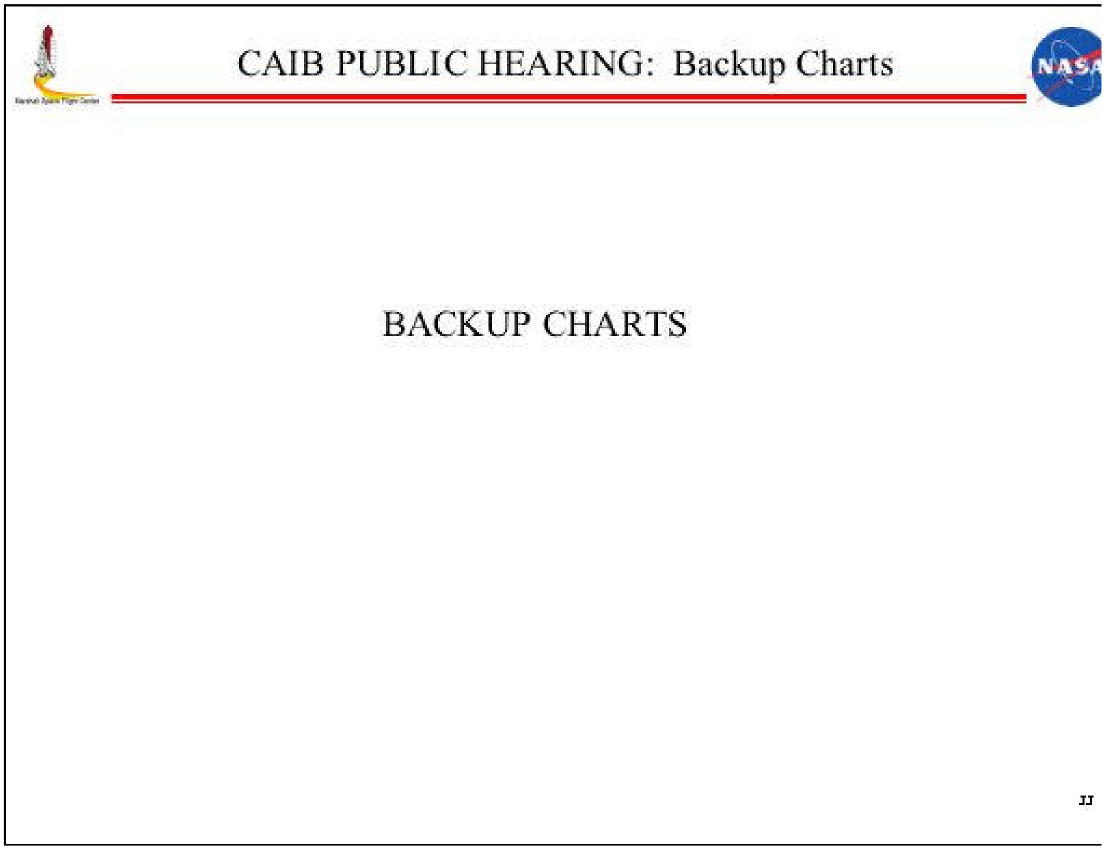

CAIB PUBLIC HEARING: Cryo-effects
Postulated Cryo-ingestion
GN2
LN2
LN2
GN2
LN2
LN2
28

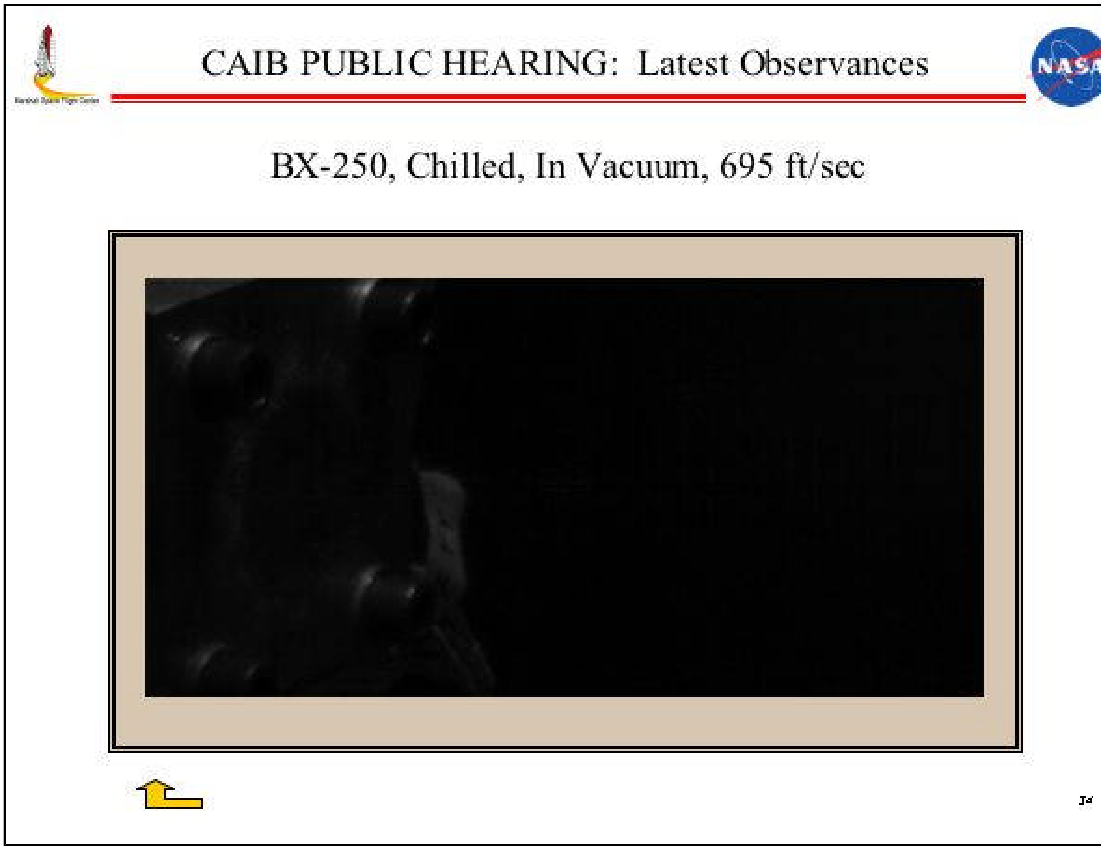

CAIB PUBLIC HEARING: Cryo-effects
NASA
Postulated Cryo-ingestion
GN2
GN2
LN2
LN2
LN2
Solid N2
29


CAIB PUBLIC HEARING: Cryo-effects
STS-107 Structural & TPS Temperature Profile:
LH2 Tank Barrel XT 1127
Effects of Nitrogen Presence in SLA not Considered
BX-250 Surface
Al 2219 Substrate
SLA-561/BX-250 Interface
Temperature - deg. F
Time - sec.
750
600
450
300
150
0
-150
-300
-450
-100
0
100
200
300
400
500
30


CAIB PUBLIC HEARING: NDE/ET-120 DISSECTION
NASA
Not SLA Item
PRELIMINARY GRAPHICS
Shearography
Foam Items
SLA Items
Shearography
Foam Items
SLA Items
+Y BIPOD ISO VIEW
-Y BIPOD ISO VIEW
+Y PLAN VIEW
+Y IN BOARD VIEW
-Y PLAN VIEW
-Y IN BOARD VIEW


CAIB PUBLIC HEARING: History of Foam Loss
NASA
STS-7/ET-6 - All four foams CFC-11
STS-112/ET-115 - Three HCFC 141b foams with one CFC-11 foam
STS-112/ET-115 - Foam loss on bipod - CFC-11
32


CAIB PUBLIC HEARING: Backup Charts
NASA
BACKUP CHARTS


CAIB PUBLIC HEARING: Latest Observances
BX-250, Chilled, In Vacuum, 695 ft/sec

CAIB PUBLIC HEARING: ET Bipod Comparison

Performance Data	ET-93	ET-94	ET-112	ET-113	ET-114	ET-115	ET-116
Bipod	--	--	--	--	--	--	--
Matl	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250
+ Y Plug Pull data	40.90	48.6	49.4	71.2	60.9	41.2	41.2
+Y Core (15 psi Min)	74.1, 90.2, 79.5, 75.9, 94.6	51.4, 37.3, 41.2, 48.7, 44.0	54.8, 42.8, 49.5, 39.8, 48.3, 51.6	66.7, 58.2, 59.2, 63.4	46.3, 52.2, 44.9, 43.9, 52.4	49.0, 40.6, 56.3, 57.4	49.1, 46.1, 45.1, 43.3
Matl	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250
-Y Plug Pull Data	44.70	41.8	51.4	67.6	26.3, Retest = 48.4	40.1	49.5
- Y Core (15 psi Min)	46.1, 38.0, 40.7, 36.8, 43.4, 47.5	72.9, 56.9, 58.0, 62.7	51.9, 43.8, 34.9, 29.8, 42.1, 39.1	53.1, 49.8, 70.5, 72.2	45.5, 41.4, 40.9, 34.2, 54.9	66.5, 72.0, 61.8, 65.4	53.7, 41.9, 50.3, 39.7

33

CAIB PUBLIC HEARING: ET Bipod Comparison

Performance Data	ET-117	ET-118	ET-119	ET-120	ET-121	ET-122	ET-123
Bipod	--	--	--	--	--	--	--
Matl	BX-250	BX-250	BX-250	BX-250	BX-265	BX-265	BX-265
+ Y Plug Pull data	62.6	42.6	51.5	28.3 Retest = 61.3	37.6	56	44
+Y Core (15 psi Min)	51.1, 67.9, 73.8, 49.2, 60.6	53.9, 55.1, 64.5, 68.5	42.0, 52.3, 55.5, 55.1	48.6, 66.4, 53.3, 46.0, 47.1	56.7, 50.2, 46.0, 42.8, 35.7	43.2, 57.2, 30.3, 51.5, 33.7, 49.5	49.5, 47.3, 48.9, 47.9, 47.1
Matl	BX-250	BX-250	BX-250	BX-250	BX-265	BX-265	BX-265
-Y Plug Pull Data	70.9	43.4	44.8	52.8	50	63.8	51.3
- Y Core (15 psi Min)	30.0, 47.3, 56.5, 46.2, 52.3	64.4, 42.4, 40.5, 70.9, 60.0	51.8, 60.8, 49.6, 64.4, 52.4	51.0, 49.1, 56.0, 51.7	37.7, 48.8, 58.7, 56.5, 48.1	35.8, 58.1, 41.0, 37.1, 42.0, 44.2, 36.5, 26.0	50.8, 58.2, 38.0, 25.0, 40.7

Back to Chart

36

CAIB PUBLIC HEARING: ET LH_2/IT Flange

Performance Data	ET-93	ET-94	ET-112	ET-113	ET-114	ET-115	ET-116
LH2 / IT Flange	--	--	--	--	--	--	--
Aft Matl	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250
Aft Lead-In Tensile	84	81.6	54.4	44.1	57.1	40.8	(1) 62.7 (2) 90.1
Aft Lead-Out Tensile	75.3	55	50.1	45	73.8	66	(1) 84.8 (2) 77.9
Fwd Matl	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250
Fwd Lead-In Tensile	86.4	84.7	67.5	67.1	50	68.6	84.6
Fwd Lead-Out Tensile	76.2	77.1	51.2	58.2	40.9	58.7	62

Performance Data	ET-117	ET-118	ET-119	ET-120	ET-121	ET-122	ET-123
LH2 / IT Flange	--	--	--	--	--	--	--
Aft Matl	BX-250	BX-250	BX-250	BX-250	BX-250	BX-265	BX-265
Aft Lead-In Tensile	54.6	45.4	52.3	(1) 57.8 (2) 54.6	53	73.3	64.4
Aft Lead-Out Tensile	64.4	64.5	62.6	(1) 57.4 (2) 61.1	77.3	67.7	54.9
Fwd Matl	BX-250	BX-250	BX-250	BX-250	BX-250	BX-265	BX-265
Fwd Lead-In Tensile	55.7	65	62.9	48.7	58.1	68.3	71.9
Fwd Lead-Out Tensile	60.4	43.8	51.8	54.2	60.1	64.4	54.5

Back to Chart

37

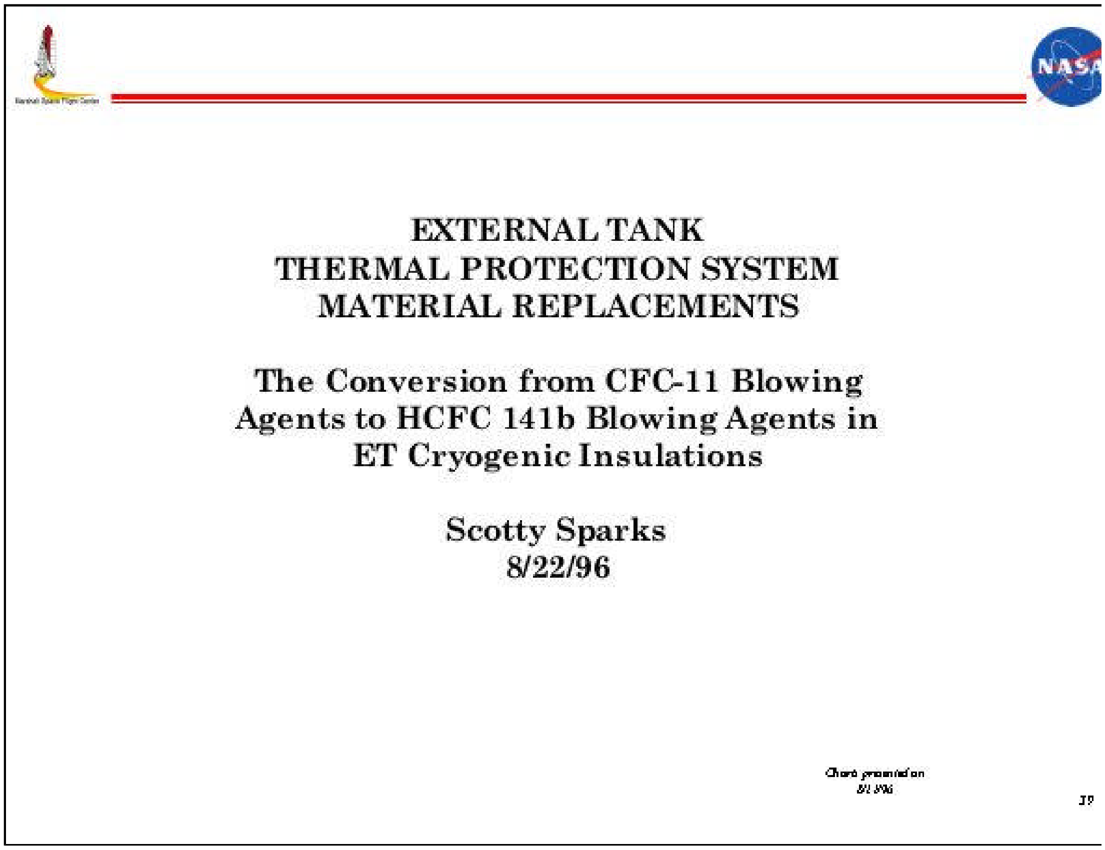
CAIB PUBLIC HEARING: ET PAL Ramp Comparison

Performance Data	ET-93	ET-94	ET-112	ET-113	ET-114	ET-115	ET-116
LO2 PAL RAMP	--	--	--	--	--	--	--
Plug Pull data	75.2, 61.7	39.2, 58.5	71.1, 58.4	81.8, 61.5	56.3, 72.7	41.7, 38.5	49.7, 61.8
Matl	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250	BX-250
Core (15 psi Min)	69.8, 53.3, 56.6, 64.9, 73.7, 36.1, 47.6	(1) 54.3, 61.6, 61.0, 47.1, 55.6, 60.7 (2) 44.3, 55.7, 46.2, 41.0	(1) 55.9, 61.8, 62.9, 57.4, 70.5 (2) 55.0, 71.3, 68.3, 23.5, 47.3	(1) 47.7, 63.2, 59.8, 68.1, 76.0 (2) 37.8, 55.5, 58.8, 64.4, 57.7	(1) 67.6, 56.3, 52.4, 56.7 (2) 62.9, 51.6, 60.9, 66.3	(1) 48.1, 66.0, 63.0, 55.7 (2) 58.2, 51.8, 52.0, 50.0	(1) 63.8, 67.4, 71.5, 53.9 (2) 47.0, 52.6, 40.9, 59.8

Performance Data	ET-117	ET-118	ET-119	ET-120	ET-121	ET-122	ET-123
LO2 PAL RAMP	--	--	--	--	--	--	--
Plug Pull data	77.5, 63.5	44.5, 46.7	42.4, 40.9	58.2, 37.0	55.1, 22.5 Retest=57.5	59.6, 53.6	57.4, 41.8
Matl	BX-250	BX-250	BX-250	BX-250	BX-265	BX-265	BX-265
Core (15 psi Min)	(1) 51.5, 55.4, 39.9, 66.7, 47.5 (2) 49.9, 54.1, 55.5, 48.9, 60.7	(1) 92.6, 72.7, 39.0, 69.6 (2) 76.2,73.8, 53.5, 49.8	(1) 26.8, 52.2, 39.8, 44.3, 53.7 (2) 36.7, 50.8, 44.6, 39.4, 41.3	(1) 50.8, 52.2, 50.0, 44.4 (2) 52.9, 53.1, 46.5, 53.3	(1) 36.6, 44.9, 33.6, 69.3, 54.8, 70.1 (2) 53.9, 49.3, 54.6, 57.1	(1) 61.7, 49.2, 56.0, 65.2, 51.0 (2) 67.6, 79.2, 66.9, 49.2, 44.3	(1) 45.8, 45.3, 30.7, 45.3, 30.7, 51.3 (2) 36.5, 49.8, 28.5, 43.1, 25.5, 44.3

Back to Chart

38


EXTERNAL TANK
THERMAL PROTECTION SYSTEM
MATERIAL REPLACEMENTS
The Conversion from CFC-11 Blowing
Agents to HCFC 141b Blowing Agents in
ET Cryogenic Insulations
Scotty Sparks
8/22/96

Regulation Chronology and Reaction

• 1978	• U.S. ban of CFC's in aerosol sprays
• 1987	• Montreal Protocol signed
• 1988	• U.S. Senate approves Montreal Protocol • EPA adopts Protocol as Domestic Regulation • Protocol adds HCFC's and VOC's
• 10/88	• Martin Marietta inititates activities to screen potential CFC alternatives
• 11/90	• Clean Air Act Amendments enacted (CFC phaseout by 2000)
• 9/91	• Martin Marietta selects best available CFC-11 replacement (HCFC 141b) and initiates action to implement in ET insulating foams by 1/1/96
• 2003	• HCFC 141b phase out (U.S. only)

Return to Chart

Chart presented on

40

Intent and Implications

- It was the intent of NASA and Lockheed-Martin to select a CFC alternative blowing agent that would incorporate equal or superior function and performance to the thermal protection materials with the least amount of facility and process modification (i.e. a "drop-in" replacement).

- Possible implications of failure to develop a "drop-in" alternative would include: performance reduction, added vehicle weight, facility modifications, process changes, open-ended development, and stockpiling of traditional materials.

- NASA and Lockheed-Martin have qualified and validated four (4) new thermal protection materials which meet current EPA regulations. The qualification and validation process was established and concurred by the ED, EE, EH, and CR Laboratories at MSFC.

Return to Chart

Chart presented on [illegible]

41


Qualification Activities
Testing Performed Throughout Qualification Activities
Several lots of material were tested to characterize the material variability and process repeatability.
Physical Properties
Bond Tension (-423 to 300 °F)
Flatwise Tension (-423 to 300 °F)
Plug Pulls
Density
Compression
Mechanical Properties
Cryoflex (-423 & -320 °F)
Monostrain (-423 to 400 °F)
Torsion Shear
Poisson Ratio
Thermal Properties
Thermal Conductivity (-423 to 200 °F)
Oxygen Index
Flammability
Specific Heat & TGA
Aero-recession (Hot Gas)
Thermal-Vac
Major Flight Acceptance Tests:
Wind Tunnel (aero-recession for ascent)
Plasma Arc (Entry recession)
PAL Ramps
Aft Dome Test (Stop Sign)
Combined Environments (combined lift-off environments)
Return to Chart

Qualification Tests Compared

CFC-11 FOAM QUALIFICATION	DESIGN REQUIREMENT	HCFC-141b FOAM QUALIFICATION
1. Initial process definition to bound process limits 2. Final process definition to develop database on material within scope of allowable parameters	Processability	1. Screening to verify processability within current processing limits 2. Same
1. Parametric evaluation of processing parameters 2. Performed testing using primarily laboratory subscale processing (low output sprays for acreage foam)	Database Development	1. Combinations of DOE and parametric evaluations 2. All qualification operations were conducted using full scale production processes at Michoud Assembly Facility
1. Bond tension (-423 to +300 °F) 2. Flatwise tension (-423 to +300 °F) 3. Cryoflex (Not used for ET 1; Implemented after ET 11 4. Monostrain 5. Density/Compression 6. Thermal Conductivity (SRI) 7. TGA 8. O2 Index 9. Friability 10. Plug Pulls 11. Torsion Shear 12. Poisson's Ratio 13. Specific Heat 14. Flammability	Properties Evaluated	1. Same 2. Same 3. Gradient Cryoflex used for all materials 4. Same 5. Same 6. Improved Thermal Conductivity test at NIST (now at MSFC), Holometrix and at MAF 7. Same 8. Same 9. Same 10. Same 11. Same 12. Same 13. Same 14. Same

Chart presented on [illegible]

Return to Chart

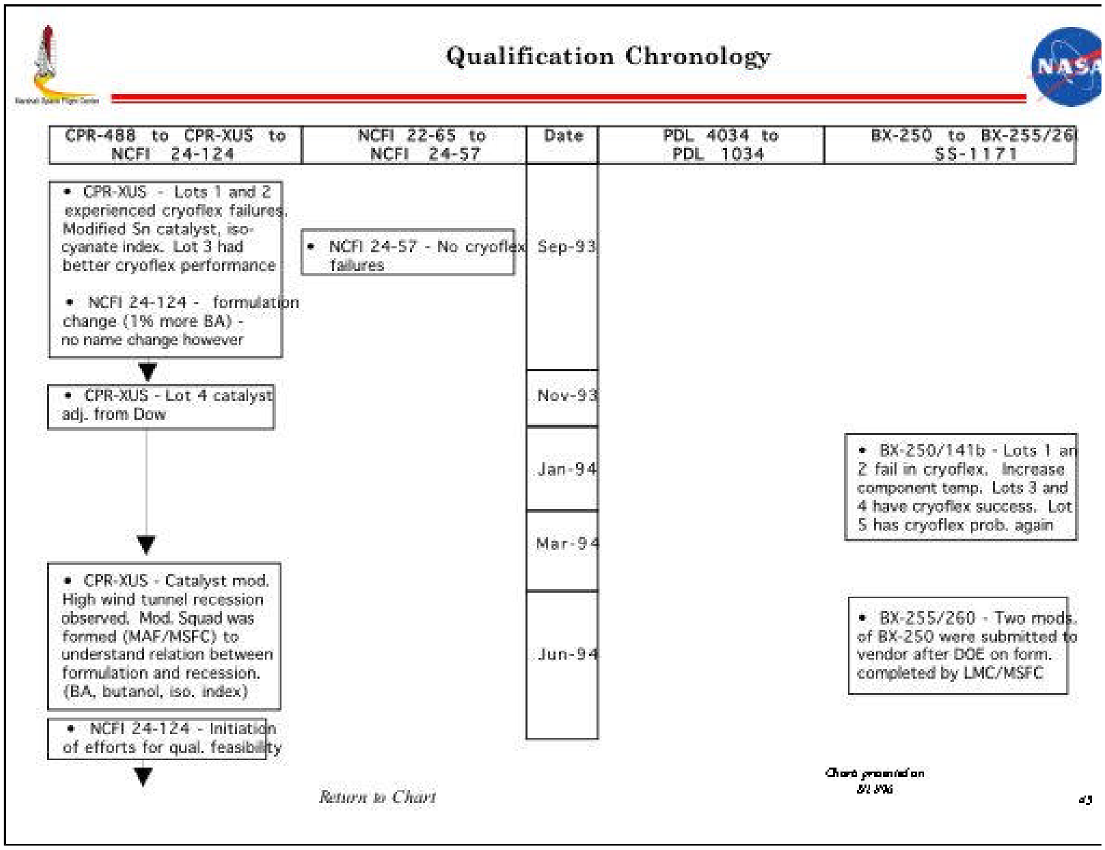
43

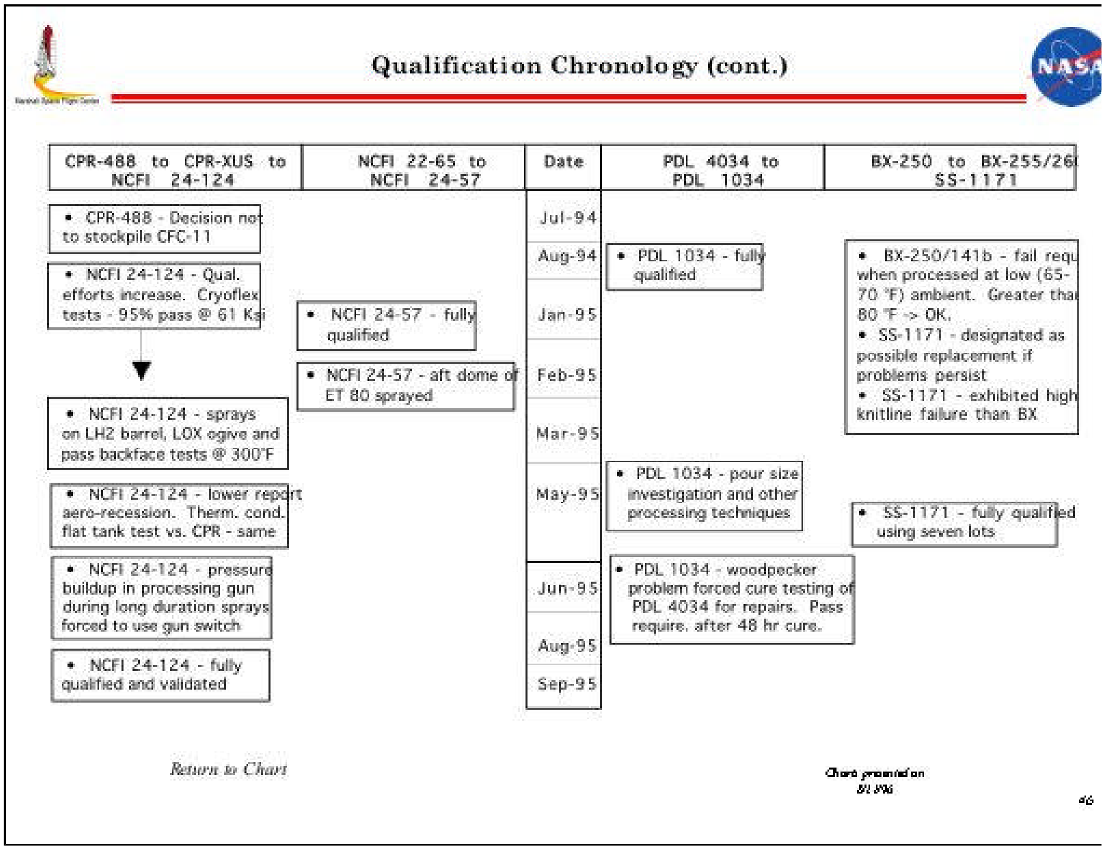
Qualification Tests Compared (cont.)

CFC-11 FOAM QUALIFICATION	DESIGN REQUIREMENT	HCFC-141b FOAM QUALIFICATION
1. Wind Tunnel (Ascent heating profiles) 2. Plasma Arc (Entry heating simulation) 3. Combined Environments 4. PAL Ramps (after STS-1) 5. Thermal Acoustic Profiles 6. Radiant - Vacuum 7. Thermal Vacuum (LOX Ogive backface heating simulation) 8. Mini-Tanks (10) 9. Flat Cryo Tanks 10. 10 ft. Tank (2) [primarily SLA test] 11. MPTA (BX-250 instead of CPR acreage foam) 12. STA 13. Not Applicable	Qualification Tests	1. Same 2. Same 3. Same 4. Same 5. Same 6. Same 7. Same 8. Satisfied using Cryoflex and Combined Env. Tests 9. Performed on NCFI 24-124 (See 13 below). Others satisfied with Therm. Cond., Cryoflex, and Combined Env. Tests 10. Satisfied using Cryoflex and Combined Env. Tests 11. Satisfied using Cryoflex and Combined Env. Tests 12. Satisfied using Cryoflex and Combined Env. Tests 13. Flat Tank test article thermal conductivity evaluation by differential temp measurements for comparison of CPR to NCFI
1. Off line Production Simulation evaluations using full-scale processing 2. Paper sprays on flight hardware with exposed areas on tank for testing or full scale mockups 3. Successful first article production application	Validation Tests	1. Not required since database development sprays were performed using full scale production process 2. Same (Two successful successive applications) 3. Same

Return to Chart

Chart presented on 8/1/96


Qualification Chronology
CPR-488 to CPR-XUS to NCFI 24-124
NCFI 22-65 to NCFI 24-57
Date
PDL 4034 to PDL 1034
BX-250 to BX-255/260 SS-1171
• CPR-XUS - Lots 1 and 2 experienced cryoflex failures. Modified Sn catalyst, iso-cyanate index. Lot 3 had better cryoflex performance
• NCFI 24-124 - formulation change (1% more BA) - no name change however
• NCFI 24-57 - No cryoflex failures
Sep-93
• CPR-XUS - Lot 4 catalyst adj. from Dow
Nov-93
Jan-94
• BX-250/141b - Lots 1 and 2 fail in cryoflex. Increase component temp. Lots 3 and 4 have cryoflex success. Lot 5 has cryoflex prob. again
Mar-94
• CPR-XUS - Catalyst mod. High wind tunnel recession observed. Mod. Squad was formed (MAF/MSFC) to understand relation between formulation and recession. (BA, butanol, iso. index)
Jun-94
• BX-255/260 - Two mods. of BX-250 were submitted to vendor after DOE on form. completed by LMC/MSFC
• NCFI 24-124 - Initiation of efforts for qual. feasibility
Return to Chart


Qualification Chronology (cont.)
CPR-488 to CPR-XUS to NCFI 24-124
NCFI 22-65 to NCFI 24-57
Date
PDL 4034 to PDL 1034
BX-250 to BX-255/26
SS-1171
• CPR-488 - Decision not to stockpile CFC-11
• NCFI 24-124 - Qual. efforts increase. Cryoflex tests - 95% pass @ 61 Ksi
• NCFI 24-124 - sprays on LH2 barrel, LOX ogive and pass backface tests @ 300°F
• NCFI 24-124 - lower report aero-recession. Therm. cond. flat tank test vs. CPR - same
• NCFI 24-124 - pressure buildup in processing gun during long duration sprays forced to use gun switch
• NCFI 24-124 - fully qualified and validated
• NCFI 24-57 - fully qualified
• NCFI 24-57 - aft dome of ET 80 sprayed
Jul-94
Aug-94
Jan-95
Feb-95
Mar-95
May-95
Jun-95
Aug-95
Sep-95
• PDL 1034 - fully qualified
• PDL 1034 - pour size investigation and other processing techniques
• PDL 1034 - woodpecker problem forced cure testing of PDL 4034 for repairs. Pass require. after 48 hr cure.
• BX-250/141b - fail requ when processed at low (65-70 °F) ambient. Greater tha 80 °F -> OK.
• SS-1171 - designated as possible replacement if problems persist
• SS-1171 - exhibited high knitline failure than BX
• SS-1171 - fully qualified using seven lots
Return to Chart
46

New TPS Flight Effectivities

NCFI 24-124	NCFI 24-57	PDL 1034	SS-1171
ET 85 (5/15/97) LH2 sidewall ET 86 (7/17/97) LOX sidewall ET 88 (10/9/97) Intertank	ET 82 (9/12/96) LH2 aft dome (Process effectivity ET 80 and subsequent)	Components/closeouts as production permits Has been installed on closeout areas since ET 79 (6/20/96)	ET 82 (9/12/96) 3rd hardpoint closeout ET 85 (5/15/97) LH2 forward dome ET 87 (9/18/97) LOX aft dome

Return to Chart

Chart presented on 8/1/96

47

Summary

NCFI 24-124 - Developing new way of processing the tank due to the possiblility of crushing due to walking loads. Includes worker awareness training and a new protection system for the tank. (First flight effectivity: ET85)

NCFI 24-57 - Ready to fly on ET 82 in September with no other processing issues at this time.

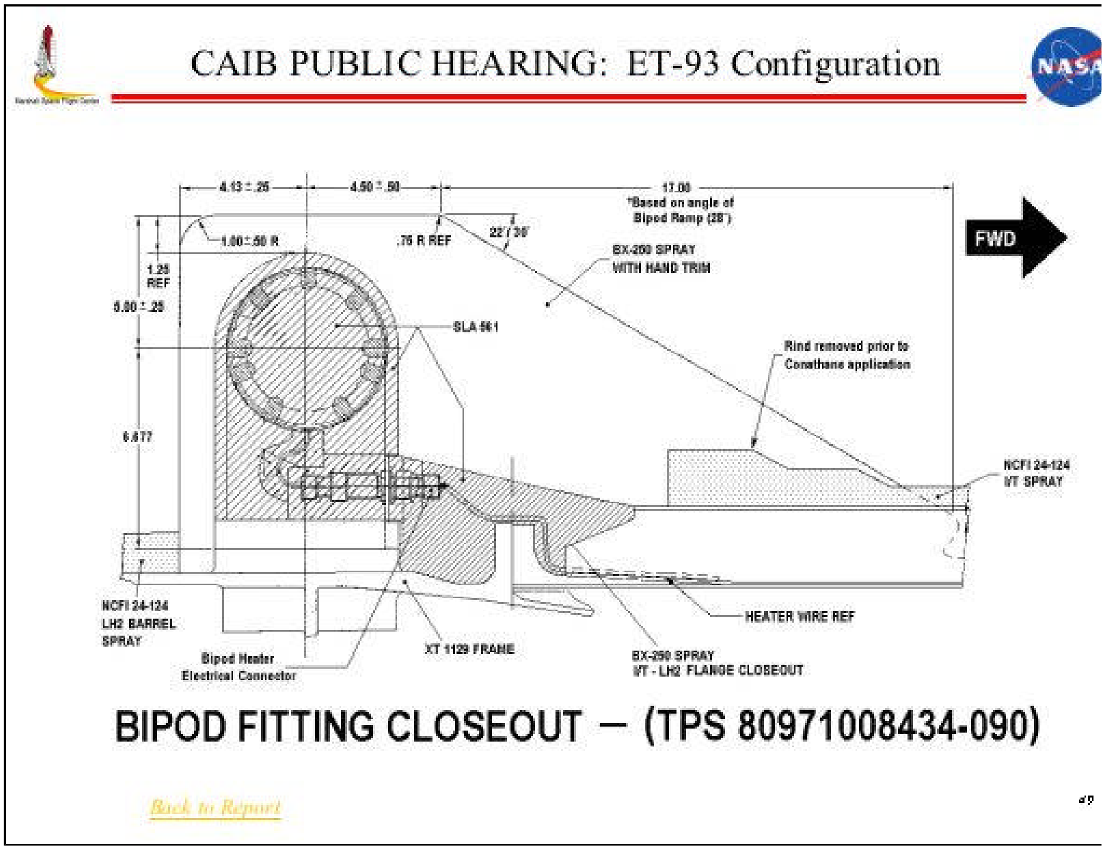
PDL 1034 - MAF is still using up reserve of PDL 4034 but will convert in September. KSC has been using PDL 1034. Vendor change is being investigated. (First flight effectivity was on ET79 which flew on 6/20/96)

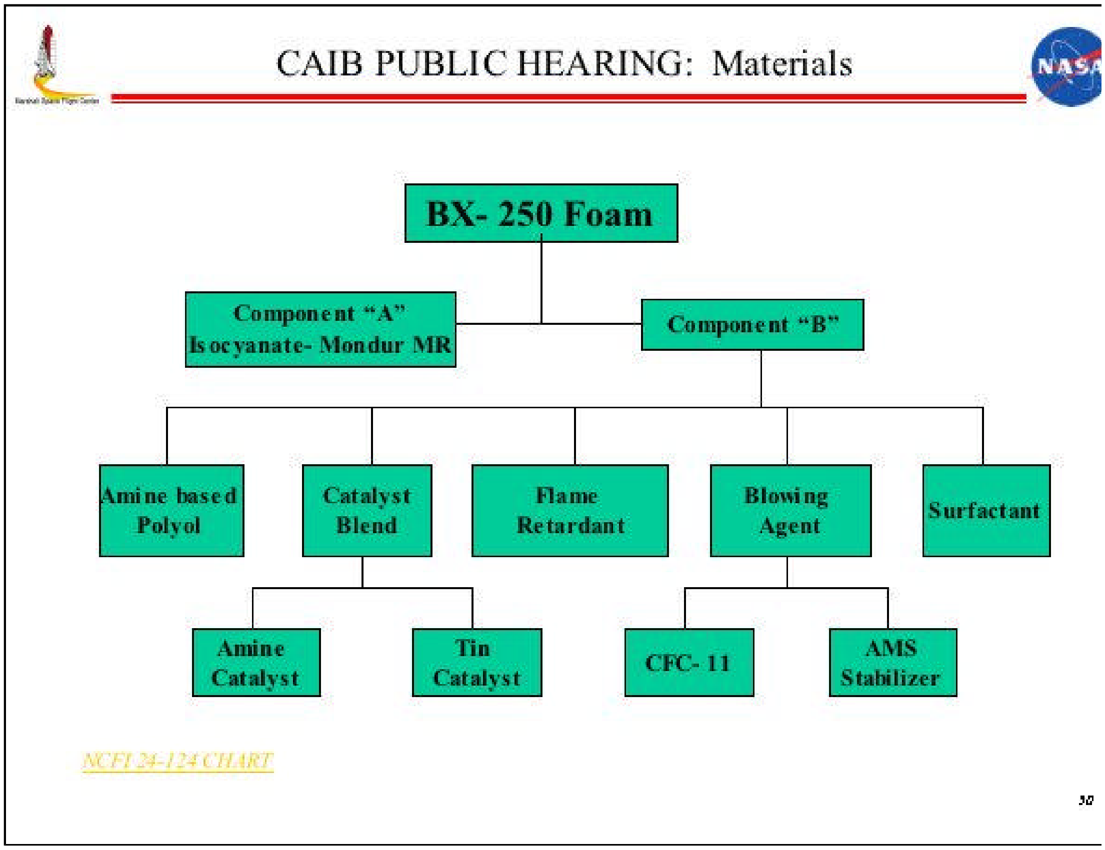
SS-1171 - Have sprayed four (4) validation domes (ET 85 and 87) along with LOX tank manhole cover (ET 86). Ready to fly on ET82 3rd Hardpoint closeout.

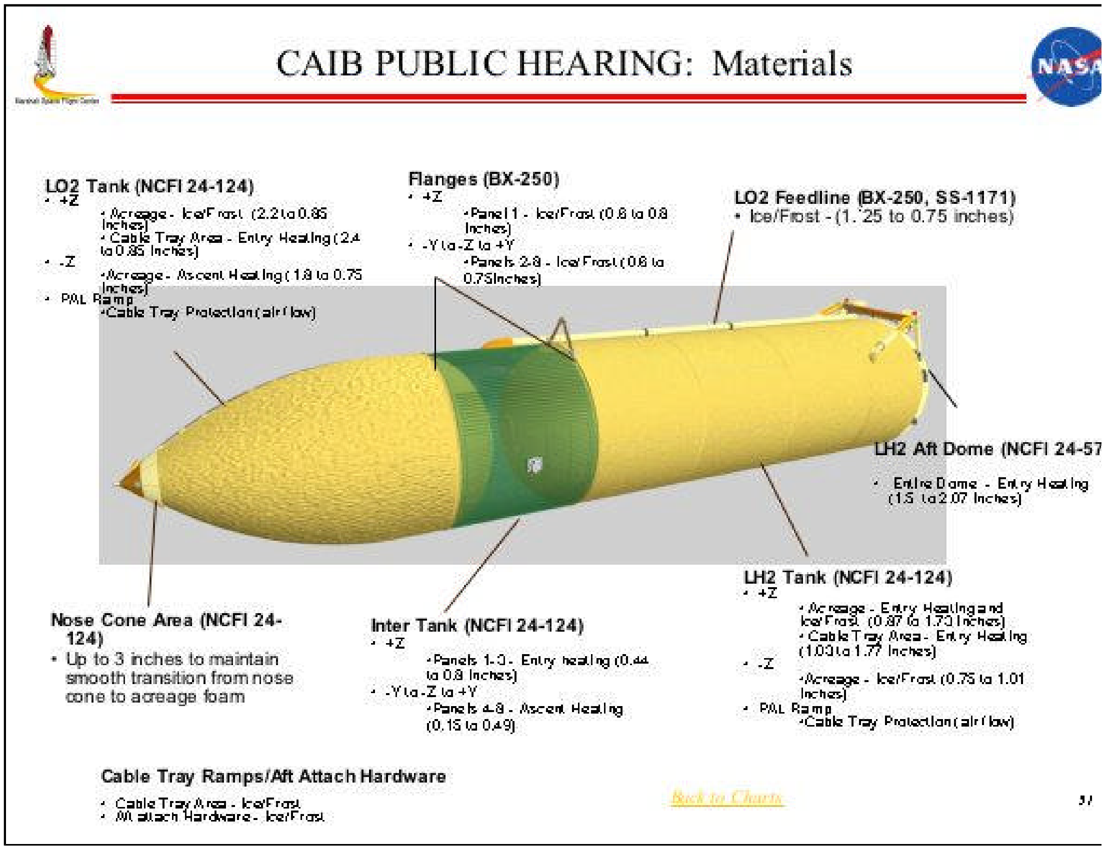
Return to Chart

Chart presented on

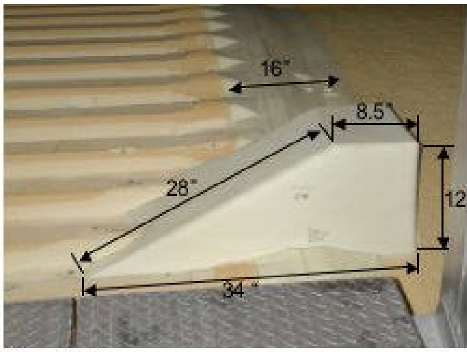
48


CAIB PUBLIC HEARING: ET-93 Configuration
4.13 ± .25
4.50 ± .50
17.00
*Based on angle of
Bipod Ramp (28°)
1.00 ± .50 R
.75 R REF
22°/ 30'
FWD
BX-250 SPRAY
WITH HAND TRIM
1.25
REF
5.00 ± .25
SLA 561
Rind removed prior to
Conathane application
6.677
NCFI 24-124
I/T SPRAY
NCFI 24-124
LH2 BARREL
SPRAY
HEATER WIRE REF
Bipod Heater
Electrical Connector
XT 1129 FRAME
BX-250 SPRAY
I/T - LH2 FLANGE CLOSEOUT
BIPOD FITTING CLOSEOUT — (TPS 80971008434-090)
Back to Report
49


CAIB PUBLIC HEARING: Materials
BX- 250 Foam
Component "A"
Isocyanate- Mondur MR
Component "B"
Amine based Polyol
Catalyst Blend
Flame Retardant
Blowing Agent
Surfactant
Amine Catalyst
Tin Catalyst
CFC- 11
AMS Stabilizer
NCFI 24-124 CHART
50


CAIB PUBLIC HEARING: Materials
LO2 Tank (NCFI 24-124)
• +Z
• Acreage - Ice/Frost (2.2 to 0.85 Inches)
• Cable Tray Area - Entry Heating (2.4 to 0.85 Inches)
• -Z
• Acreage - Ascent Heating (1.8 to 0.75 Inches)
• PAL Ramp
• Cable Tray Protection (air flow)
Flanges (BX-250)
• +Z
• Panel 1 - Ice/Frost (0.6 to 0.8 Inches)
• -Y to -Z to +Y
• Panels 2-8 - Ice/Frost (0.6 to 0.75 Inches)
LO2 Feedline (BX-250, SS-1171)
• Ice/Frost - (1.25 to 0.75 inches)
LH2 Aft Dome (NCFI 24-57
• Entire Dome - Entry Heating (1.5 to 2.07 Inches)
LH2 Tank (NCFI 24-124)
• +Z
• Acreage - Entry Heating and Ice/Frost (0.87 to 1.73 Inches)
• Cable Tray Area - Entry Heating (1.03 to 1.77 Inches)
• -Z
• Acreage - Ice/Frost (0.75 to 1.01 Inches)
• PAL Ramp
• Cable Tray Protection (air flow)
Nose Cone Area (NCFI 24-124)
• Up to 3 inches to maintain smooth transition from nose cone to acreage foam
Inter Tank (NCFI 24-124)
• +Z
• Panels 1-3 - Entry heating (0.44 to 0.8 Inches)
• -Y to -Z to +Y
• Panels 4-8 - Ascent Heating (0.15 to 0.49)
Cable Tray Ramps/Aft Attach Hardware
• Cable Tray Area - Ice/Frost
• Aft attach Hardware - Ice/Frost
Back to Charts

CAIB PUBLIC HEARING: Bipod Area Configuration



Note: Dimensions from ET-121

Bipod Ramp

- Estimated volume -1.1 cu. Ft.
- Estimated weight - 1.98 to 2.86 Lbs (1.8 to 2.6 lbs./cu.ft)

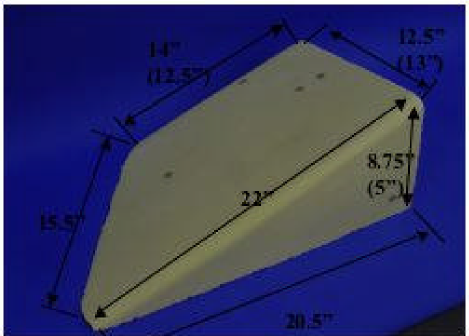
Flange Closeout

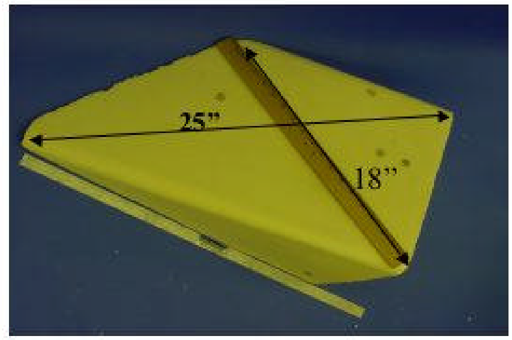
- Estimated volume/foot of length
  - Between bipod ramps (16" width) - 0.235 cu/ft per foot
  - Outboard of bipod ramps (12" width) - 0.177 cu/ft per foot
- Estimated volume
  - Between ramps - 0.42 to 0.61 lbs/ft (1.8 to 2.6 lbs./cu.ft)
  - Outboard of ramps - 0.32 to 0.46 lbs/ft (1.8 to 2.6 lbs./cu.ft)

Back to Chart

52

CAIB PUBLIC HEARING: ET-120 Dissected Ramp





ET-120 Ramp From Dissection

- Measured Weight - 1.02 lbs

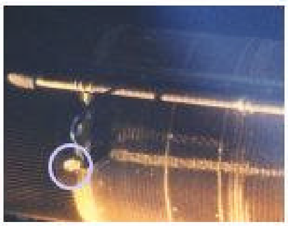
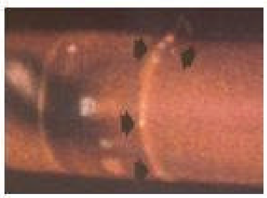
Photo Analysis Estimate of Impact Particle

- One of at least three particles seen leaving bipod area
- 24" ($\pm$3") x 15" ($\pm$3") - from camera E212
- 5" ($\pm$1") - from trajectory analysis
  - Volume estimate - 0.58 to 1.68 cu. Ft.
  - Estimated weight - 1.04 to 4.37 lbs. (1.8 to 2.6 lbs./cu.ft)

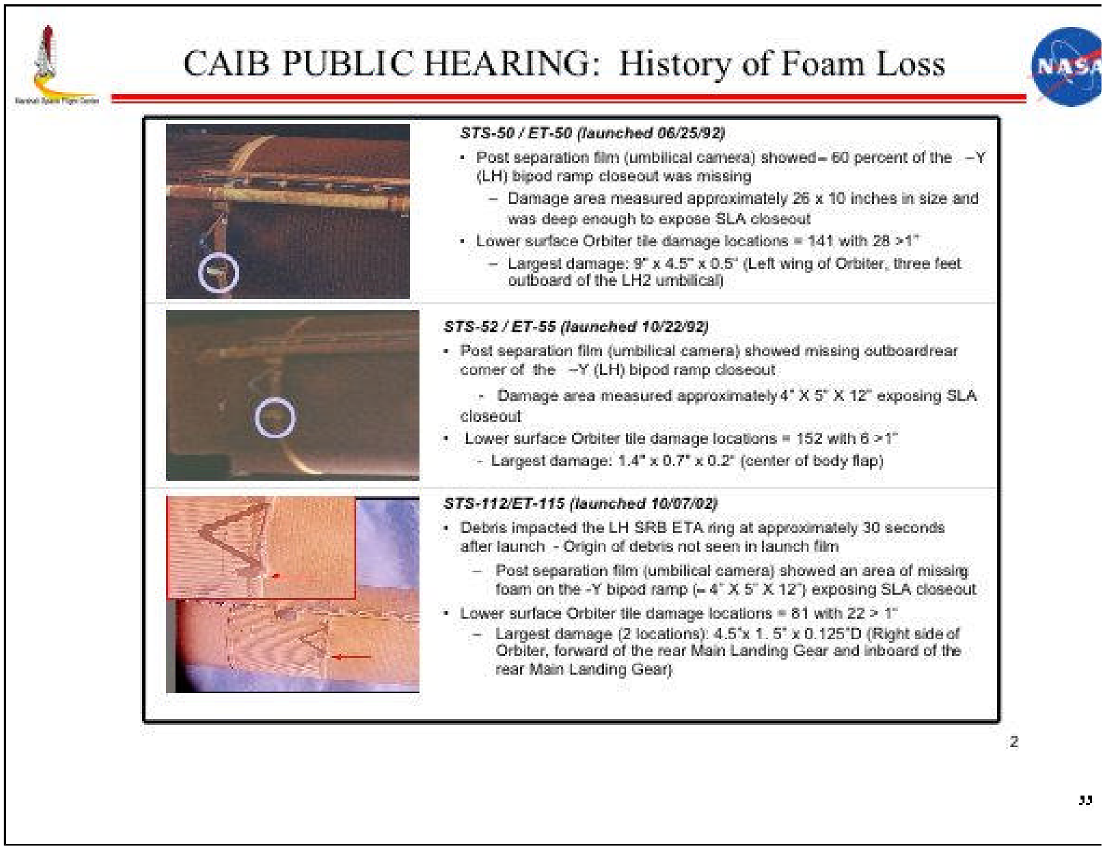
Back to Chart

53

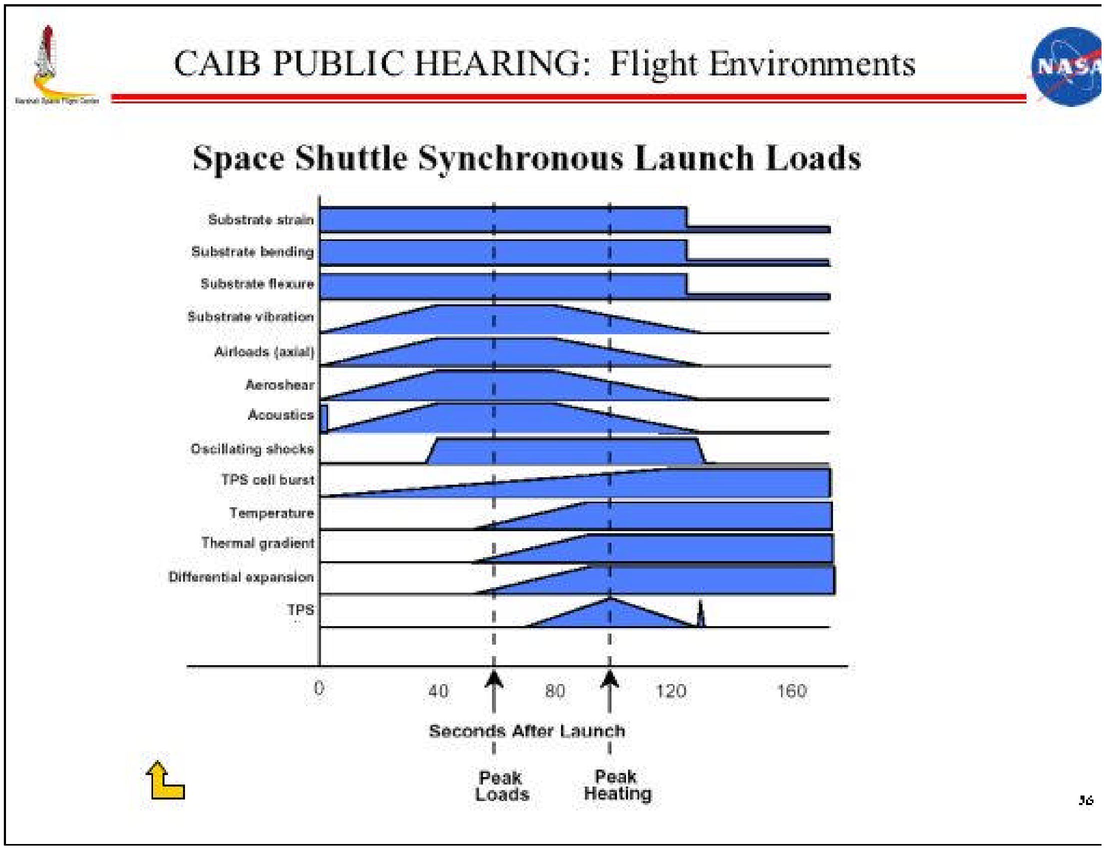
CAIB PUBLIC HEARING: History of Foam Loss

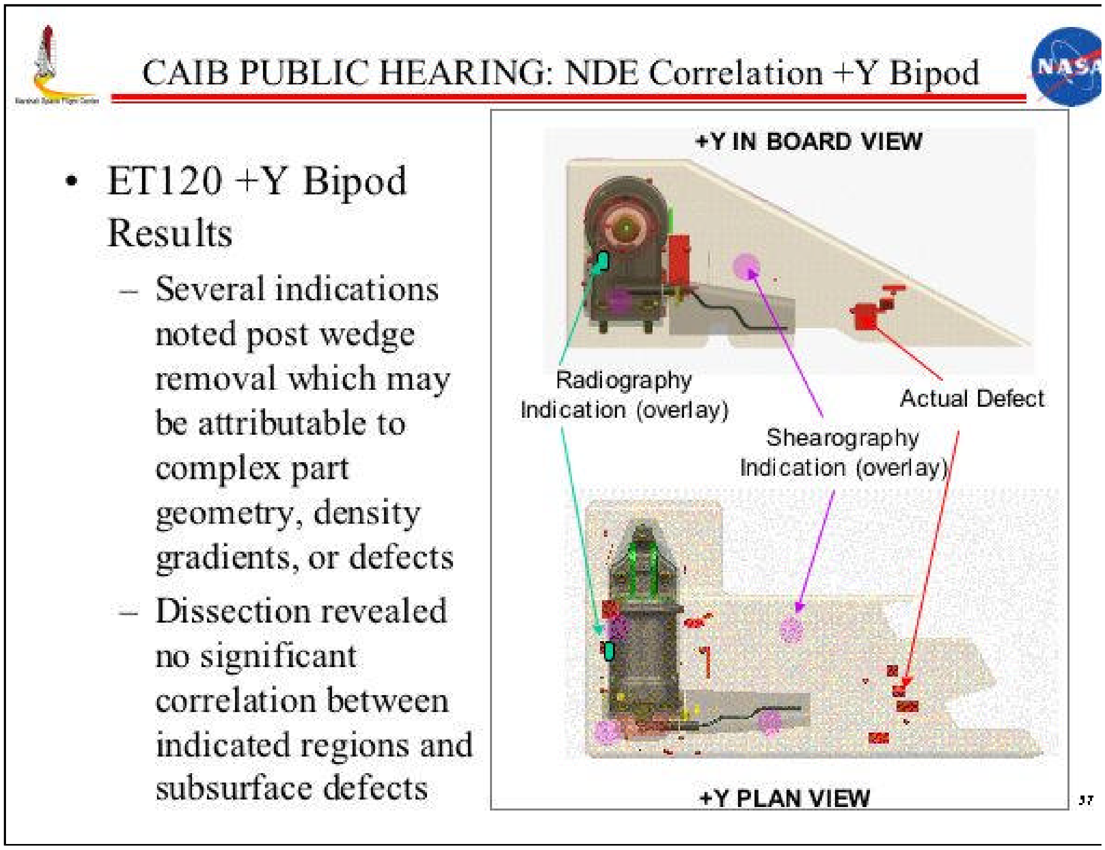
	***STS-7/ET-6 (launched 06/18/83)*** • Post separation film showed a large portion of the –Y (LH) bipod ramp missing • Lower surface Orbiter tile damage locations = 151 with 40 >1"
	***STS-32/ET-32 (launched 01/09/90)*** • Post separation film showed two divots measuring 12 to 14 inches between bipod and just above the flange and a third divot 14" in diameter centered between between ramps and extending into the flange area measuring 28" wide. The third divot surrounded the forward part of the –Y (LH) bipod ramp • Lower surface Orbiter tile damage locations = 111 with 13 >1" – Largest damage: 2.0" x 3.0" x 0. 5"D (Right side of Orbiter, aft of the forward Main Landing Gear)
	***STS-35/ET-35 (launched 12/02/90)*** • Ten circular TPS divots in the Intertank to Hydrogen tank flange closeout (ranging 8 to 10") • Lower surface Orbiter tile damage locations = 132 with 15 >1" – Largest damage: 5.75" x 3.75" x 0.25"D (Right side of Orbiter, aft of forward Main Landing Gear)

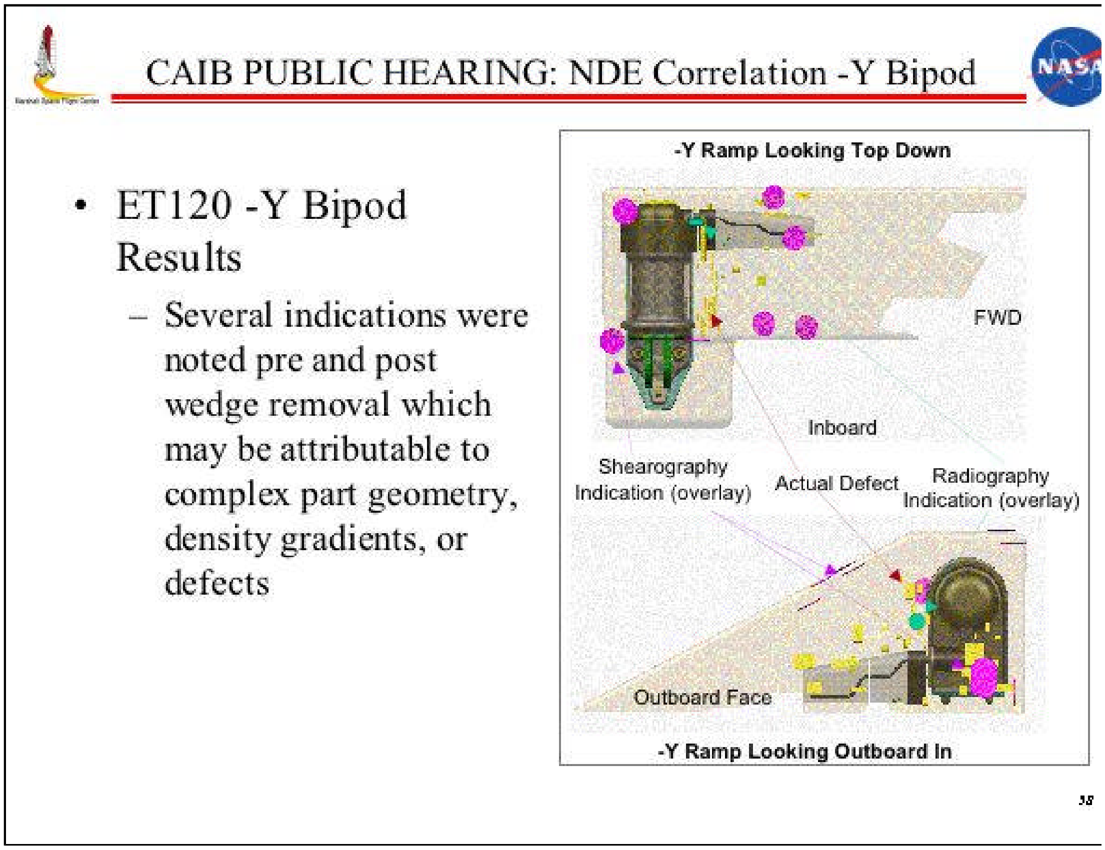
54


CAIB PUBLIC HEARING: History of Foam Loss
NASA
STS-50 / ET-50 (launched 06/25/92)
• Post separation film (umbilical camera) showed ~ 60 percent of the –Y (LH) bipod ramp closeout was missing
– Damage area measured approximately 26 x 10 inches in size and was deep enough to expose SLA closeout
• Lower surface Orbiter tile damage locations = 141 with 28 >1"
– Largest damage: 9" x 4.5" x 0.5" (Left wing of Orbiter, three feet outboard of the LH2 umbilical)
STS-52 / ET-55 (launched 10/22/92)
• Post separation film (umbilical camera) showed missing outboardrear corner of the –Y (LH) bipod ramp closeout
- Damage area measured approximately 4" X 5" X 12" exposing SLA closeout
• Lower surface Orbiter tile damage locations = 152 with 6 >1"
- Largest damage: 1.4" x 0.7" x 0.2" (center of body flap)
STS-112/ET-115 (launched 10/07/02)
• Debris impacted the LH SRB ETA ring at approximately 30 seconds after launch - Origin of debris not seen in launch film
– Post separation film (umbilical camera) showed an area of missing foam on the -Y bipod ramp (~ 4" X 5" X 12") exposing SLA closeout
• Lower surface Orbiter tile damage locations = 81 with 22 > 1"
– Largest damage (2 locations): 4.5"x 1. 5" x 0.125"D (Right side of Orbiter, forward of the rear Main Landing Gear and inboard of the rear Main Landing Gear)
2

"


CAIB PUBLIC HEARING: Flight Environments
Space Shuttle Synchronous Launch Loads
Substrate strain
Substrate bending
Substrate flexure
Substrate vibration
Airloads (axial)
Aeroshear
Acoustics
Oscillating shocks
TPS cell burst
Temperature
Thermal gradient
Differential expansion
TPS
0
40
80
120
160
Seconds After Launch
Peak Loads
Peak Heating
56


CAIB PUBLIC HEARING: NDE Correlation +Y Bipod
NASA
• ET120 +Y Bipod Results
– Several indications noted post wedge removal which may be attributable to complex part geometry, density gradients, or defects
– Dissection revealed no significant correlation between indicated regions and subsurface defects
+Y IN BOARD VIEW
Radiography Indication (overlay)
Actual Defect
Shearography Indication (overlay)
+Y PLAN VIEW
37



April 7, 2003 Presentations

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