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SRMU/SRM STORAGE
(NUSTO-92-002B-R1-C1)

Corrosion Prevention & Control On SRMU D6AC Steel

Final Team Report

February, 1994

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FOREWORD

This is the final NUSTO-92-002B-R1-C1 report documenting Martin Marietta's findings on minimizing the impact of corrosion for the SRMUs while in long term storage. Lessons learned have been reviewed/evaluated for use in improving SRM operations. As SRM corrosion concerns were identified, they were worked, also.

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Number	Title
I	MMTI Test Report Coating Evaluation for Titan SRMU (9 pages)
II	Hercules Report Investigation on the Effects of Cortec VCI-368 on Selected Titan Rocket Motor Components (30 pages)
III	Cortec VCI-368 Product Data Sheet (4 pages)
IV	Braycote 194 Product Data Sheet (2 pages)

1.0 SUMMARY

1.1 GENERAL

The current corrosion preventative product used by Hercules, Inc. (HI) on the D6AC steel of the Solid Rocket Motor Upgrade (SRMU) segments is Braycote 194. In the interest of product improvement and to minimize Life Cycle Cost (LCC) due to corrosion while the SRMU segments are in long term storage, this study was directed to research and evaluate alternative coatings and methods to mitigate corrosion.

Of the corrosion preventative coatings tested at Martin Marietta Technologies, Inc. (MMTI) Denver Laboratories, one product has the potential to protect better/longer than Braycote 194: It is Cortec's VCI-368 (See Attachment I for detail laboratory data). Testing by Hercules (Attachment II) demonstrated that there are no compatibility or contamination concerns between the VCI-368 and the SRMU materials. Also, their testing and Denver's demonstrated that VCI-368 is as good, or better than Braycote 194 in protecting D6AC, and the manufacturer states VCI-368 is effective for a minimum of 24 months (Braycote 194 is good for 12 months). However, when this data was presented at the January 1994 Corrosion TIM most participants still had concerns with extending the annual maintenance period to greater than 12 months. Concerns focused on correct application and handling hardware scraping off the Braycote 194 (see Section 3.4 for details). Without the added benefits of less handling and less Braycote removal cycles, there is no strong advantage to switching protective coatings.

In the Fall of 1993, Denver Laboratories purged pre-rusted D6AC discs in dry gaseous nitrogen (GN2) for 56 days and no new corrosion or changes to the pre-rusted spots occurred. This test demonstrated that GN2 has the potential to inhibit corrosion for the 10 year service life of the SRMU segments. A GN2 Purge concept was briefed at the January 1994 Corrosion Technical Interchange Meeting (TIM) for the Air Force (AF) to consider as a follow-on work effort to this NUSTO (Non-UPI Support Task Order). See Section 3.8 for details.

1.2 SIGNIFICANT ACCOMPLISHMENTS (See Section 6.0 for a complete chronology)

Completed comparative testing between Braycote 194, Cortec VCI-368, Conoco HD-2, Mil-C-85054 and Dow Corning-33.

HI completed compatibility/contamination testing of VCI-368 on SRMU materials.

GN2 purge concept (AI #46) defined and presented to AF as a means to eliminate annual maintenance and any corrosion for the 10 year service life of the SRMU segments while in storage.

Worked with HI to identify Braycote Removal, Inspection and Reapplication (RIR) scenario at Vandenberg AFB (VAFB) and identify all necessary equipment and procedures, including dimensioning/tolerance checks.

Identified/proposed new and/or modified concepts/scenarios that have a potential to reduce Life Cycle Cost (LCC) and/or program risk (i.e., GN2 purge, sampling, witness panels, and coupon travelers).

Part of the HI/VAFB/MMTI team that identified key deficiencies in the SRMU annual maintenance/cleaning scenario at Solid Motor Processing Facility (SMPF) during VAFB visit, 21 December 1993.

The Space Launch Systems PMPCB (Parts, Material, and Processes Control Board) was made aware of the SRMU corrosion issues and concerns. HI to be made a member of the PMPCB per MMTI's Standard Procedure EN 04.10.

1.3 RECOMMENDATIONS TO IMPROVE CORROSION PROTECTION

Two recommendations were presented to the January 1994 Corrosion TIM. First, to switch the temporary protective product from Braycote 194, which protects the D6AC steel from corrosion for 12 months, to VCI-368 because of its capability to protect for 24 months. However, the Corrosion TIM participants still had concerns with any coating being applied correctly and the handling hardware scraping off the protective coating. Without the advantage of extending the annual maintenance cycle, there is no strong advantage to changing the temporary corrosion protective product. The second recommendation is to protect the D6AC steel from corrosion for the 10 year service life by purging it with dry GN2, similar to the concept presented in Section 3.8 of this report. Implementation of this concept is presently being reviewed by the Air Force and MMTI.

1.4 FUTURE ACTIVITIES (see Section 5.0 for an expanded list)

HI/MMTI developing GN2 purge AGE (potentially new NUSTO effort).

Maintenance Engineering Analysis (MEA) updates for VAFB, CCAFS and long term storage facilities.

Input Corrosion/Humidity requirements into facility design (e.g. GN2 purge can eliminate need for air conditioning (to reduce corrosion) and high bay area of Transfer, Inspection & Maintenance Facility (TIMF) (no requirement to verticalize segments to perform annual maintenance while under GN2 purge).

Attend National Association of Corrosion Engineers (NACE) convention, 27 February 1994 to 04 March 1994 (canvas industry on new protective/preventative products). MMTI/Baltimore will send representative.

Humidity TIM to review/resolve open humidity/corrosion concerns.

Review VAFB cleaning scenario (proposal due from HI on or about 31 March 1994).

2.0 INTRODUCTION/OVERVIEW

2.1 PURPOSE

The team was chartered (MOU 92-074/CL 6817 and NUSTO 92-002) to investigate and evaluate the current methods of corrosion protection and prevention used on the SRMU, look at new products and evaluate a preferred method for use on SRMUs while in long term storage (both VAFB and permanent). Any lessons learned would be passed on to Chemical Systems Division (CSD) for consideration to be used on the Solid Rocket Motors (SRMs).

2.2 ISSUE/BACKGROUND

Initially, MMTI was requested to investigate different ways/methods of accomplishing preventative maintenance on the SRMU segments as corrosion removal from the D6AC is the major driver for the annual maintenance cycle. Because the annual maintenance requires the SRMU segments to be moved to a maintenance facility, any relief from the annual movement would have a positive impact on Life Cycle Cost (LCC), program risk, safety and reliability.

Hercules has demonstrated methods to minimize corrosion for short term storage, shipping and launch site processing. When the team investigated other solid rocket manufacturer's materials and practices, we found that materials and practices varied widely. Also, no solid rocket manufacturer or military department has done testing of temporary products on bare D6AC for long term storage/service life. Therefore, one of our first tasks was the comparative testing/evaluation of currently used/available corrosion protective coatings to recommend the best option for SRMU long term storage.

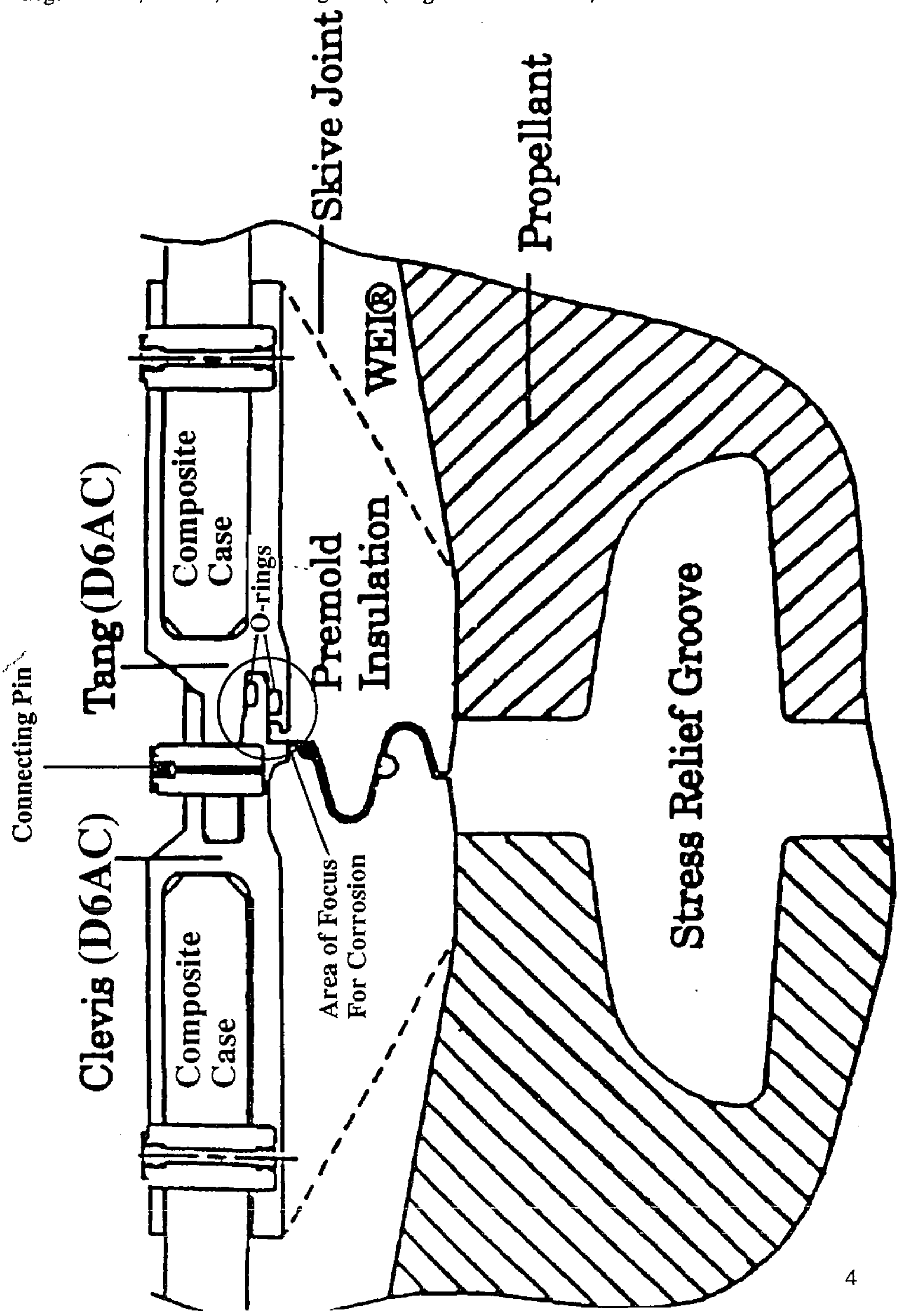
2.3 DESCRIPTION

The SRMU motor segment cases are filament wound "composite" cases with D6AC steel attachment rings at each end for mating and attaching flight hardware (Figure 2.3-1, Details SRMU Segment, shows a representative Tang and Clevis joint, for an example).

D6AC is an ultra high strength low alloy steel that corrodes readily without a protective finish or coating. Denver Laboratory testing of D6AC steel, in October 1993, showed 0.5 mils corrosion pits after 144 hours exposure in the Humidity Cabinet with >90% humidity and 120°F. Also, the SRMU D6AC rings are manufactured with tight tolerances; therefore, these rings can only tolerate minimal corrosion and associated metal removal during cleaning while in storage. See Figure 2.3-2, D6AC: Example of Build Dimensions and Tolerances (Tang), for details.

The corrosion noted is classified as galvanic action. Galvanic corrosion requires an electromotive potential (dust and/or carbon particles on the D6AC surface are most probably the electromotive potential sources), electrolyte (moisture in this situation) and oxygen (again, moisture is the agent). The initiation of this corrosion will be mitigated by diligent cleaning (which should remove pre-existing corrosion and loose dust/carbon) and application of a rust protective coating (which blocks out moisture when properly applied) - or removal of any one of the ingredients by other means, such as a GN2 purge.

Figure 2.3-1, Details, SRMU Segment (Tang and Clevis Joint)



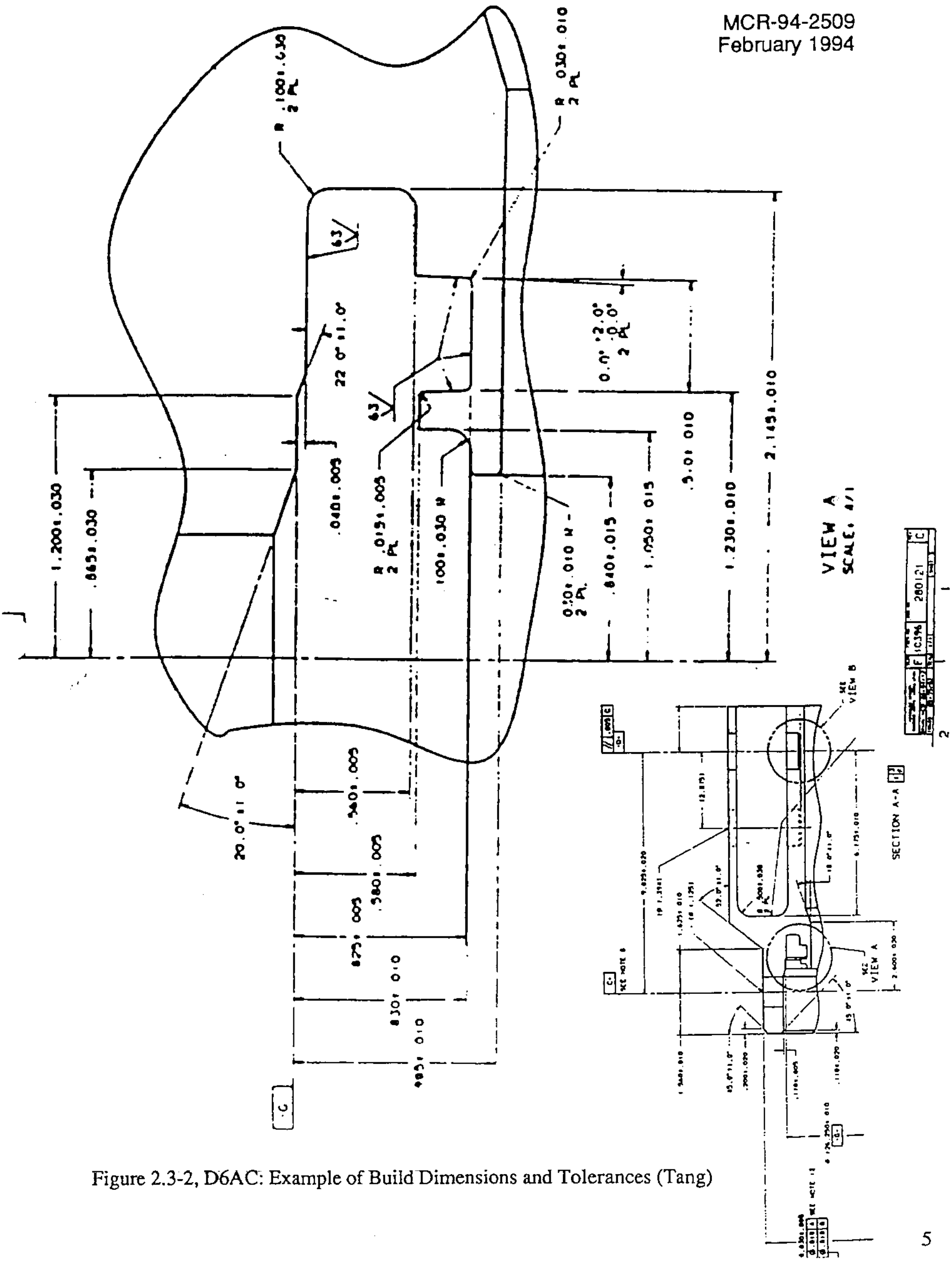


Figure 2.3-2, D6AC: Example of Build Dimensions and Tolerances (Tang)

2.4 APPROACH

Through research, vendor/industry recommendation and laboratory testing, the team identified one product (VCI-368) that has the potential to prevent corrosion better than Braycote 194, and has been demonstrated, through commercial use, to protect metal from corrosion for 2 years or more. MMTI did some preliminary testing and HI did additional testing to confirm that VCI-368 was compatible with the SRMU materials and did not contaminate the SRMU.

While HI was receiving authority to do compatibility/contamination testing/evaluation, MMTI continued to pursue additional methods of corrosion mitigation, such as GN2 (section 3.8 for details) and anodic protection. Since HI uses other methods and materials to provide up to 18 months of corrosion protection while the SRMU is setting unprotected on the launch pad, the Team investigated these materials and methods to see if they could be used in storage to give the SRMU segments at least 18 months between the "Braycote RIR" cycle while in long term storage. Also, the team continued to work Maintenance Engineering Analysis (MEA) updates, participating in CCT meetings and addressing other corrosion related issues (such as Braycote RIR at VAFB).

The team researched other solid rocket motor companies, NASA, AF, Navy, Army and vendors to see what products/methods are available/being used to protect steel from corrosion. These findings were evaluated with HI's inputs to test there potential use on the SRMU (i.e., although Conoco HD-2 is used by Shuttle and CSD, it can not be used by HI because it is not compatible with some of the SRMU materials).

2.5 ACTION ITEMS

The following Action Items (AI) are assigned to the corrosion team to answer/resolve:

AI 40: ISSUE-Corrosion is decreased in a dryer climate. Need to address option of humidity control for the entire storage area with respect to corrosion. Assign by Bill Roberson of the Space and Missile systems Center (SMC), MESL office.
STATUS-Closed at 6-7 July 1993 TIM. TIM accepted 72°± 10°F and Relative Humidity (RH) of 40 ± 5%.

AI 44: ISSUE-For vertical storage of the FWD segments w/aft skirt dome down, do we need to have periodic inspection on Inconel 718 pins, handling rings and composite shell? HI to revise MEA according to result found and recommended. Assigned by Kirk Sterzik of Aerospace.
STATUS-Closed at 6-7 July 1993 TIM. Point paper of 6/18/93, approved by Bill Roberson of SMC/MESL on 6/22/93, recommended horizontal storage as the most practical and cost effective.

AI 46: ISSUE-Find out & study effect of humidity on segment handling rings for corrosion. Recommend what can be done to do corrosion inspection in storage every other year instead of annually. Study will include the LCC cost for humidity control and corrosion inspection. Consider HVAC and GN2 purge boot. Assigned by John Gaines of Aerospace.
STATUS-Closed MMTI and HI Lab testing showed VCI-368 to be as good or better than Braycote 194 and the VCI-368 is advertised to be effective for a minimum of 24 months (see Section 3.4 for details on why the annual maintenance period is not being extended). AI 40 closed the humidity/HVAC portion of the AI. Preliminary evaluation of the GN2 purge concept showed that it is the best technical solution to corrosion mitigation and the concept was

presented to the AF at the January 1994 Corrosion TIM and at Denver on 15 February 1994 (details in Section 3.8).

AI 70: ISSUE-HI to tell MMC their best educated guess, the anticipated number of days it takes the desiccants to turn pink in a 45% relative humidity. HI will look into history, data & vendor information to arrive at this date. Provide propellant RH exposure limit for stored segments. Assigned by Bill Roberson of SMC/MESL and Ed Fox of MMTI.
STATUS-Closed at 8/16/93 Telecon. Steve Adams of HI stated the desiccants will be good for approximately 4 months in 45% relative humidity environment.

AI 71: ISSUE-Inspection of composite fiber case, desiccant inspections, and other inspections as proposed in HI MEA (based on worst case scenario & permanent storage) need to be looked at for temporary storage in igloo. Assigned by Mike Slusher of SRS Technologies.
STATUS-Closed 02/25/94 Telecon with Mike Slusher. HI agreed to consider basing desiccant inspections on actual data at the test igloo in lieu of doing the inspections weekly and a 9/20/93 MOU was sent to the HI Resident Team to initiate this action (Note: this change still needs to be implemented into the VAFB MEA). However the 14 January 1994 MEA/AVE-3 (Revision 1) has added three additional weekly tasks; therefore, the weekly inspections cannot be eliminated at this time (see Section 3.6 for additional details). Mike Slusher will get his comments to Maj Case of SMC/MEF. The MEAs should be an item to be addressed at the future Humidity TIM.

AI 78: ISSUE-Test Igloo, historical temperature & humidity data. Research & investigate historical records on the test igloo's HVAC performance to ensure it will meet the SRMU requirement of <45% Relative Humidity (RH). Because the HVAC system is not currently being used. Assigned by John Gaines of Aerospace.
STATUS-Closed Testing of test igloo air handling system from 7/22/93 to Nov '93 shows the system can maintain the relative humidity at approximately 45% when the temperature is 75 to 80°F (Presently, CSD is using the test igloo for SRM storage and their records indicate the RH is staying at approximately 43 to 45% @ 77°F when the doors remain closed).

AI 84: ISSUE-Coordinating MMC/HI testing & MEA updates. Appropriate MMC Denver, MMC HI resident, HI personnel jointly review/coordinate on all Denver (MMC), Bacchus (HI) & CCAFS (HI) lab & field testing to minimize duplication, make efficient use of resources & ensure timely dissemination of testing status & results. As appropriate, coordinate all findings and jointly make recommendations that will improve SRMU storage methods and concepts (e.g. updating MEA (s), storage plans, etc.). Assigned by Ed Fox of MMTI.
STATUS-Open Through weekly telecons, Yellow Book, video-conferences, CCTs, Corrosion TIM, and Interim/Final Report all SRMU personnel have been kept informed of testing, industry search, and improvements suggested by the Team. A copy of the Interim Report was given to Jim Becker, MMTI representative for CSD corrosion issues (will provide him with a copy of this final report, also). HI's Revision 1 of MEA/AVE-3 (14 January 1994) added in three additional weekly tasks that will have an impact on storage of the SRMU segments in the test igloo (see Section 3.4 for details).

2.6 TEAM MEMBERS

Hank Juister	Lead
Maj. Doug Case	SMC/MEF
Pat Hogue	PMP, Denver
Mike Henson	VAFB
Fred Ashley	bd Systems
John Gaines	Aerospace
Marshall Hendrick	Facilities, Resident Team
Jim Becker & Byron Troutman	Hardware, Resident Team
Steve Adams & Roy Jenkins	Technical Integrators, HI
Eric Malloy	Contractor's Corrosion Team (CCT) Lead, HI
Greg Alflen	Laboratory Testing, Denver
Michelle Jackson	Laboratory Testing, HI
Dave Hollis	Logistics, MMC
Ray Dettmer	AGE Design, MMC

2.7 ACRONYMS

AQ	As quenched
AF	Air Force
CCT	Contractor's Corrosion Team
CPC	Corrosion Prevention and Control
CSD	Chemical System Division
DOD, DoD	Department of Defense
DC	Dow Corning
FA	Failure Analysis
GN2	Gaseous Nitrogen
HAR	Hardware Acceptance Review
HI	Hercules Incorporated
LCC	Life Cycle Cost
MEA	Maintenance Engineering Analysis
MCR	Martin Contracts Requirement
MMC	Martin Marietta Corporation
MMTI	Martin Marietta Technologies, Inc. (formerly MMC)
MOU	Memorandum of Understanding
MRB	Material Review Board
NACE	National Association of Corrosion Engineers
NUSTO	Non UPI Support Task Order

P/F	Pathfinder
PL	Phillips Lab at Edwards AFB
PMP	Parts, Material and Processes
PMPCB	PMP Control Board
RGTI	Rail Garrison Test Igloo
RH	Relative Humidity
RIR	Removal, Inspection and Reapplication (see 2.8 DEFINITIONS)
RP	Rust Preventative/Rust Protective
SMARF	Solid Motor Assembly and Readiness Facility
SMC	Space and Missile systems Center
SMPF	Solid Motor Processing Facility
SRM	Solid Rocket Motor
SRMU	SRM Upgrade
TIM	Technical Interchange Meeting
TIMF	Transfer, Inspection and Maintenance Facility
UPI	Unified Payload Integration
VAFB	Vandenberg Air Force Base
VCI	Volatile Corrosive Inhibitor

2.8 DEFINITIONS

Corrosion: Any change to the metal due to the environment.

Braycote RIR: The annual Braycote 194 Removal, the Inspection/removal of corrosion on the D6AC after the Braycote 194 is removed [including the dimensioning/tolerance checks to ensure the D6AC is still within build tolerances - if out of tolerance, then this includes the Material Review Board (MRB) action, also] and the Reapplication of Braycote 194 per HI processes/procedures.

2.9 APPLICABLE DOCUMENTS

The following documents were used to 1) review the contractual requirements for corrosion prevention, 2) be followed during laboratory testing, 3) review product qualification, or 4) are MMTI/HI documents that the particular company states it will adhere to.

2.9.1 GOVERNMENT

MSFC-SPEC-250A	Protective Finishes for Space Vehicle Structures and Associated Flight Equipment General Specification for. Called out in SS-ELV 401 Specification and HI's System Effectiveness Plan (SR-M01).
MIL-C-16173	Corrosion Preventive Compound, Solvent Cutback, Cold-Application. Called out in MIL-F-7179F as applicable document. VCI-368 meets Grade 1 (hard film and indoor/outdoor use) of specification and Braycote 194 meets Grade 4 (hard film and indoor use).
MIL-C 85054	Corrosion Preventive Compound, Water Displacing Clear (Amlguard). Capt Wickham of SMC/MES suggested that we evaluate this for possible SRMU use (hard film and outdoor use).
MIL-F-71179	Finishes, Coatings, and Sealants for the Protection of Aerospace Weapons Systems. Called out in MIL-STD-1568. Requires contractors to provide a "Contractor's finish specification".

MIL STD 1568	Materials and Processes for Corrosion Prevention and Control (CPC) in Aerospace Weapons Systems. Called out in HI's CPC and System Effectiveness Plan. Requires CPC plan, Corrosion Prevention Advisory Board (CPAB), and Contractor's Corrosion Team (CCT).

2.9.2 MMTI

CP-T01DSRM	Prime Item Development Spec. for Upgraded Solid Rocket Motor for the Titan IV Launch Vehicle, CI Number T01DSRM. Calls out MSFC-SPEC-250 and MIL-STD-1568, and MMTI review and approval of corrosion prevention and control measures.
SS-ELV-401	System Specification for Titan IV System. Calls out MSFC-SPEC-250A.
EN 04.10	Standard Procedure: Parts, Materials, and Processes Control Board (PMPCB). Part of the PMPCB functions are to "Approve and coordinate...selection for all new design flight hardware..." and "Review metallic and non-metallic parts for...corrosion..."

2.9.3 HERCULES

BU90U-2000-0715	TIV SRMU Corrosion Prevention and Control Finish Specification. Identifies the SRMU finish requirements per MIL-STD-1568 and MSFC-SPEC-250. Should detail how the D6AC is cleaned, how the Braycote 194 is applied (e.g., thickness, drying time between coats).
BU91U-2000-0625	10 Year Service Life Evaluation Report, Case Metal Structures and Core Attach Assembly Hardware, 2 December 1991.
CP-1 thru 4	Coatings Developments Test Report. Identifies Braycote 194 as the temporary rust preventative HI will use on the SRMUs, 24 August 1990.
CPC	Corrosion Prevention and Control Plan. Calls out 1) SRMU...to... perform...with a minimum of maintenance over its specified lifetime, 2) ensure compliance with MIL-STD-1568 and MSFC-SPEC-250 and 3) personnel who work in corrosion prevention shall be trained and certified....
SR-S08	SRMU Storage Plan. Calls out the daily, weekly, quarterly and annual MEA tasks required on the SRMU. Addresses the permissible environments (temperature and humidity). Also, requires MRB for nonconformances that exceed S283047 (see S283047 below).
SR-M01	System Effectiveness Program Plan. Appendix F is the CPC (see CPC above).
S283032C	Critical Item Development Specification for Rocket Motor Segments. Covers performance, design, development, and test requirements for the SRMU.
S283047	Workmanship, Standard Acceptance Criteria For. Covers workmanship standards to be used as acceptance criteria for the SRMU.

3.0 SRMU ACTIVITIES

3.1 DENVER LABORATORY TESTING (July 1993 - February 1994)

VCI-368, Braycote 194 and Conoco HD-2 performed equally well in the first phase of Denver tests in the Fall of 1993. However, the Conoco HD-2 can not be used by HI as it is incompatible with the SRMU materials. VCI-368 has a potential to be the better product for SRMU storage because it provides corrosion protection for two years or more (Braycote 194 has a 1 year advertised life) and VCI-368 has self-healing capability (see Attachment III for details). VCI-368 compatibility with the SRMU materials was tested by HI in November/December 1993 and there are no HI concerns (see Section 3.2 for details).

After receiving HI's test results in December 1993, which showed both the Braycote 194 and VCI-368 protecting better than the initial Denver laboratory tests, Denver ran additional tests in January - February 1994 using HI's preparation methods. Basically, HI ensured a more consistent surface between the coupons and the corrosion preventative material by grit blasting each coupon. Although this gives more consistency between coupons, it is not representative of the actual "smoother" surface on the flight hardware. Also, HI was putting on a thicker coat (about 4 mils). Using HI's preparation methods and thicker coating, Denver Laboratory's second testing compared well with HI's results after 4 weeks of Salt Fog Testing (See Attachments I & II for details). HI ran their testing for 4 weeks, where as Denver continued it's testing for 6 weeks to see if either coating would start showing signs of corrosion. After 6 weeks, the VCI-368 and Braycote 194 were still performing equally and the testing was terminated (there is some concern in the technical community that the salt fog test is not representative of real performance of the products - it is just a good one time test for comparing products).

MMTI's testing of dry GN2 in Fall 1993 showed that it is the best method, of those evaluated during this study, for preventing corrosion (it removes two of the three necessary ingredients needed for corrosion; namely, moisture and oxygen). Some areas of the bare D6AC steel discs were pre-rusted to see if these rust spots would grow while being purged with GN2. After 56 days purged with GN2, the D6AC discs, including the pre-rust spots, showed no changes.

Anodic protection does not appear to be a viable option for protecting D6AC; however, further testing would be required on an assembled segment piece to accurately test/evaluate all electrical paths (i.e., if the D6AC is not adequately isolated from the rest of the segment, anodic protection would not be effective).

MMTI completed additional testing on two newly identified RP products: MIL-C-85054 and DC-33. Capt. Wickham of SMC/MES has used MIL-C-85054 and recommended we evaluate it, and HI uses DC-33 (silicone grease) in lieu of Braycote during stacking at the launch pads. Test results show neither of these products performed as well as the Braycote 194 or VCI-368 on D6AC steel.

3.2 HERCULES LABORATORY TESTING (October - December 1993)

The 4 week salt fog testing showed that VCI-368 and Braycote 194 are equal in their ability to protect the D6AC from corrosion (Attachment II for details). HI compatibility tests showed the VCI-368 is identical to Braycote 194 and is a viable candidate for protecting the SRMU D6AC steel from corrosion.

6) Aft Segment Tang Cleaning, Inspection & Rework, and Concerns - Bob Boone of HI briefed status of the options that HI is reviewing. He stated that HI may not have a proposal to MMTI until 11 May 1994 (Note: February 1994 Yellow Book status telecons changed this to on or about 31 March 1994)

7) General - I mentioned to Eric Malloy of HI that I put in a redline to the CPC Plan that identifies HI as a representative to the Titan IV PMPCB (this replaces the Corrosion Prevention Advisor Board [CPAB] that is called out in MIL-STD 1568)

3.5 HARDWARE ACCEPTANCE REVIEW (HAR) (5-7 January 1994)

The following corrosion issues/concerns were given to the MMTI/HI Resident Team prior to the first HAR (Hardware Acceptance Review) as still requiring resolution:

1) How does HI/MMTI have confidence that the Braycote 194 was adequately applied, since the Finish Specification that identifies the how, where, how thick, etc. of applying the Braycote 194 has not been approved?

2) Air leakage passed the Handling Ring/Tang or Clevis Attachment Rings has not been resolved to assure humid air is not being "flowed" pass the critical O-ring sealing surfaces of the D6AC. (Note: during the SRMU segment humidity testing in the Fall of 1993, HI used tape as a temporary fix to stop moisture from getting to the propellant through the Tang/Clevis joint. To date, a permanent resolution of the problem has not been submitted to MMTI for approval - should be an item for Humidity TIM).

3.6 VAFB STORAGE ACTIVITIES

Action Item #78, from the 7-8 July 1993 SRM/SRMU Storage TIM, requested MMTI determine the performance of the environmental system at the Rail Garrison Test Igloo (RGTI) since the system was not currently being used. Our first finding was the system does not have dehumidification capability. However, by minimizing door openings and keeping the inside temperature at approximately 75°F, the Relative Humidity (RH) can be kept at approximately 45% (this can be continually monitored by existing recorders). By keeping the RH at 45% this would have reduced the need for weekly desiccant inspections; however, the latest MEA, dated 14 January 1994 has added additional weekly tasks that now make the weekly inspections necessary (see details on page 15).

VAFB submitted a Liaison Call (Figure 3.6-1, Liaison Call #1372) to ensure all necessary equipment/procedures are identified and approved for Braycote RIR. A MMTI/HI fact finding trip to VAFB on 12/21/93 identified the following concerns:

1) Existing Tang/Clevis Cleaning Adapters can not be used with the Handling Rings (they were designed to interface with the adjoining segments attachment ring only).

2) V-31 (SMPF) 200 ton crane can not be left attached to the segment while the Tang/Clevis, in the down position, is being cleaned.

3) The 125 ton crane can not take the full weight of the AFT or Center segments, therefore, some other means of rotating the segments 180° will have to be identified.

(Note: Currently, HI is working a proposal for an "H" shaped yoke and vertical storage stand adapter so all Braycote 194 RIR can be accomplished from the top).

Figure 3.6-1, Liaison Call #1372

E01164

MARTIN MARIETTA — LIAISON CALL SHEET

Page 1 of 1

Program and Effectivity	Mfg Control Point	Book No.	Call No.
IV SRMU		271	1372
Document No(s).	**Originator**	**Date**	**Date Accepted**
MEA AVE-3	Bill Rusnic	10/11/93	
	Need Date 11/15/93 — **Dept No.** 7090	**Mail No.** SRM90	**Phone No.** 5-3817
Responsible Engineer Tom Lundberg	**Phone No.** 885-2608	☒ Engineering Liaison ☐ Mfg Liaison	☐ Quality Liaison ☐ AMT

Check Inventory Location and Indicate Total Quantity

☐ Firm Folders ☐ WIP Stock ☐ Next Assemblies (Where Used) ☐ Other Areas (Den/Offsite) ☐ Purchased Part or Material on Order

Qty ______ Qty ______ Qty ______ Qty ______ Qty ______

MEA AVE-3 requires an annual cleaning and inspection of all metal tang and clevis areas on SRMU segments. In support of this operation, SMPF personnel procured the common stand used at Phillips Lab, EAFB. Hercules personnel are expressing a concern that this stand is not adequate to perform the cleaning of the Aft Segment Forward Ring when Forward End is down on cleaning adapters.

This cleaning operation, performed at Phillips Lab, was the major cleaning effort prior to stack for all five (5) test firings.

If this cleaning cannot be accomplished in this configuration, then direction and necessary SE must be provided.

Fred L. Bolme
12 Oct 93

12 Oct 93

Answer

Root Cause Code

Denver received the 14 January 1994 Revision 1 to the MEA/AVE-3 on 14 February 1994 and we have concerns with three new weekly tasks. They are:

<u>Item 1.4</u> - Moisture barrier sealing (tape and RTV) applied around the entire circumference between the handling ring and either the tang or clevis is intact.

<u>Item 1.5</u> - Freeze plugs (three places) in tang handling ring are in place.

<u>Item 1.6</u> - Tape over field joint holes that do not contain pins appears to be in tact and forming a seal.

The impact of these tasks needs to be evaluated by VAFB and Denver. Specifically, they add manhours to the weekly inspections at the RGTI. Since the RGTI is considered a hazardous area for personnel (due to seismic concerns), it is essential that we evaluate ways to limit personnel exposure in the RGTI. Also, the Workmanship Specification needs to be updated to show the criteria by which these tasks will be judged.

Personnel at VAFB have not been trained in the Braycote RIR requirements. Although the training courses have been completed by HI, the cleaning scenario is not available (proposal not due until approximately 03/31/94). With the first Braycote RIR due approximately December 1994, VAFB needs to receive the new HI hardware to pathfind the operation and get their people trained in time.

3.7 PERMANENT STORAGE ACTIVITIES

As presented in the 7-8 July 1993 SRM/SRMU Storage TIM (Figure 3.7-1, Action Item #40 Data), the corrosion rate of steel increases greatly above 45-60% RH. Therefore, it is recommended that the RH be kept below 45% to reduce corrosion. Since high strength steels are sensitive to salt and industrial pollutants, these must be considered accordingly.

3.8 DRY GN2 PURGE CONCEPT

AI #46, from the 31 March - 1 April 1993 SRM/SRMU Storage TIM, initiated the dry GN2 purge investigation. Initially, we looked at encapsulating the entire segment and purging it with dry GN2; however, when it was learned that the propellant could not experience 0% humidity, the Team began its investigation of GN2 concepts of just the O-ring areas. The following concept evolved in the fall of 1993 with the assistance of HI:

Figure 3.8-1, SRMU Steel Surfaces Requiring Corrosion Protection, shows the areas that GN2 has a potential to mitigate corrosion (Figure 2.3-1, Details, SRMU Segment [Tang and Clevis Joint], shows a detail of the O-ring area).

Figure 3.8-2, Preliminary GN2 Purge Concept, 5 pages, details the Team's initial concept to show that it is possible to isolate GN2 to just the D6AC areas. The following requirements (preliminary) must be met by the system (these requirements must be verified by future test, demo or analysis):

1) The GN2 system shall protect the SRMU (O-ring sealing surfaces and pin holes) from corrosion for a minimum of 10 years.

2) GN2 hardware (Not GN2 supply) stays in place during T&H and segment verticalization (or easily removed/installed).

3) GN2 system must be usable in SMPF/SMARF vertical storage.

Figure 3.7-1, Action Item #40 Data (page 1 of 2)

SRM/SRMU Storage TIM

Corrosion/Humidity/Fwd Segment Vertical Study (I)

- Humidity (Action Item #40)

  Susceptibility Of D6AC To Moisture & Salt

  - Lab Testing In Process @ Denver To Characterize Susceptibility To Moisture And Salt*
  - Recommend to store in controlled environment 72° ±10° 40% RH ±5%

* NOTE: Testing Will Not Be Conclusive To Change Baseline Requirements. A Long Term Extensive Study - Similar To CSD Study - Must Be Authorized And Conducted (1 To 3 Years) Before Reasonable Data Would Be Available To Benefit SRMU. Recommend Closing Action Item #40 For This Study.

HMJ July 6, 1993/3

105

Figure 3.7-1, Action Item #40 Data (page 2 of 2)

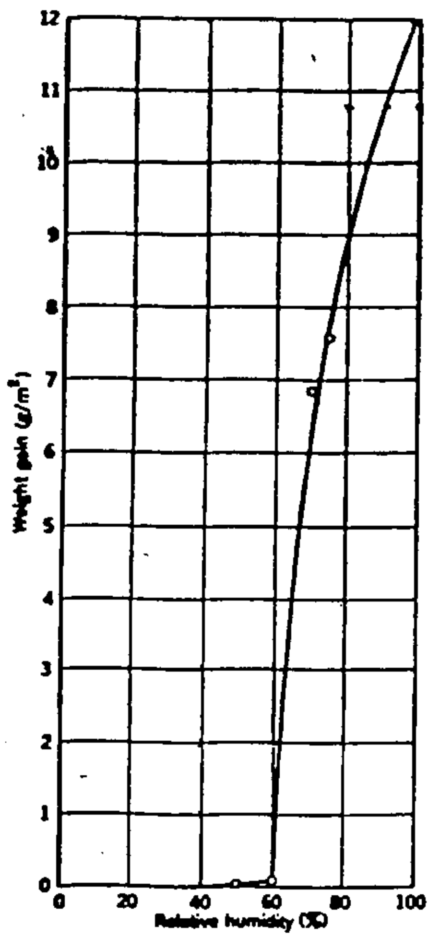


FIGURE 3. Corrosion of iron in air containing 0.01% SO_2, 55 days' exposure, showing critical humidity (Vernon[23]).

for the critical relative humidity are found to fall, in general, between 50 and 70% for steel, copper, nickel, and zinc. Typical corrosion behavior of iron as a function of relative humidity of the atmosphere is shown in Fig. 3. In a complex or severely polluted atmosphere, a critical humidity may no longer exist.[24]

An important factor determining susceptibility to atmospheric corrosion of a metal in a particular environment is the percentage of time that the critical humidity is exceeded.[25] This period of time is called the "time of wetness." It is determined by measuring the potential between a corroding

[24] D. Rice, P. Phipps, and R. Tremoureux, *J. Electrochem. Soc.*, 126, 1459 (1979); 127, 563 (1980).

[25] P. Sereda, in *Corrosion in Natural Environments*, p. 7, Spec. Tech. Publ. No. 558, American Society for Testing and Materials, Philadelphia, Pa., 1974.

Figure 3.8-1, SRMU Steel Surfaces Requiring Corrosion Protection

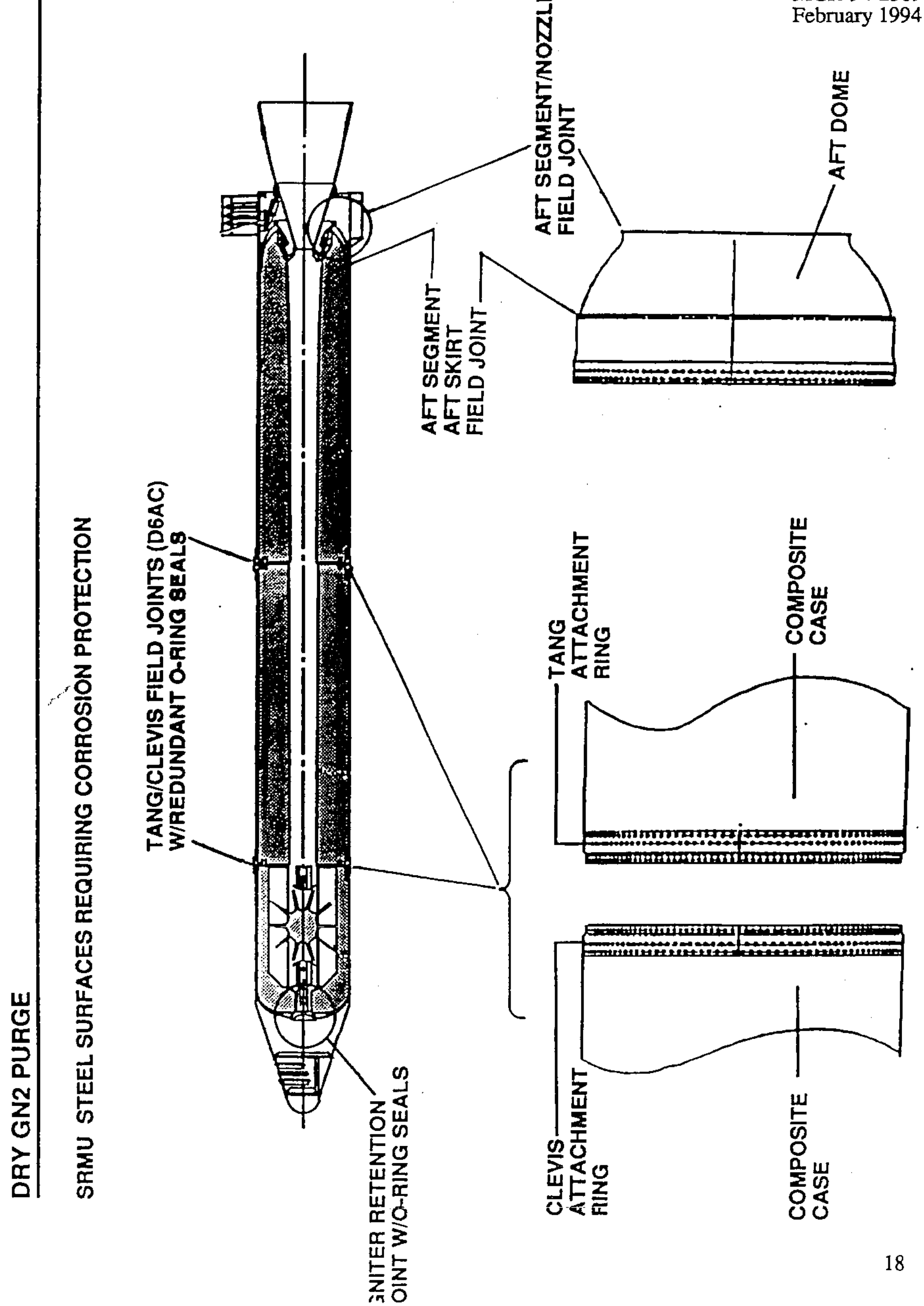
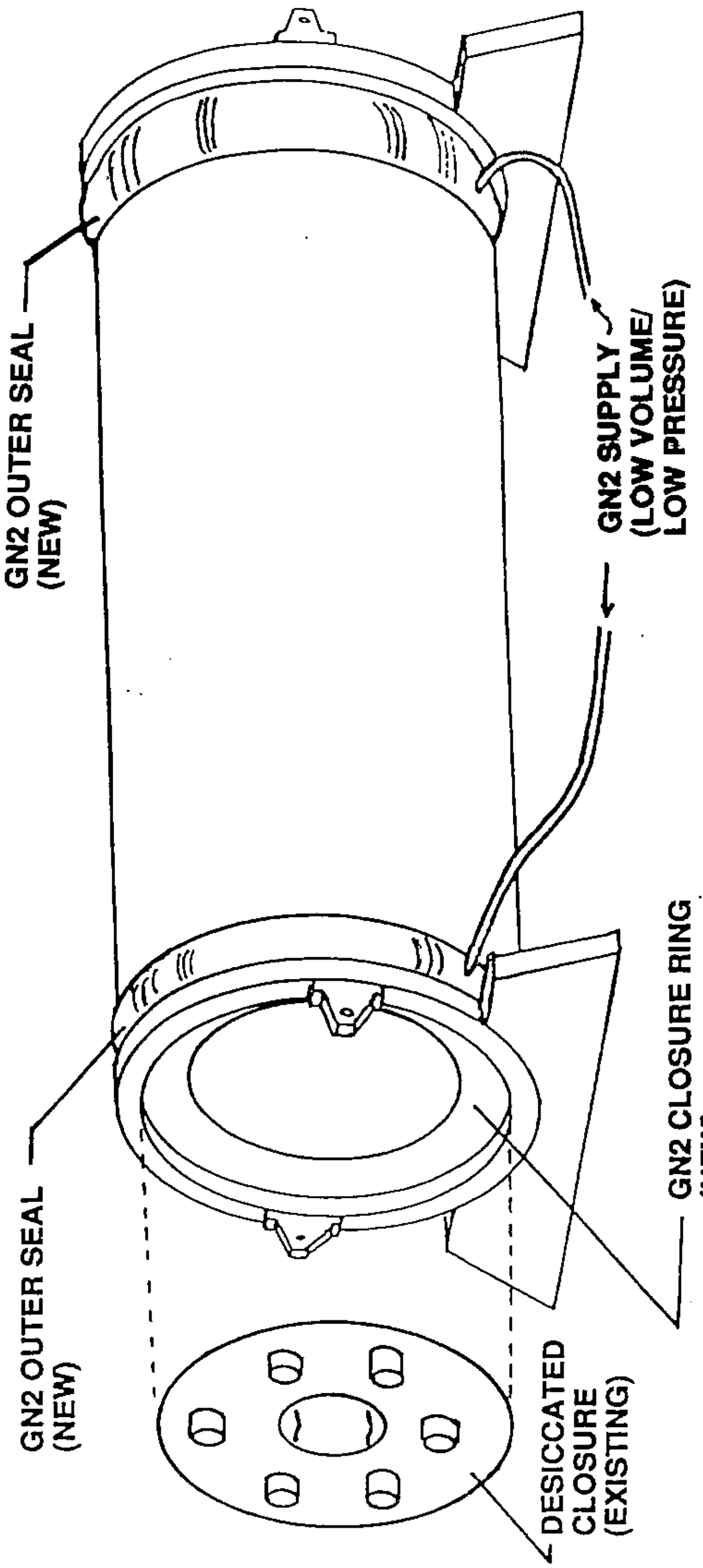
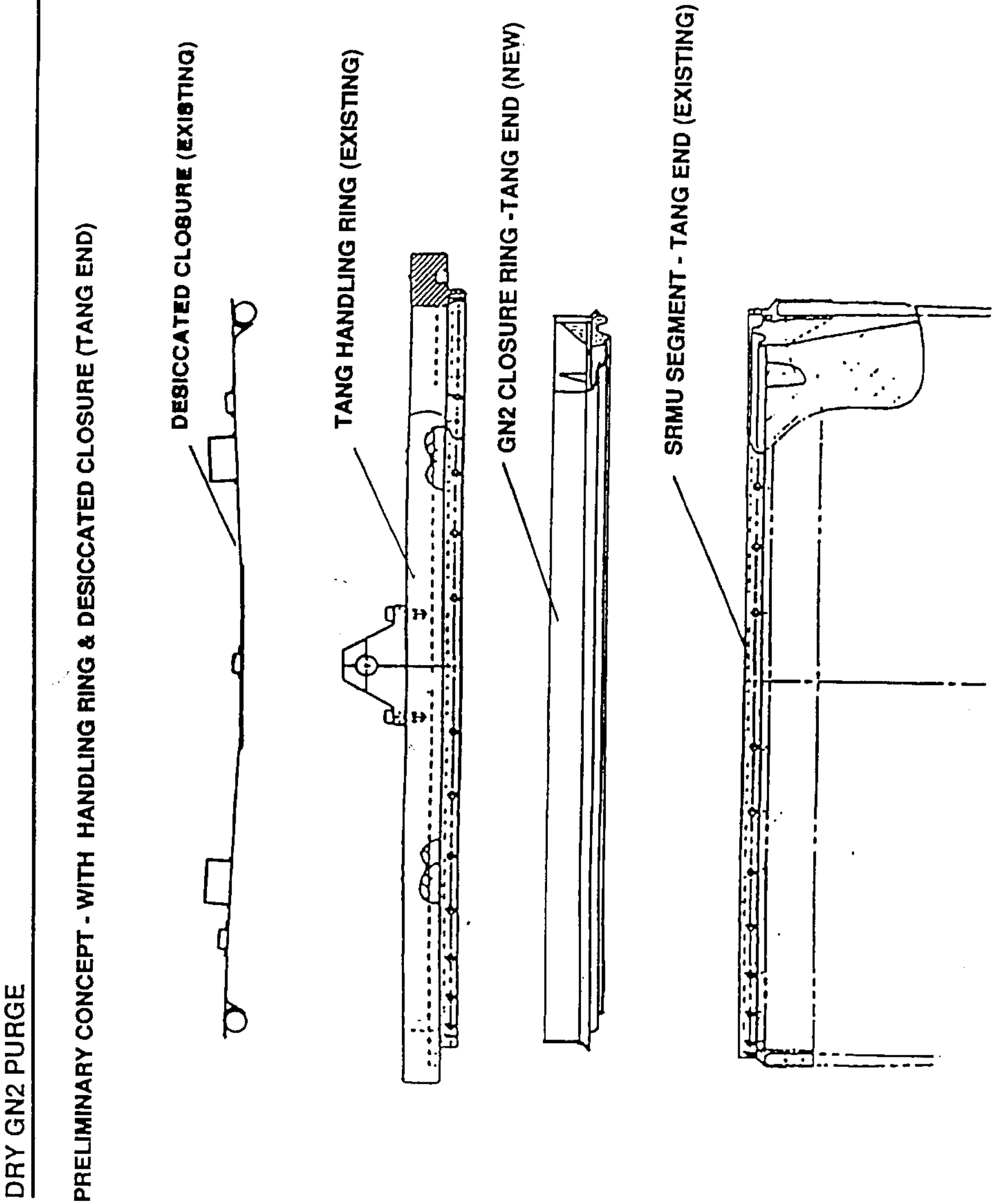


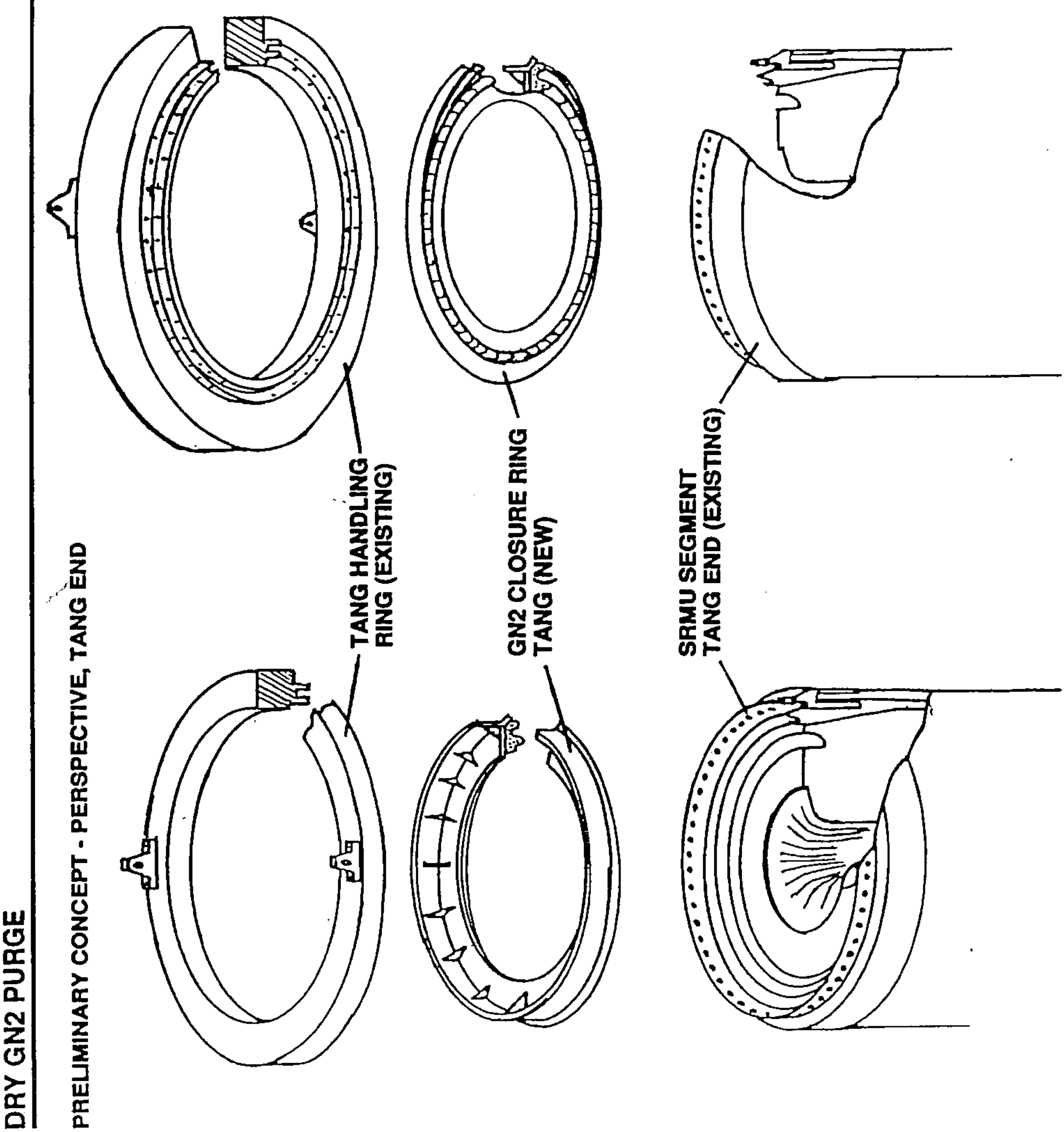
Figure 3.8-2, Preliminary Concept (page 1 of 5)

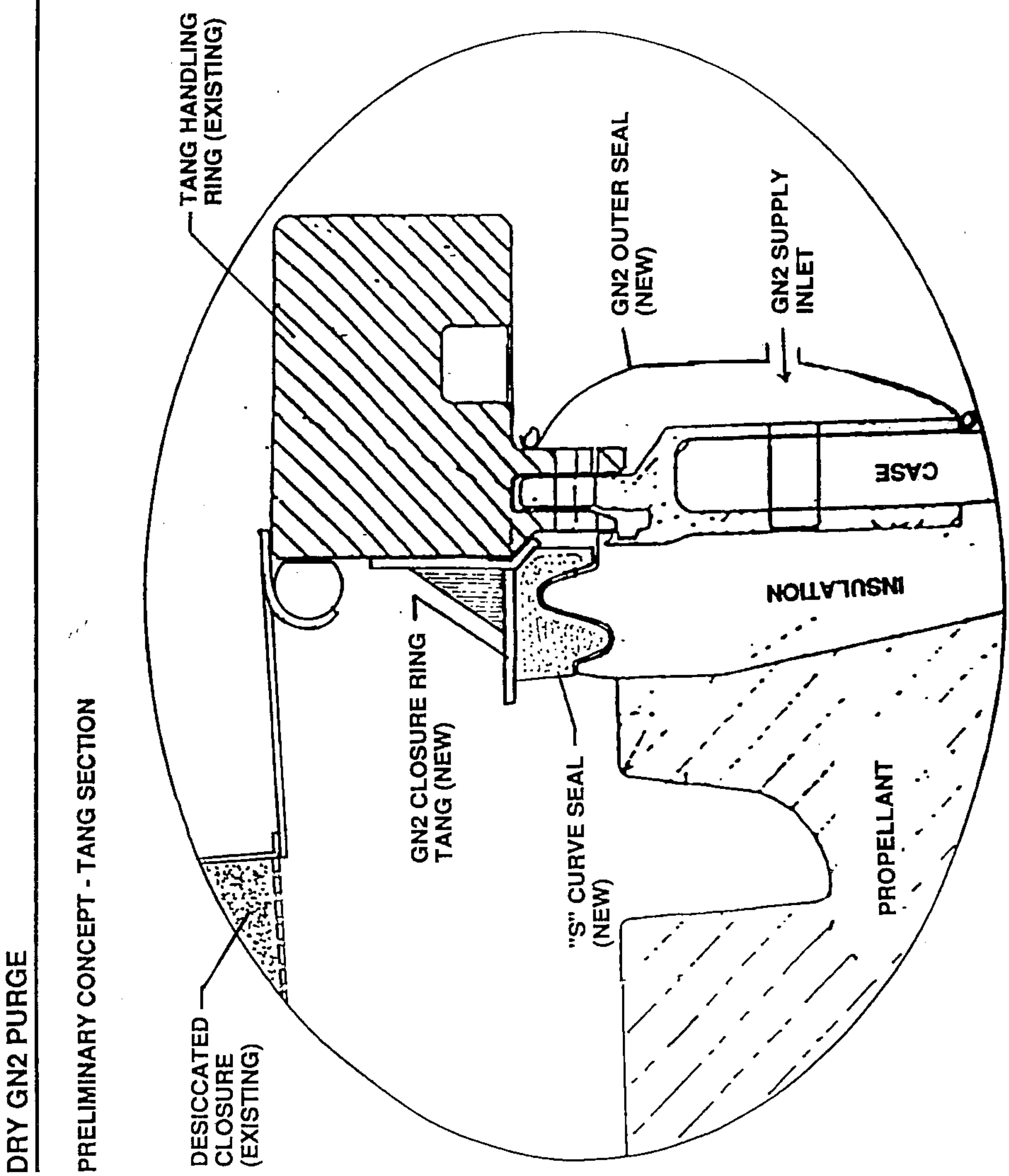
DRY GN2 PURGE

PRELIMINARY CONCEPT - OVERALL (CENTER SEGMENT)



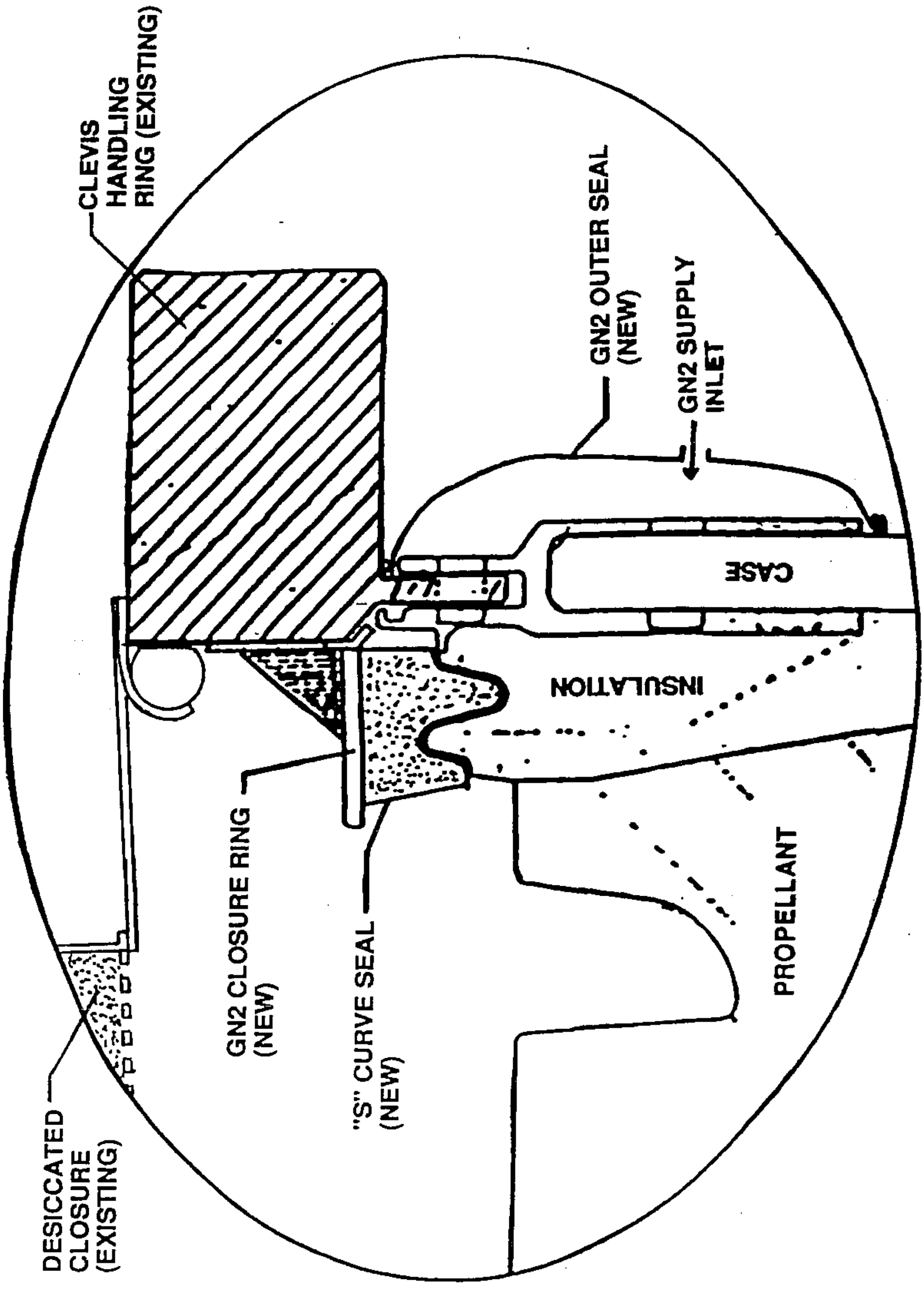

DRY GN2 PURGE
PRELIMINARY CONCEPT - WITH HANDLING RING & DESICCATED CLOSURE (TANG END)
DESICCATED CLOSURE (EXISTING)
TANG HANDLING RING (EXISTING)
GN2 CLOSURE RING -TANG END (NEW)
SRMU SEGMENT - TANG END (EXISTING)


DRY GN2 PURGE
PRELIMINARY CONCEPT - PERSPECTIVE, TANG END
TANG HANDLING RING (EXISTING)
GN2 CLOSURE RING TANG (NEW)
SRMU SEGMENT TANG END (EXISTING)


DRY GN2 PURGE
PRELIMINARY CONCEPT - TANG SECTION
DESICCATED CLOSURE (EXISTING)
TANG HANDLING RING (EXISTING)
GN2 CLOSURE RING TANG (NEW)
"S" CURVE SEAL (NEW)
GN2 OUTER SEAL (NEW)
GN2 SUPPLY INLET
CASE
INSULATION
PROPELLANT

DRY GN2 PURGE

PRELIMINARY CONCEPT - CLEVIS SECTION



4) GN2 hardware can be used with the existing Heavy Handling Rings and can be installed with the Heavy Handling Rings already installed on the segments.

5) SRMU propellant shall not be exposed to dry GN2.

6) GN2 hardware design will not push existing ICD envelopes.

7) GN2 system shall have means of verifying that it is functioning properly (e.g., pressure gages, test ports, witness panels, etc.). Limited sampling of the segments will be allowed to ensure the GN2 purge concept is functioning as designed.

Figure 3.8-3, Benefits, details the first cut at the potential benefits of any system that eliminates the annual SRMU segment movement for corrosion maintenance.

Table 3.8-1, Engineering Estimate Matrix, shows the items/events where cost data must be developed to evaluate GN2 with the baseline Braycote RIR (Preliminary engineering estimates show the GN2 has a savings of greater than 10 to 1 over Braycote RIR).

Figure 3.8-4, Corrosion Mitigation-GN2 Purge Schedule (Proposed), is the preliminary look at how long this effort would take based on receiving NUSTO funding. Presently, MMTI and the Air Force are evaluating alternate funding methods.

The GN2 purge concept was presented to the Air Force (AF) at the January 1994 Corrosion TIM and on 15 February 1994 to AF personnel attending the T IV program review in Denver.

DRY GN2 PURGE

BENEFITS

Technical/Mission Success

- Reduce Risk To Segment
  - Minimize Segment T&H (HI To Verify No Other MEA Tasks Require T&H)
  - Minimize Removal Of Handling Rings/Proofloading
  - Minimize Overhead Crane Operations
  - Ensures Tang/Clevis Dimensions/Tolerances Do Not Go Out Of Specifications Due To Removal Of Corroded D6AC Steel

Safety

- Safest Approach - No Movement While In Storage
- Reduces Personnel Risk (Minimizes Hazardous Ops and T&H)
- Environmentally Safe

Cost

- Must Consider Cost Of New GN2 Purge AGE And Facility GN2 System (Low Pressure And Low Volume)
- Minimizes LCC
  - No Need For Facility Air Conditioning For Corrosion Mitigation
  - Saves Annual Braycote RIR Manhours
  - Saves Annual T&H/Crane Operations
  - Reduces Quantity Of Spares Required
- Reduce Or Eliminate Inspection/Maintenance @ TIMF - Transfer Only (Saving Minimum Of 68' x 60' High Bay Area)

Figure 3.8-3, Benefits

Table 3.8-1, Engineering Estimate Matrix

DRY GN2 PURGE

ENGINEERING ESTIMATE MATRIX

TO BE COMPLETED DURING NUSTO

EVENT/COST ITEM	BRAYCOTE 194	GN2
INITIAL		
Apply Braycote 194 at HI during SRMU Segment Build Up	Baseline	Baseline
New GN2 Segment Hardware	N/A	TBD
GN2 System In SSF	N/A	TBD
AC Acquisition Cost (SSF/TIMF)	TBD	N/A
TIMF Facility Area For Verticalization Operations	TBD	N/A
Delta Savings: Facility Crane Vs Horizontal Transfer Equipment Only	TBD	N/A
Spares Required To Support Annual Braycote RIR (Handling Rings, Stands, Railcars, etc.)	Usually 10 - 20% TBD	TBD
RECURRING		
Annual Braycote RIR	TBD	N/A
Annual GN2	N/A	TBD
Annual AC Cost	TBD	N/A
Annual SRMU Segment T&H	TBD	N/A
Annual SRMU Segment Breakover	TBD	N/A
OTHER		
R&M Degradation Due To Annual Segment T&H	TBD	N/A
SUMMARY		
LCC - Assuming Each FSS Is In Storage An Average Of TBD Years:		

TO BE COMPLETED DURING NUSTO

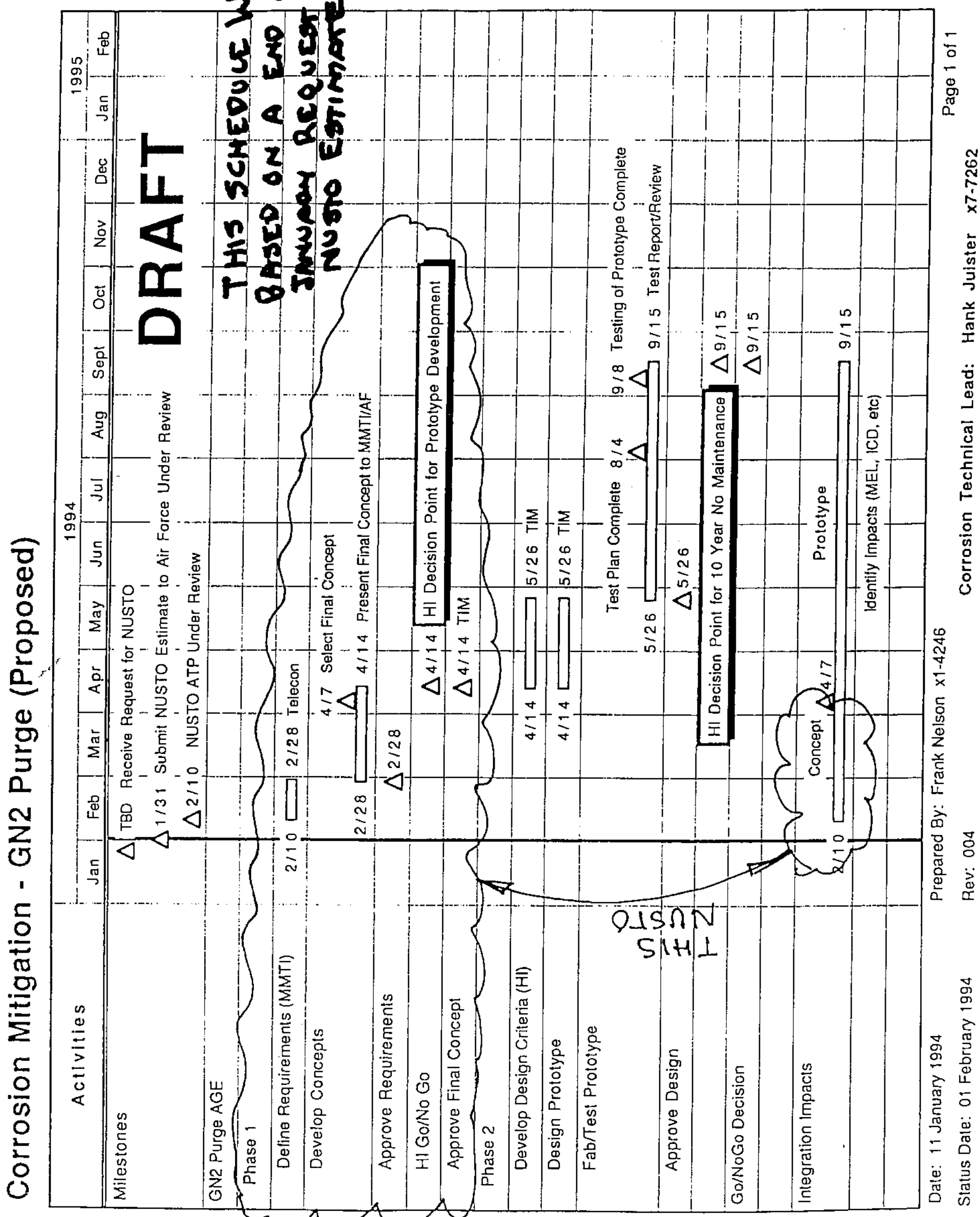


Figure 3.8-4, Corrosion Mitigation-GN2 Purge (Proposed) Schedule

4.0 VENDOR, INDUSTRY, DOD SEARCH DATA

The initial approach to this area was through existing networks of personal contacts in the launch rocket industry and Department of Defense (DoD). Vendor products were selected from personal recommendations. PMP did a library search of articles/vendors to ensure that technology had not provided new products that we should consider and to ensure that we hadn't overlooked a potentially better product or method of preventing corrosion.

HI sent Michelle Jackson to the 1993 National Association of Corrosion Engineers (NACE) conference in March 1993. Michelle canvassed most of the vendors. Cortec was the only vendor that gave her data on products they thought could improve protection of the D6AC steel (by coincidence, VCI-368 was one of the products they recommended).

Army (Waterton Arsenal), Navy (Aircraft Maintenance & Corrosion Center), Air Force (Davis Monthan AFB, Robins AFB (AF Corrosion Office) and Wright-Patterson AFB Labs) and NASA (MSFC) personnel were contacted between January 1993 and December 1993. In general, they all recommended testing various products on the D6AC steel to determine which product performs the best. None of the agencies had any current information on recent corrosion protection testing of D6AC steel, other than NASA and they use Conoco HD-2 that is not permitted by HI.

The team has been made aware of the Aging and Surveillance testing CSD is doing at CCAFS. To date, no data or cross-talk has come to us from that testing.

A representative from MMTI's Baltimore office will be attending the February 1994 NACE conference in Baltimore and has been requested to look for products that could improve protection of high strength steels.

5.0 REQUIRED FUTURE ACTIVITIES (not part of this NUSTO effort)

5.1 VAFB

Work with the CCT and the CCT Facility Working Group to ensure all facility corrosion issues are addressed and resolved.

Continue to work with the facility/AGE engineers to work corrosion concerns and alternate corrosion protective/prevention methods and concepts.

Work with HI on updating MEAs, procedures and practices as required.

Have Braycote 194 RIR in-place by December 1994 (approximate need date for first annual maintenance per the MEA)

Complete the SRMU cleaning scenario (annual maintenance) by December 1994, including design, fabrication, and pathfinder.

Complete training of VAFB personnel in Braycote 194 RIR.

5.2 GN2 PURGE

GN2 Purge Tool NUSTO (see section 3.8 for details) - the concept requires development and testing, taking approximately 9 months to accomplish. Future effort to validate this concept will have to be funded through a new NUSTO or another source of funding, such as Value Engineering.

5.3 OTHER

Conduct a Humidity TIM to resolve open humidity concerns.

Ensure Workmanship Specification (and/or Finish Specification) is/are updated to include Braycote 194 application details (thickness, drying time between coats, etc.).

Consider findings from the 1994 NACE convention to revise/update corrosion mitigation materials and practices.

6.0 CHRONOLOGY OF KEY ACTIVITIES & EVENTS

05 January 1993	MOU 92-074 tasks MMC to work corrosion issues dealing with long term storage.
05 February 1993	Kick off meeting identifies Team to work horizontal vs vertical study and corrosion issues.
22 February 1993	Orientation visit to HI identifies corrosion as the major reason for annual inspections. Braycote 194 is only qualified for 12 months use.
07-12 March 1993	Michelle Jackson, HI, attends National Association of Corrosion Engineers (NACE) conference. Cortec Corporation representatives and Michelle discuss possible use of VCI-368 as a corrosion protective coating on SRMU D6AC steel. (Cortec was the only vendor that gave Michelle a positive response for an alternate to Braycote 194)
11 March 1993	Denver PMP is brought on board to assist in identifying new/better protective coating products/methods that will inhibit corrosion better than Braycote 194. This data is needed in order for HI to extend out the annual maintenance requirements to a more reasonable period.
24 March 1993	HI Resident Team finds corrosion under Braycote on hardware arriving at Phillips Lab (PL). Corrosion could be caused by inadequate workmanship (application) or inadequate corrosion protective material.
31 March - 01 April 1993	TIM at Denver - Alternative coatings are discussed and Action Item #46 is assigned to Team to identify alternative coatings and investigate GN2, etc. to mitigate corrosion effects on the SRMUs. Team efforts are put on hold during NUSTO proposal discussions.
24 May 1993	Team directed to continue to work vertical storage of the FWD segment (not addressed in this report) and current corrosion issues (AI's 40, 44 and 46).
01 June 1993	Participated in CPC Annual Review @ HI.
03 June 1993	SRM corrosion issues added to Team activities.
10 June 1993	CSD uses VCI-368 (with Conoco HD-2) for corrosion protection of D6AC.
14 June 1993	Team picks up additional task of working corrosion issues in VAFB RGTI.
25 June 1993	HI can not use Conoco HD-2 because it is not compatible with the SRMU materials.
7-8 July 1993	SRM/SRMU TIM @ Denver.
13 July 1993	Begin VAFB RGTI temperature and relative humidity (RH) performance testing.

13 July 1993	Begin Denver Lab testing of Braycote 194, VCI-368, Conoco HD-2, etc. corrosion protective coatings.
15 July 1993	Working draft MOU with HI Resident team and HI to do away with the weekly inspections in the RGTI and go to TBD weeks between required inspections.
27 July 1993	Telecon with Col. Paszek, Capt. Case, Fawn Dare, et. al. of SMC/MEF on status of corrosion team activities.
09 August 1993	Complete first phase of Denver Lab testing. GN2 and anodic protection testing still in process.
07 September 1993	Begin looking into what methods, materials, procedures HI uses to protect the SRMU for 18 months on the launch pad. If we can incorporate these methods, etc. into storage; hopefully, we can extend the annual inspection requirements out to 18/24/etc. months. (Initial findings are HI uses a Dow Corning (DC) silicone grease (DC-33) on all bare D6AC when they stack the SRMU segments. Team begins process of obtaining DC-33 for evaluation against Braycote 194 and VCI-368).
15 September 1993	Verbal information from HI Resident team that the Braycote RIR clock starts at Braycote application at HI. Since this could be as much as 3 months before receipt of the segments at VAFB, it means the segments would require Braycote RIR as early as 9 months after arrival at VAFB. CCT given action items (CCT #24 & 52) to get written definition as to when Braycote RIR must be accomplished and how it will be tracked.
27 September 1993	Denver Lab begins DC-33, Braycote 197, Mil-C-85054 and VCI-368 comparative testing.
28 September 1993	Participated in first CCT meeting at HI.
12 October 1993	Participated in second CCT meeting at HI.
19 October 1993	HI given authority to do VCI-368 compatibility/contamination testing.
26 October 1993	Participated in CCT meeting at HI and visit Case Prep #2 Facility (Observe Braycote removal and D6AC inspection for corrosion).
28 October 1993	Made aware of CSD's plan for 12 month inspection of SRM segments: 1) to inspect for corrosion and 2) inspect bond line integrity.
02 November 1993	Made aware of SCNP to change 48 hours in 60-90% RH to 15 hours. Brief Ed Fox, Charlie Bunker and Trip Carter of MMTI on potential impact to VAFB V-31 Braycote RIR activities.
03 November 1993	HI begins VCI-368 compatibility/contamination testing.
09 November 1993	Participated in CCT #5.
11 November 1993	Requested HI submit a NUSTO proposal on GN2 purge concept (s).

23 November 1993	Participated in CCT #6.
30 November 1993	Interim CPC Report is completed (shows activities through October 1993).
02 December 1993	HI reports that the 4 week salt fog test shows VCI-368 and Braycote 194 to be equal in their ability to prevent corrosion. None of the test panels showed any signs of corrosion.
07 December 1993	Participated in CCT #7 and visit HI's lab. to get update of testing. HI advised MMC that a pathfinder with the Tang Down can not be accomplished with existing equipment without modification. HI and MMC resident team to work out the details.
15 December 1993	HI Lab Testing results shows VCI-368 to be identical to Braycote 194 with respect to material compatibility/contamination and ability to protect the D6AC from corrosion.
21 December 1993	Participated in HI/MMTI visit to VAFB to resolve annual Braycote RIR issues per Liaison Call #1372 (see Figure 3.6-1).
5 - 7 January 1994	HAR for first SRMU segment.
27 January 1994	Corrosion TIM (briefed AF and HI on lab tests results and GN2 Purge Concept).
09 February 1994	Participated in CCT. Briefed that after 6 weeks of salt fog testing, the Braycote 194 and VCI-368 were still performing about equally (Pat Hogue was in the process of doing a detailed visual inspection of the panels). Picked up draft answer to CCT-25 that discussed 10 year corrosion rate on 4340 steel when protected from the environments (some or all of HI's rationale/logic/analysis can be applied to the D6AC steel during the 10 year storage scenario).
14 February 1994	Denver receives Rev 1 of MEA and identifies three new weekly tasks that must be done at the RGTI.
15 February 1994	Briefed SMC/MES on GN2 Purge Concept.
23 February 1994	Participated in last CCT under this NUSTO.
28 February 1994	Completed Final Report.
28 February 1994	End of NUSTO funding.

7.0 CONCLUSIONS/RECOMMENDATIONS

7.1 CONCLUSIONS

The early philosophy of "ship and shoot" did not emphasize the long term storage requirements of the SRMU. The effects of corrosion during SRMU long term storage and better ways to mitigate corrosion were not initially researched/evaluated. As a result of the ship and shoot philosophy, specific findings are:

The effects of the annual maintenance cycle on long term storage were not adequately addressed. There was minimal testing/analysis accomplished to validate the annual Braycote 194 maintenance cycle. No long term testing was accomplished to see how long the Braycote 194 will perform under long term storage conditions. If the long term testing would have been performed, the community would now have more confidence in the workmanship and the ability of the Braycote 194 to prevent corrosion; and a maintenance period based on tests and analysis could be identified.

There was minimal testing or analysis accomplished to validate the 10 year service life.

7.2 RECOMMENDATIONS

Specific recommendations are:

HI, using their approved processes, do real time testing at CCAFS and/or VAFB to demonstrate the real protective capability of Braycote 194 and VCI-368 to protect D6AC steel.

There needs to be a "gate" (Andy Mahtani of TRW, 27 January 1994 @ the Corrosion TIM) that the material/processes must pass that shows the customer that the material/process meets the 10 year service life and/or 18 month pad life. This testing and analysis needs to be added to the 10 Year Service Life Report (BU91U-2000-0625), also.

If the GN2 purge, or similar long term corrosion preventative method like paint, is not implemented, continue to test alternate coatings so the best coating can be used and the longest storage period (longest time between maintenance cycles) can be implemented.

Have Denver PMP participate in CCT meetings and TIMs.

Conduct a Humidity TIM.

Consider findings from the 1994 NACE convention to revise/update the SRMU corrosion mitigation program.

Ensure the Workmanship Specification and Finish Specification are updated to include Braycote 194 application details.

Denver PMPCB to ensure that HI identifies a metallic corrosion representative to be a member of the board.

Ensure the PMP comments to HI's CPC Plan and Finish Specification are incorporated.

Modify the MEA to account for actual environments at VAFB, CCAFS and permanent storage facilities.

MCR-94-2509
February 1994

Attachment I

MMTI Test Report

Coating Evaluation for Titan SRMU

TEST REPORT

COATING EVALUATION

FOR

TITAN SRMU

Test plan released on December 23, 1993

Report written on 2-21-94

Patrick Hogue

and

Timothy Frey

Substrate description

Starting sample lot consists of 17 flat plates of D6AC. 9 from Ladish forging (8" x 9" x 1/4" with 1/8 " diameter hole). Eight from Hercules, Inc. with through holes or flat bottom holes; approximately 1/4" thick.

Hercules substrates had a flat face ground on one side, average hardness Rc 44.6 (std. dev. 1.24). Viberetch numbers 10 through 17. Panel 17 was ground flat to facilitate thickness measurements.

Ladish substrates EDM cut from heat treated forging pieces, then ground to 1/4" thickness. Average hardness Rc 46.8 (std. dev. 0.80). Viberetch numbers 1 through 9.

Substrate preparation

1. Grit blast all substrates with 100 grit alumina using 80 psi pressure with back-and-forth motion. Blast until a uniform dull gray finish is achieved.

2. Degrease with triple solvent wipe using fresh 1,1,1 trichloroethane and fresh rumple cloth rag for each wipe. Keep covered and do not touch with bare hands.

3. Pre-rust: place 0.5 ml of deionized water onto the face of each clean substrate and allow to evaporate to dryness. See Figure 1.

4. Use notched wood planks to hold the panels in a vertical position (Figure 1).

5. The sample matrix shown below will help to identify the coated substrates.

Substrate Number	Coating Material	Coating method	Photo Numbers CN XXXX-94
1	BR 194	Brush	251, 259, 3916
2	BR 194	Dipped	252, 260, 3917
3	BR 194	Sprayed	253, 261, 3918
4	VCI 368	Brush	254, 266, 3919
5	VCI 368	Dipped	255, 262, 3927
6	VCI 368	Sprayed	256, 263, 3926
7	Mil-C-85054	Sprayed	3924, 264, 257
8	DC 33	Hand Rubbed	3925, 265, 258
9	BR 194	Brushed	3933, 198, 380, 381, 409
10	DC 33	Hand rubbed	199, 307, 3922
11	DC 33	Hand rubbed	382, 3930, 408
12	Mil-C-85054	Sprayed	200, 308, 3923
13	Mil-C-85054	Sprayed	196, 383, 3931, 407
14	BR 194	Dipped	193, 3928, 386, 404
15	VCI 368	Brush	195, 384, 3934, 406
16	VCI 368	Dipped	194, 3955, 385, 405
17	VCI 368	Sprayed	201, 387, TBD, TBD

6. Details of coating applications.

a. BR 194 brush applied: use acid brush to apply as uniform a coating as possible. Allow to dry for at least 2 hours, then recoat. Repeat as necessary to achieve 4 mil thick coating. Color shall match Hercules photographs.

b. BR 194 dip applied: if necessary, dilute BR 194 with mineral spirits until a dippable consistency is achieved. Record volume of mineral spirits (MS) and volume of BR 194. Color shall match Hercules photographs.

100 ml BR 194 80 ml MS

c. BR 194 spray applied: dilute BR 194 with MS until a sprayable consistency is achieved. Record volume of mineral spirits (MS) and volume of BR 194:

100 ml VCI 368 80 ml MS

Use standard non-silicone spray gun to apply coating to 100% of surface area, including holes. Allow to dry at least 2 hours and reapply. Repeat until 4 mils is achieved.

d. VCI 368 brush applied: use acid brush to apply as uniform a coating as possible. Allow to dry for 2 hours, then recoat. Repeat as necessary to achieve 4 mil thick coating. Color shall match Hercules photographs.

e. VCI 368 dip applied: if necessary, dilute VCI 368 with mineral spirits until a dippable consistency is achieved. Record volume of mineral spirits (MS) and volume of VCI 368. Color shall match Hercules photographs.

100 ml VCI 368 80 ml MS

f. VCI 368 spray applied: dilute VCI 368 with MS until a sprayable consistency is achieved. Record volume of mineral spirits (MS) and volume of VCI 368:

100 ml VCI 368 80 ml MS

Use standard non-silicone spray gun to apply coating to 100% of surface are, including holes. Allow to dry at least 2 hours and reapply. Repeat until 4 mils is achieved.

g. DC 33 application: using the hand (finger) rubbed method demonstrated by Eric Malloy of Hercules, Inc. apply a medium coating to all surfaces of the substrate. This method will be performed by Pat Hogue. Reweigh tube after each application and calculate average thickness based on a density of 0.97 g/cc, record below.

Panel Number	Average Thickness (inches)
8	0.0060
10	0.0076
11	0.0061

h. Mil-C-85054 application: spray a uniform coating on all surfaces. Allow to dry for at least 2 hours, then recoat. Repeat until 4 mils is achieved.

Note: film thicknesses are determined with a micrometer in such a way that the anvil just contacts the coating.

Substrate Number	Actual Film Thickness (mils)
1	5
2	5
3	2.5
4	5
5	3.5
6	1 TO 1.5
7	1.5
9	5*
12	1.5*
13	1.5*
14	5*
15	5*
16	3.5*
17	4

*These curved substrate coating thicknesses were determined by visual comparison with actual measurements made on the panels shown in the first portion of this table.

Scribing

After coating application, an "X" shall be scribed through the coating using an x-acto knife with the blade held normal to the surface. Both lines forming the X shall be 2 inches long. The scratched and pre-rusted coated substrate is sketched in Figure 1.

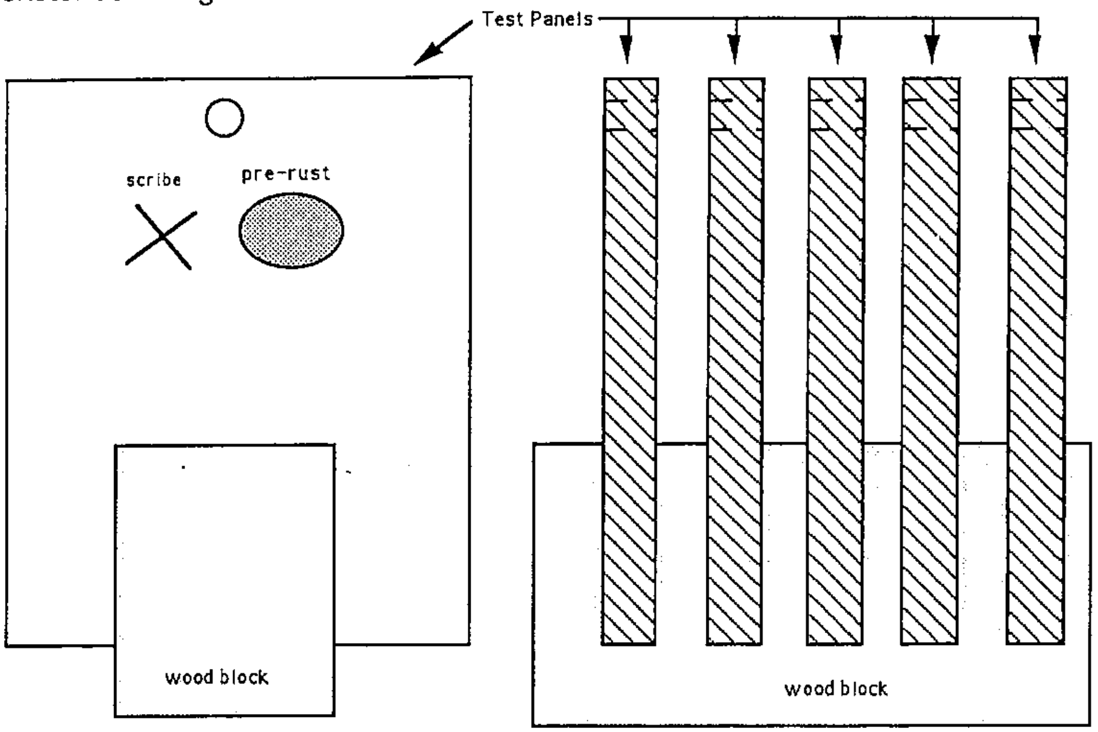


Figure 1 Pre-rust and X Scribe

Salt Fog Testing

1,000 hours per ASTM B117. Check status of substrates every day (except holidays, which are checked weekly). Record observations in the table below (use continuation sheet if necessary).

Removability: Tric. vs Prepsolv.

Prepsolv and 1,1,1 trichloroethane were compared in their ability to remove all the coatings mentioned above. The number of wipes to remove the coating with a saturated rumple cloth were equal for the two solvents.

Results

Panel No.	Description	Coating thickness mils	Time in salt fog	Pre-rust Growth ?	Condition of Scratch	Comments
1	Brushed 194	5	2 wk	no	25%*	no corrosion
2	Dipped 194	5	2 wk	no	0%	no corrosion
3	Sprayed 194	2.5	2 wk	no	0%	no corrosion
4	Brushed 368	5	2 wk	no	0%	one spot
5	Dipped 368	3.5	2 wk	no	5%	stains
6	Sprayed 368	1.5	2 wk	no	0%	3 spots
7	Mil-C-85054	1.5	2 wk	no	0%	stains. pits(1)
8	DC33***	6	2 wk	no	2 %	stains, some pits
9	Brushed 194	5**	6 wk	no	10%	stains, pits (2)
10	DC33***	7.6	4 wk	no	80%	stains. pits
11	DC33***	6.1	6 wk	no	65%	stains, pits (3)
12	Mil-C-85054	1.5**	4 wk	no	5%	stains, pits
13	Mil-C-85054	1.5**	6 wk	yes	90%	stains, pits (4) (8)
14	Dipped 194	5**	6 wk	(5)	0%	no corrosion
15	Brushed 368	5**	6 wk	no	20%	3 pits
16	Dipped 368	3.5**	6 wk	yes (6)	60%	stains, pits (6)
17	Sprayed 368	4	6 wk	no	0%	no corrosion (7)

Notes:

* This percentage refers to the amount of the "X" actually rusted after coating removal.

** These curved substrate coating thicknesses were determined by visual comparison with actual measurements made on the panels shown in the first portion of this table.

*** DC33 has rubbed in by Pat Hogue using the finger techniques demonstrated by Eric Malloy of Hercules Corporation.

"no corrosion" refers to the lack of corrosion in areas other than the scratch.

(1) Stains and pits located on topmost portion of pane;l.

(2) Stains and pits were due to unintentional damage to coating during handling.

(3) 25 mil pit at center of "X".

(4) About 20% of the stains appearing on the photograph consist of pits when examined microscopically.

Results (continued)

Notes:

(5) a few pits were observed within the brown stain (typical of the pre-rust area), possibly indicating very localized growth of pre-rust during salt fog exposure.

(6) most of the corrosion occurred on the upper portion of the panel, consistent with reduced coating thickness in this area due to drain-down. Dipping does not seem to result in good wetting of the surface.

(7) Rust spots were evident at the line formed by unintentional disruption of the coating. This coating defect is visible in the photographs as a horizontal line on the face of the panel about half way up.

(8) Severe pitting can often take the form of "island corrosion". This is sketched below. Although these island are far too large to represent actual grains, this form of corrosion does resemble intergranular corrosion in its morphology (see Figure 2).

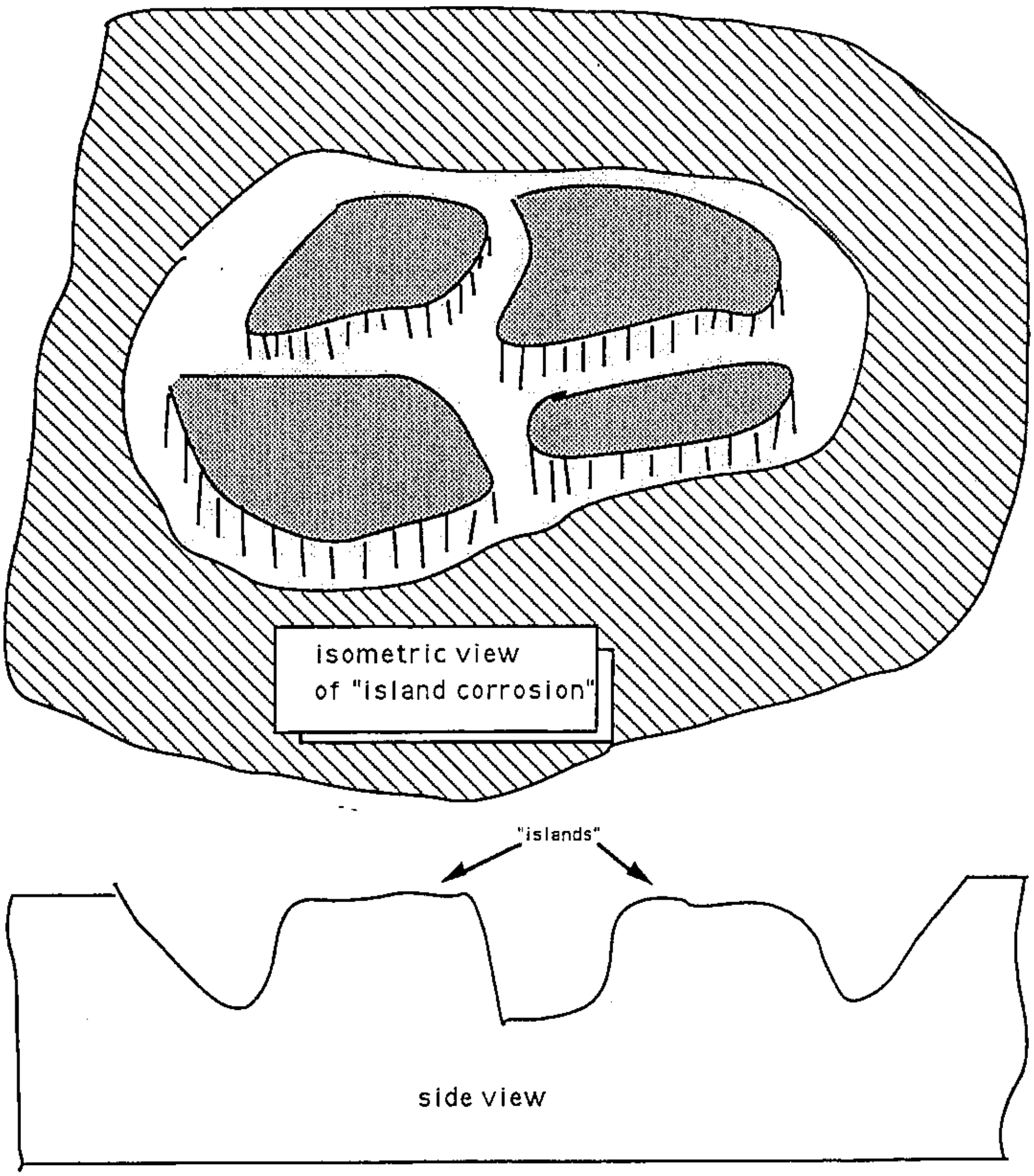


Figure 2. "Island Corrosion"

Conclusions

The 2 week brushed 194 corrosion in the "X" was unexpected. This is probably anomalous. Dipping is not a recommended application method, in spite of the better performance of panel 14 over panel 9. Spraying is a satisfactory application method, as is brushing (in spite of the exception just cited). DC 33 is able to protect D6AC for only a fraction (about one day vs 6 weeks) of BR 194 or VCI 368. BR 194 seems to have about the same protective capability, in the salt fog environment, as VCI 368. Consideration should be given to increasing the life of BR194 to two years.

Salt fog testing is too severe to adequately demonstrate the protective qualities of the volatile corrosion inhibitor (VCI) of Cortec's VCI 368 product. Earlier humidity testing (95% RH, 120°F) was not severe enough to differentiate the coatings described in this report. It is the author's opinion that VCI 368 may offer a slight advantage over BR 194 in actual field storage environments.

Prepsolve is a satisfactory substitute for 1,1,1 tric. in the application of removing the coatings described in this report. Prepsolv is a product of the Glidden company.

MCR-94-2509
February 1994

Attachment II

Hercules Report

Investigation on the Effects of Cortec VCI-368
on Selected Titan Rocket Motor Components

INVESTIGATION ON THE EFFECTS OF CORTEC VCI-368 ON SELECTED TITAN ROCKET MOTOR COMPONENTS

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15 December 1993

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INTRODUCTION

The current corrosion preventive system for Titan parts includes Braycote CPT-4 (Braycote 194 with a fluorescent tracer) on all exposed rocket motor metal hardware, and Braycote 103 on heavy handling rings. Although the use of Braycote has provided satisfactory corrosion prevention on these parts and Hercules has been satisfied with the current system, it is in the interests of continuous improvement to investigate and evaluate alternative available coatings.

Cortec VCI-368 was the alternative identified for purposes of testing conducted for this report. Use of the Cortec material holds several advantages over the current system. First, the viscosity of the Cortec can be varied, thus allowing variation in the applied thickness tailored to the part being protected. The current system is available in one viscosity only, which is low enough that it could lead to runs and drips. A thicker coating would prevent that occurrence. Second, the alternative coating contains a corrosion inhibitor which would protect small areas where the coating may be damaged during shipment. The current coating protects only by providing an environmental barrier. Finally, the Cortec material has a rated corrosion prevention life of two years minimum to five years maximum of outdoor exposure (MIL-C-16173, Grade 1), while the current system is rated for a minimum of one year of sheltered exposure (MIL-C-16173, Grade 4).

Prior process service testing has shown the Cortec VCI-368 to be compatible with cured and uncured Titan IV SRMU propellant. Concurrent testing has evaluated the corrosion preventive effectiveness of the alternate material, and the effect the Cortec would have if exposed to surfaces prior to the propellant-to-insulation bonding operations. This paper presents the results of testing conducted to determine the effect of Cortec VCI-368 on Titan metal components, insulation materials, and propellant-to-insulator bondlines.

CORROSION TESTING

The current coating system (Braycote 194, CPT-4, and 103) were compared to the alternative coatings (various viscosities of Cortec VCI-368) under extended salt spray exposure. The testing was to determine a point where the current system began to deteriorate and the alternative system to surpass in corrosion prevention.

Method

Grit blasted, degreased, D6AC alloy steel coupons were coated with the current coating systems (Braycote 103, 194, or CPT-4) and the alternative coating system (Cortec VCI-368 spray, 20% dilution with mineral spirits, and concentrate). Approximate coating thicknesses of four mils per side were achieved by applying two coats in most cases (three for the VCI-368 spray). Coatings were allowed to dry at ambient conditions for two hours between coats.

All coupons were exposed to salt spray per ASTM B117 for 0, 1, 2, 3, and 4 weeks.

Results

Coupons were visually examined following salt spray exposure for any signs of corrosion or coating degradation. The only corrosion evidenced was confined to the mounting holes and is allowed per the test standard.

No coating degradation (cracking, checking, peeling, powdering, etc.) was noted. Photographs of the individual test coupons are found in Appendix A.

Corrosion Summary

Although no coating degradation for either coating system was noted, several conclusions can be drawn from the testing.

First, surface preparation is essential. If the coatings are applied to clean, corrosion-free surfaces, no corrosion is generated in up to four weeks of salt spray.

Second, coatings must be applied in multiple coats (allowing sufficient dry time between coats) up to a minimum coating thickness of four mils to achieve maximum corrosion resistance.

Third, if the current coating system (MIL-C-16173, Grade 4, two mil thickness) is applied to Grade 1 minimum thickness requirements (four mils), longer sheltered exposure times are anticipated.

INSULATOR COMPATIBILITY

During the application of a corrosion preventive coating, it is possible that the coating could come into contact with insulation materials and insulator bondlines. This section describes work performed to determine the effect of Cortec VCI-368 on Titan insulation materials, insulator-to-steel bondlines, and insulator-to-insulator cocure bondlines.

Mechanical Property Tests

For the effect on insulation materials, two insulator formulations were selected: the aft dome, tang, and clevis insulation (-044 {specification S283146}), and the internal WEI™ insulation (-045 {specification S273096}).

Sample Preparation

The two insulation materials were separately milled on a two-roll mill to a thickness of approximately 0.1". Five-inch by seven-inch panels were cut from the rubber and cured in a mold at 290°F under 200 psi minimum for 45 minutes. Twelve ASTM Die-C dogbones of each rubber were cut from the cured slabs, with the Kevlar™ fiber oriented perpendicular to the gage length of the dogbone. (Historical data have shown the perpendicular orientation provides more sensitive measurements of the insulation elongation than does the parallel orientation.)

After cutting and measuring the dogbones, six dogbones from each insulator were placed in a pan and coated with the control corrosion preventive coating (Braycote 194, CPT-4), while the other six were exposed to the Cortec VCI-368 (20% dilution). The samples were exposed for one hour, after which they were removed and wiped dry. It should be noted that this "wipe" did not return the samples to a pristine state -- there was still some coating material left on the dogbones. The samples were dried for 72 hours at ambient temperature and pressure prior to testing. The dogbones were pulled at ambient temperature and pressure at 20.0 inches per minute (ipm).

Results

The results of these tests are summarized in Table 1 (individual data for all tests can be found in Appendix B). Both sets of samples yielded results well above the specification limits, and representative of the original vendor acceptance test results (control). Comparison of the test samples using a Student's t-test shows that only the tensile strength of the -044 is statistically different between the two coatings. Since this trend is not repeated in the elongation results, or for either of the two -045 measurements, we consider this to be a test anomaly resulting from the high variability of ultimate properties of Kevlar-filled materials. Based on this, and the comparison to original vendor data, we conclude that the Braycote and Cortec materials have essentially no impact on the mechanical properties of the two insulation materials.

Table 1: Summary of Mechanical Property Tests (samples tested perpendicular to fiber direction)				
	Specification Limits	Control[1]	Braycote (CPT-4)	Cortec VCI-368
044 Insulation (aft dome, tang, clevis)				
Tensile strength (psi)	> 800	1199	1094	1208
Elongation (%)	> 40	100	76.1	84.2
045 Insulation (WEI)				
Tensile strength (psi)	> 450	599.8	599.1	586.4
Elongation (%)	> 50	95.5	101.3	111.0

Bond Tests

Two insulator bondlines were evaluated for this investigation. The first involved the bond between the insulation and the end rings (-044-to-steel), in an area where the corrosion preventive coating would normally be applied. The second bond was an insulator-to-insulator cocure (cured -044 with an uncured -045 overlay), which could be splashed or otherwise contaminated with the coating.

Sample Preparation

For each of the two systems, we prepared twenty tensile adhesion specimens, and twelve 90° peel specimens. The -044-to-steel samples were prepared by grit-blasting 4340 steel plates with 20 grit aluminum oxide and triple degreasing with 1,1,1 trichloroethane (TCA). After the plates dried 30 minutes minimum at ambient conditions, Chemlok 205 was applied. This was followed by another 30 minute minimum dry, and an application of Chemlok 236A. After the 236A dried for 30 minutes minimum, a "tackifier" was applied to maintain consistency with earlier samples prepared for Titan IV SRMU insulation characterization. The tackifier is the Titan IV flap insulation dispersed in TCA at a 5% loading level. This also was allowed to dry for a minimum of 30 minutes.

The uncured -044 insulation, milled to approximately 0.1" thickness, was then layed up on the prepared steel plate. Tensile button end tabs (which had been prepared in the same manner as the steel plates) were placed on the top of the insulation. The samples were vacuum bagged and cured in an autoclave for 1 hour at 290°F under 100 psi minimum. After removal from the autoclave, the tensile samples were cork bored to ensure a 1 in² bond area, and the 90° peels were cut to 1" strip width. Ten tensile buttons and six 90° peel specimens were exposed

1 - Control values taken from the original acceptance testing of these materials, as reported by the original vendor Quality Control Inspection Documents.

to the Cortec VCI-368, while the other ten buttons and six peels were exposed to the Braycote 194. The coatings were applied to the bondline area and were allowed to sit for 72 hours at ambient temperature and pressure prior to testing. Figure 1 shows the sample configuration for both sets of tensile bond specimens.

The -044-to-045 cocure bondline samples were prepared in much the same way. Aluminum plates were grit-blasted with 20 grit aluminum oxide and triple degreased with TCA. The Chemlok 205/236A system was applied, followed by the flap-rubber tackifier. The uncured -044 insulation was then vulcanized to the aluminum plates (290°F, 100 psi minimum, 1 hour). After cure, the -044 insulation was buffed with a Brushalon disk, degreased with TCA, and dried for 30 minutes to simulate the buffing operation conducted during manufacturing. Uncured -045 insulation, approximately 0.1" thick, was then applied to the previously cured -044. Tensile button end tabs, prepared with the Chemlok adhesives, were placed on the -045 insulation, and the samples were vacuum bagged and cured in an autoclave for 1 hour at 290°F under 100 psi minimum.

These tensile samples were also cork bored and peels cut to width after cure to ensure the proper bond test area. Peel specimens had fiberglass cloth cured on the top side of the -045 to reduce the tendency for the rubber to elongate during the peel test. Again, the bondlines from ten tensile button and six peel specimens were exposed to the Cortec material, while the other

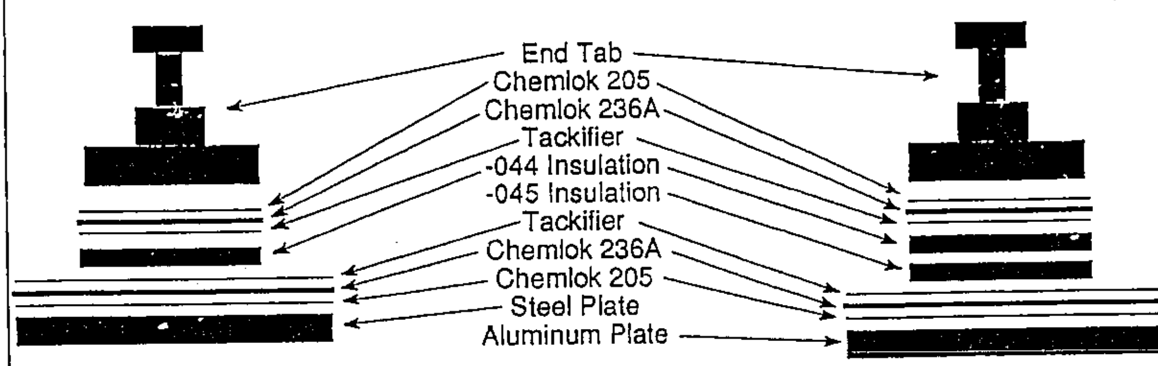

Figure 1:
Sample preparation configuration for tensile buttons.
(Note: Peel specimen layup is the same, except instead of an end tab, fiberglass cloth is used to aid in eliminating rubber elongation during test)

half were exposed to Braycote 194. These samples were also allowed to sit for 72 hours at ambient prior to testing. Tensile adhesion specimens were tested at ambient temperature and pressure at 0.2 ipm, while the peels were pulled at ambient conditions and 1.0 ipm to maintain consistency with the original Titan IV insulation characterization tests.

Results

Tensile adhesion test results and 90° results are shown in Table 2 below.

Table 2:
Summary of Tensile and Peel Adhesion Tests

	Control[2]	Braycote (CPT-4)	Cortec VCI-368
044-to-Steel Tensile (psi)	549	569.7	571.0
044-to-045 Cocure Tensile (psi)	270	250.8	245.0
044-to-Steel 90° Peel (pli)	nt	nt	nt
044-to-045 Cocure 90° Peel (pli)	na	56.98	53.54

Results of the 044-to-steel tensile bonds indicates that there is no significant difference between the samples exposed to the two coatings, and both generated results slightly higher than the control samples. In the cocure samples, there was again no statistical difference between the two exposed samples, and results were comparable to the control. All samples failed cohesively in the insulation, indicating an interfacial bond stronger than the rubber substrates.

Peel samples for the -044-to-steel bond all failed at the glass backing, which had been applied to reduce the effect of insulation elongation during test. This was not surprising, as a similar failure mode was observed during the initial characterization and development of Titan IV SRMU insulation materials. The -044-to-045 cocure samples yielded results that were not significantly different between the two coatings. Control samples for these materials were not available for comparison, however all samples failed cohesively uniformly in the -045 material. There was no degradation or change in failure mode at the exposed edges, indicating the bond was not deleteriously affected by the two coatings.

Based on the bond test results and the statistical analysis, we conclude that the two coatings do not deleteriously effect either the 044-to-steel bond, or the -044-to-045 cocure bond.

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2 - Control values taken from the original testing of these materials, as reported in report from R. H. Page to Distribution, "*Results of No-Vanfre Mechanical, Bond, & Rheologic Testing,*" Sept. 6, 1991, Ref. HITC/T240/40-0177, Lib. Accession No. BU91U-2002-0146.
- "nt" indicates no-test; samples failed at glass backing
- "na" indicates no historical control data were available

Insulator Compatibility Summary

Two insulation materials and two insulator bondlines were evaluated during this testing. Mechanical properties, determined through the use of ASTM Die C dogbones, showed no insulation degradation after the material was exposed to the corrosion preventive coating and dried 72 hours. Insulator-to-steel and insulator cocure bonds were evaluated using tensile adhesion and 90° peel specimens. Results show no significant difference in the effects of the two coatings on the bonds evaluated. Samples were also comparable to historical control samples. Based on these results, we conclude that the use of Cortec VCI-368 should have no deleterious effects on the Titan IV SRMU Kevlar-filled insulations or the investigated bondlines.

LINER SYSTEM COMPATIBILITY

There was concern about the possible effects of VCI-368 contamination of the case insulation during the application process. From conversations and an audit with the Case Prep supervisor, we ascertained that any possible contamination would occur during the application process to the rings and could affect the cured dome insulation (044 rubber) or the WEI material (045 rubber), both Kevlar-filled EPDM's. Figure 2 shows the casebond cross-section and the migration paths of various materials. It has been shown during earlier work that a good coating of the Z451 barrier is effective against low energy material migration.

Method

A test was designed employing a full factorial matrix to compare the relative threat of the VCI-368 to the present Braycote 194 system. The matrix design employs a balanced orthogonal array of the parameter levels which allows the parameter effects and interactions to be determined easily and efficiently. After all of the resultant data is collected the average effect from the parameter or the parameter interaction can be calculated by determining the difference of the average test response at the low and high level of the input parameter.

Both corrosion inhibitors use an aliphatic carrier which is quite aggressive to the rubber and would be readily absorbed if contaminated in bulk. It was assumed that the material would be dripped/splattered on the surface and then would be cleaned off with 1,1,1-trichloroethane either: 1) within three hours of the contamination if it was noticed during the application process, or 2) only after the case had gone through the insulator dry cycle and was unnoticed until the normal pre-buff cleaning.

The bond testing consisted of 90° barrier peels at 1 ipm (two per panel) and barrier tensile buttons at 0.02 ipm (three per panel). These specimens represent an abbreviated analog of the liner system and consist of 0.125" of the insulator material backed with glass fiber/epoxy and coated with the EPDM primer (EP5711-35) and six mils of Z451 barrier. (This thickness is toward the low end of the variable and would be worst case for migration.) This configuration concentrates on the insulator/primer and primer/barrier interfaces which would be the most vulnerable to this contamination. Contamination migration to the barrier surface was considered unlikely, but the surface was analyzed after cure by FTIR for foreign material.

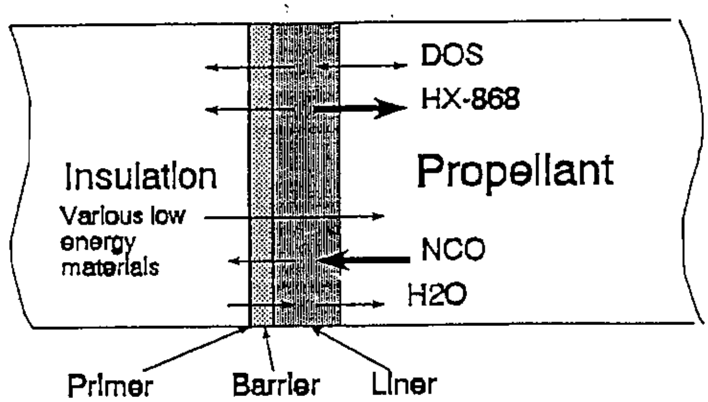

Figure 2: Casebond Cross-Section and Migration Paths

Full Factorial Matrix Design and Test Plan (COR1)

* Determine the effect of corrosion inhibitor contamination on the 3-part liner system in the Titan segments. Contamination would be assumed to occur during painting operations on the hardware after hydrotest. A full factorial matrix was performed to determine the sensitivity of the casebond to the insulation type and contamination residence time with the Cortec material and the baseline Braycote 194.

Table 3: Test Parameter Levels

Variable	Low Level	High Level
A - Contaminant[1]	Braycote 194	Cortec VCI-368 with 20wt% added solvent[2]
B - Insulation[3]	045 (WEI)	04 (Dome)
C - Residence time/cleaning before continuing processing	Three hours - clean with dry wipe then TCA until rag clean. Continue with dry cycle.	Seven days - continue with dry cycle.

1 - Contaminants applied by flowing over insulator surface. Braycote averaged 24 mils and Cortec 36 mils due to viscosity difference.
2 - Solvent used is a mineral spirit with a 135°F flash point.
3 - One control panel of each rubber left uncontaminated as control.

Constants

* Casebond Process - Ins. dry cycle (60-72 hours @ 140°F)
  - Clean with TCA/rympiecloth. Dry 1-2 hours
  - Buff insulation with 80 grit Brushalon
  - Clean with TCA/rympiecloth. Dry 2-3 hours
  - Spray EP5711-35 primer (two coats) and dry 2-3 hours
  - Spray barrier (Z451 with 0.33% #9984, 6 mils in four coats)
  - Cure 48 hours @ 140°F

Data Collected

* Barrier peels at 1 ipm (2)
* Barrier tensile buttons at 0.02 ipm (3)
* IR analysis of barrier surface after cure

Table 4:
Individual Test Specimen Parameters and Randomized Process Sequences

Panel	A	B	C	Ins.	Contam.	Residence Time	Contam. Sequence	Cleaning Sequence
1	-	-	-	045	194	3 hrs.	2	4
2	+	-	-	044	194	3 hrs.	1	1
3	-	+	-	045	368	3 hrs.	4	3
4	+	+	-	044	368	3 hrs.	3	2
5	-	-	+	045	194	7 days	2	3
6	+	-	+	044	194	7 days	4	1
7	-	+	+	045	368	7 days	1	2
8	+	+	+	044	368	7 days	3	4
9	n/a	n/a	n/a	045	n/a	n/a	n/a	n/a
10	n/a	n/a	n/a	044	n/a	n/a	n/a	n/a

Data Analysis and Conclusions

The data were analyzed using simple coefficient determination from the orthogonal array with a minimum differential threshold of 20 psi for the tensile test and 1 pli for the peel.

The equation for the tensile maximum stress was found to be:

$$\sigma_{max} \text{ (psi)} = 314 + 14(A) + 94(B) - 37(C) - 20(BC) - 14(AC)$$

Average absolute error in y est. = 16 psi
Maximum absolute error in y est. = 32 psi
Where A, B, and C refer to the variables in Table 3
(BC and AC are interactions)

The equation for the peel strength was calculated after eliminating non-casebond (backing) failure and found to be:

$$\text{peel (pli)} = 15.6 + 1.7(A) + 0.7(B) - 2.8(C) - 1.3(BC)$$

Average absolute error in y est. = 0.9 pli
Maximum absolute error in y est. = 2.2 pli
Where A, B, and C refer to variables in Table 3
(BC is an interaction)

From these equations we were able to draw the following conclusions about the relative effects of the corrosion preventive coatings on the insulator-to-propellant liner system bond performance:

1) Overall, the VCI-368 causes less bond degradation than the Braycote 194 over the process range tested. Refer to variable A in the equations.

2) The residence time of both contaminants was the most significant processing factors as seen in the equations. Refer to variable C in the equations. Any contamination of the insulation should be cleaned as quickly as possible.

3) The effect of VCI-368 is more sensitive to residence time than the Braycote 194. This was seen in the tensile testing and the peels although the peel sensitivity was below the threshold for inclusion in the equation. Refer to variable interaction AC in the tensile equation.

4) The 044 insulation is more sensitive to residence time of the contaminant than the 045. Refer to variable interaction BC in the tensile equation.

5) The 044 insulation is more sensitive to contamination than the 045. The 044 showed degradation of bond strength under almost all conditions except for the scenario with VCI-368 cleaned off the insulation within three hours. The 045 only showed degradation at the worst case condition of VCI-368 going through the entire dry cycle without being removed from the insulation. Refer to general data table (Appendix C) with non-contaminated controls.

Liner System Compatibility Summary

A full-factorial matrix was employed to determine the effect of the two corrosion preventive coatings under varying process conditions on the bond performance of the insulator-to-propellant 3-part liner system. Results indicate that the Cortec VCI-368 overall causes less bond degradation than the currently used Braycote 194. Residence time of the contaminant on the insulator is the most important processing factor, with longer times (including going through the insulator dry cycle) causing significantly lower bond strength. The Cortec coating and the 044 insulation also appear to be more sensitive to the "residence time" effect.

CONCLUSIONS

Cortec VCI-368 was identified as a potential replacement for the current Braycote 194 corrosion prevention system. While Hercules has been satisfied with the protection afforded by the current system, the Cortec coating held several advantages over Braycote. These include variable viscosity, corrosion inhibitors in addition to barrier protection, and extended corrosion prevention life. To evaluate the effect of the candidate replacement on current Titan IV SRMU hardware and materials, we conducted corrosion testing, insulation materials testing, and insulator-to-propellant liner system testing.

Although VCI-368 has the advantage of varying viscosity and incorporation of an inhibitor, corrosion testing showed no degradation of either system within the parameters tested. It appears that if the Braycote system (MIL-C-16173 Grade 4, two mil thickness) is applied to the minimum thickness requirements of the Grade 1 system (four mils), longer sheltered exposure lives are anticipated.

Insulator testing evaluated the effects on two insulator materials and two insulator bondlines. Results of the testing showed no deleterious effect of either coating on the Titan IV internal insulation or aft dome insulation after a 72 hour drying period. Results also showed no significant degradation of the aft dome insulator-to-steel bonds, or the internal insulator-to-aft dome insulator cocure bonds. Based on these results, we conclude that proper and careful use of the Cortec VCI-368 should have no deleterious effect on the Titan IV SRMU Kevlar-filled insulations or the investigated bondlines.

The effect of the two corrosion preventive coatings under varying process conditions on the bond performance of the insulator-to-propellant 3-part liner system were studied. Results indicate that the Cortec VCI-368 overall causes less bond degradation than the currently used Braycote 194. Residence time of the contaminant on the insulator is the most important processing factor with longer times (including going through the insulator dry cycle) causing significantly lower bond strength. The Cortec coating and the 044 insulation also appear to be more sensitive to the "residence time" effect. Note that if the Cortec coating is removed within three hours of contamination, there is no significant loss of bond performance even with the sensitive 044 insulation. This could be accommodated with a contamination inspection incorporated in the coating application procedure.

Appendix A:

Individual Test Coupon Photographs for Corrosion Testing

Photos, Salt Fog @ 4 Weeks Exposure - Contact Pat Hogue at (303) 971-2543 to review