JUN 12 1996 <i>Sta. 2</i>		21 ENGINEERING DATA TRANSMITTAL		Page 1 of 1 1. EDT 158625
2. To: (Receiving Organization) Distribution		3. From: (Originating Organization) Instrument Systems, 74F40		4. Related EDT No.: NA
5. Proj./Prog./Dept./Div.: Safety Programs		6. Cog. Engr.: CA ESVELT		7. Purchase Order No.: NA
8. Originator Remarks: For approval and release		9. Equip./Component No.: NA		10. System/Bldg./Facility: 200G
		12. Major Assm. Dwg. No.: H-14-100457		
11. Receiver Remarks:		13. Permit/Permit Application No.: NA		14. Required Response Date: 6/5/96

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Designator	Reason for Transmittal	Originator Disposition	Receiver Disposition
1	WHC-SD-WM-DA-202	ALL	0	NEC Hazardous Classification and Compliance Regarding the Surface Moisture Monitor Measurement System	S	1	1	

16. KEY									
Approval Designator (F)		Reason for Transmittal (G)				Disposition (H) & (I)			
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)		1. Approval	4. Review			1. Approved	4. Reviewed no/comment		
		2. Release	5. Post-Review			2. Approved w/comment	5. Reviewed w/comment		
		3. Information	6. Dist. (Receipt Acknow. Required)			3. Disapproved w/comment	6. Receipt acknowledged		
SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)									
(G)	(H)	37 ADVANCE COPY							
Reason	Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(J) Name	(K) Signature	(L) Date	(M) MSIN
1	1	Cog. Eng. CA Esvelt	<i>[Signature]</i>	6-11-96	S7-12	CM Monesmith	<i>[Signature]</i>	6-11-96	E6-27
1	1	Proj. Mgr. CE Hanson	<i>[Signature]</i>	6/11/96	H5-09	GP McDonald	<i>[Signature]</i>	6-11-96	E6-27
		QA				RA Huckfeldt	<i>[Signature]</i>	6/11/96	R3-01
1	1	Safety LS Krogsrud	<i>[Signature]</i>	6/11/96	H5-07				
1	1	* GF Vargo	<i>[Signature]</i>	6/12/96	H5-09				
1	1	JH Bussell	<i>[Signature]</i>	6/11/96	H6-11				
1	1	TI Stokes	<i>[Signature]</i>	6/11/96	L6-37				
18. Signature of EDT Originator		19. Authorized Representative Date for Receiving Organization		20. Cognizant Manager Date		21. DOE APPROVAL (if required) Ctrl. No. ☐ Approved ☐ Approved w/comments ☐ Disapproved w/comments			

NEC HAZARDOUS CLASSIFICATION AND COMPLIANCE REGARDING THE SURFACE MOISTURE MONITOR MEASUREMENT SYSTEM

JH Busell
TI Stokes

Westinghouse Hanford Company, Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-87RL10930

EDT/ECN: 158625 UC: 2030
Org Code: 74F40 Charge Code: N2249
B&R Code: EW3120074 Total Pages: 75^{KJ}

Key Words: NEC, classified location, intrinsically safe, explosion proof, surface moisture probe, neutron moisture probe, waste tank, SMMS, tank safety

Abstract: The National Electrical Code (NFPA 70) and National Fire Protection Association requirements for use of Surface Moisture Monitor Systems in classified locations are discussed. The design and configuration of the surface moisture monitor are analyzed with respect to how they comply with requirements of the National Electrical Code requirements, articles 500-504.

TRADEMARK DISCLAIMER. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

Printed in the United States of America. To obtain copies of this document, contact: WHC/BCS Document Control Services, P.O. Box 1970, Mailstop H6-08, Richland WA 99352, Phone (509) 372-2420; Fax (509) 376-4989.

Karen H. Noland 6/12/96
Release Approval Date

Approved for Public Release

**NEC HAZARDOUS CLASSIFICATIONSnd AND COMPLIANCE
REGARDING THE
SURFACE MOISTURE MEASUREMENT SYSTEM**

AUTHOR LIST:

**J.H. BUSSELL
T.I. STOKES**

**Dated:
5/9/96**

TABLE OF CONTENTS

	<u>Page</u>
1.0 Executive Summary	4
2.0 System Overview	4
3.0 Hazardous Location Classification	6
4.0 Design Requirements	7
4.1 General	7
5.0 Approval Process of Electrical Equipment	9
5.1 Equipment Enclosures	9
6.0 Hazardous Classification & Equipment of the SMMS	10
6.1 Deployment Device Upper Enclosure(s)	10
6.2 Deployment Device Mast & Arm	10
6.3 Neutron Probe	11
6.4 Miscellaneous Equipment Adjacent to Deployment Device	11
7.0 Equipment Compliance with Hazard Classification	11
7.1 Deployment Device Upper Enclosure(s)	11
7.2 Deployment Device Mast & Arm	12
7.3 Neutron Probe	12
7.4 Miscellaneous Equipment Adjacent to Deployment Device	12
8.0 References	13
Appendix A Bussell intrinsic safety circuit writeup, inclinometer and probe wiring, barriers regarding neutron probe power in & zener diode network protected faulted power back from probe.	A-1
Appendix B Bussell catalog cut sheets and test reports submitted to ETL, explosion proof thing, rest of ETL package.	
	(Project Files)
Appendix C ETL findings report, Comparison of Probe Housing to UL-1203.	C-1
Appendix D SAIC and PNNL Explosion Pressure Calculations.	D-1
Appendix E SMMS Structural Evaluations for Normal Operating and Handling Conditions.	E-1

Abbreviations and Acronyms

WMC-SD-WM-DA-202, REV 0

Page 3 of 13

NEC	National Electrical Code
NFPA	National Fire Protection Association
EDT	Engineering Data Transmittal
ETL	Electrical Testing Laboratory
AHJ	Authority Having Jurisdiction
NRTL	Nationally Recognized Testing Laboratory
HECB	Hanford Electrical Codes Board

1.0 Executive Summary

This document discusses the hazardous classification of the SMMS, and how the SMMS equipment complies with the National Electric Code (NEC) for the worst case hazardous location. Furthermore, the basic approval processes for equipment, in a hazardous location, is discussed.

Signature on this document's EDT indicates concurrence by the technical community and the Hanford Electrical Codes Board (HECB), the Hanford Site "Authority Having Jurisdiction" (AHJ), that the SMMS equipment has been found to meet the intent of UL-1203. This system is therefore approved for use in any of Hanford's waste tanks, including those classified as Class I, Division 1, Group B Hazardous locations as defined by the National Fire Protection Association (NFPA).

2.0 System Overview

The Surface Moisture Monitor System (SMMS) is designed to measure the moisture in the near surface layers of tank waste. The depth of interrogation depends on the moisture level encountered. The probe must be placed on the surface of the waste to make these measurements. See the SMMS engineering work plan (WHC-SD-WM-WP-200 Rev. 1) for the background of this project.

The SMMS consists of a deployment device, a probe containing a neutron source, decontamination system, and a data acquisition van. Additionally, an overview camera system as required. However, this document does not address the overview camera system. Figure 1 shows the SMMS.

At the top of the deployment device, there is a single large enclosure, divided into two separate enclosed areas. One area contains the manual winches and is open to the tank atmosphere. The other area contains electrical equipment, such as the line driver electronics, intrinsic safety barriers, and the cable terminations and connectors for power and signal connection to the data acquisition van.

A crane picks up the deployment device and lowers it into the tank through a 4" or larger riser. Once the deployment device is seated to the riser, power is connected and the probe electronics are energized. The probe is manually lowered using a worm gear driven winch while simultaneously observing the lowering process via a separate in-tank camera located in an adjacent riser. The probe cable drives a distance encoder (via a rolling wheel on the probe cable) which is used to measure the amount of probe cable deployed. The probe is lowered to the waste surface and a count is obtained from each of the three detectors over a 3 to 6 minute period. The probe is then moved to a different test point location within the work space defined by the geometry of arm.

Figure 1 Surface Monitor System Deployed in Waste Tank

3.0 Hazardous Location Classification

The typical classification for the interior of single shell tanks is Class I Division 2 Group B [Reference 1]. The tank classification for the interior SY-101 is Class I Division 2 Group B [Reference 2]. Table 2 lists the common flammable gases that may be found in the waste tanks. These classification positions are highly disputed, and constantly challenged. Therefore, the SMMS has been designed to be operable in a Class I Division 1 Group B criteria to minimize project risk.

It is considered that the tank dome space or vapor space may have several different flammable gases present during unusual conditions. These gases are; nitrous oxide, ammonia, hydrogen, methane, and non-paraffinic hydrocarbons (kerosene-like or naphtha-like hydrocarbons). The group classification and auto-ignition temperatures per NFPA 497M for these gases is shown below in Table 2.

The classification of gases may appear to be linked to an order of flammability or explosive pressures. This link should be considered to be coincidental only. The Group designations are based on factors that are unique to the gases in that group. Molecular size, ease of migration, weight relative to normal atmosphere, auto-ignition temperature and pressure expansion on ignition are only some of the factors that determine the grouping of a particular gas. Equipment used in an atmosphere of mixed gases, such as this, must be qualified for all the gases present e.g. equipment to be used in an atmosphere containing both hydrogen and methane must be approved for Group B (hydrogen) and Group D (methane). A qualification to Group B does not include all Groups alphabetically past that Group, qualification of a group B gas only does not automatically qualify that equipment for a group C or D gas also.

Table 2 NFPA Group Classification for Common Flammable Gases Found in Waste Tanks		
Gas	NFPA Group	Auto-ignition Temperature
Ammonia	D	928° F
Hydrogen	B	968° F
Methane	D	999° F
Naphtha (NPH)	D	550° F

4.0 Design Requirements and Equipment Description

4.1 General

DOE Orders require electrical equipment to be Listed by a nationally recognized testing laboratory, e.g. Underwriters Laboratory, Factory Mutual, etc. The applications of Listed equipment must be within the parameters of the Listing. The application of Listed intrinsically safe equipment must also consider all associated equipment. Associated equipment is any other equipment or device connected to, or otherwise coupled to the same wiring. Specific apparatus and wiring requirements vary with the Class I and Division 1 or 2 classification for the location specified in the National Electrical Code (NEC) Articles 500, 501, and 504.

In the NEC there are two distinct areas in classified locations, Division 1 and Division 2. Division 1 is used for locations where there is a concentration of a flammable gas above the lower flammability limit (LFL) during normal operating conditions. This does not mean there is always flammable concentrations of gases present. In a probability of explosion analysis in Magison [Reference 3] the percentage of time when flammable concentration of gases is set at 10% for Division 1 classified locations. Division 2 is used when the location has a possibility of flammable gases in concentrations above LFL only in abnormal conditions. In the probability of explosion analysis previously cited, 0.01% of the time there is a flammable gas concentration above LFL in Division 2 classified locations. The same risk analysis establishes that in non-classified locations $1 \times 10^{-11}\%$ of the time there is flammable gas concentration above the LFL. The preceding information is provided to give a qualitative meaning between the differences of Division 1 and Division 2 classified locations and the reason for more stringent requirements in Division 1 classified locations as compared to Division 2 classified locations.

4.1.1 Methods

The NEC provides for three alternative methods to prevent fire or explosions from electrical equipment operating in a classified hazardous locations. These methods are (simplified interpretations):

4.1.1.1 Intrinsically Safe Apparatus

Intrinsically safe apparatus: the electrical equipment/device does not store and can not provide sufficient energy to ignite a flammable mixture. Intrinsically safe equipment is approved for the flammable vapor group (A to D) and for area classification (Class I Division 1 or Class I Division 2). An intrinsically safe system for a vapor group (such as B), can also be considered intrinsically safe for lesser gas groups C and D. Figure 2 shows a fault tree illustrating the number of faults of an intrinsically safe apparatus to ignite a flammable mixture. This figure is provided for illustrative purposes and is not meant to convey or represent an accident probability.

Figure 2. Simple fault tree illustrating faults required for intrinsically safe apparatus to ignite flammable vapor. [Bossert, 1994]

4.1.1.2 Purging

Purging and pressurizing of electrical enclosures: reducing either the fuel or the oxidizer, or both, to a noncombustible level and providing power cutoff switches to the equipment if purge and pressurization control is lost. Three different purging methods are recognized by the NEC, type X, Y, and Z the requirements for these purging and pressurizing methods and the appropriate Class and Division for X, Y and Z applications are described in NFPA 496.

4.1.1.3 Explosion Proof

Explosion proof enclosures and wiring methods: housing the electrical device within a qualified enclosure which is capable of containing explosions due to arcing or other possible ignition sources within the enclosure. Combustion gases will not escape from the enclosure with sufficient temperature to ignite combustible gas mixtures that may be present outside of the enclosure. The requirements for explosion proof housing are described in UL-1203.

Enclosures are Listed for Class I Division 1 locations only. Enclosures are not Listed for Class I Division 2 locations. Electrical devices used in a Class I Division 2 location may not produce either sparks or high heat as required by NEC Article 501-3(b)(1). Note that if "arcing/sparking" components must be used in a Class I, Division 2 location, that equipment must be housed in an

explosion proof housing approved for Class I, Division 1 locations.

5.0 Approval Process of Electrical Equipment

The NEC code is typically adopted by a jurisdiction (state, city, county, DOE, etc) and is used to provide binding regulations. Equipment can be considered suitable for use in a hazardous location if it has been listed for that service by a Nationally Recognized Testing Laboratory (NRTL), or if the "Authority Having Jurisdiction" (AHJ) approves its use.

The DOE is the Authority Having Jurisdiction, since it is the DOE that is the governmental body requiring application of the NEC to its electrical installations. DOE-RL has chosen to allow the Hanford Electrical Codes Board (HECB) to provide the approval as required by the NEC. The HECB can only provide permission to use systems or equipment that are code compliant as per their judgement. Use of systems that are prohibited by the NEC can only be granted by DOE-RL.

An NRTL may provide a Listing of equipment that has met the applicable national standard as interpreted by the NRTL for use in a specific area. [For example, an "FM" label on an intrinsic safety barrier having received Factory Mutual approval.] Often the AHJ will accept the Listing of equipment as its approval without further investigation of the equipment.

5.1 Equipment Enclosures

Approval by the AHJ of custom built equipment for use in a specific location can be accomplished in several ways. It is considered for this discussion that custom built enclosure equipment is not Listed by a NRTL.

5.1.1 Approval by NRTL Testing

AHJ can require an enclosure be tested by a NRTL to prove that it is indeed capable of containing an explosion from within. This involves a destructive test of a sample of the enclosure to be evaluated. The enclosure is filled with the particular gas for the atmosphere requested. i.e. If an enclosure is seeking to be rated for Group B a Group B gas must be used. The enclosure also will contain a spark producing (ignition source) device. The gas filled enclosure will be placed in a Westerbeke Chamber which is also filled with the test gas. A Westerbeke Chamber is a special test chamber that will withstand the explosive pressures that can potentially be involved if the test item fails. When the enclosures internal spark device ignites the gases inside, it must not ignite the same gas mixture inside the Westerbeke Chamber.

This test usually destroys the integrity of the enclosure being tested. The test must be repeated for each Group of gases for which Listing is sought.

5.1.2 Approval by AHJ

AHJ can evaluate the enclosure using the expertise it has available within its own jurisdiction and issue a document approving the specific enclosure for a specific application. The AHJ must have the expertise within its own ranks sufficient to evaluate and qualify a design. The AHJ has evaluated the SMMS neutron probe enclosure against the UL-1203 standard.

6.0 Design Hazardous Classification & Equipment of the SMMS

6.1 Deployment Device Upper Enclosure(s)

The enclosures were NEMA 4X rated prior to modification and installation on the top of the deployment device.

6.1.1 Winch Enclosure

The winch box space is considered a Class I, Division 1, Group B classified area, because the winch box is open to the waste tank which is also considered a Class I, Division 1, Group B classified area.

6.1.2 Electrical Enclosure

This box is considered a non-classified location. Although this box is immediately adjacent to the winch box, it is separated by a sealed metal barrier from the winch box. There are approximately 3 mechanical shafts and one electrical connector running from the winch box into the electrical enclosure box. All the mechanical shafts employ a double lipped seal, [similar to a wheel seal on a car axle] to externally seal leakage paths around the shaft. Two of the shafts are hollow, and serve as conduit passages for wiring. This hollowed area has been potted and sealed with ScotchCast Resin #8. The electrical connector uses a glass metal seal around the pins, and uses an external bulkhead type O-ring seal, so leakage through the connector is very minimal. In short, plausible leak paths from the winch box to the electrical enclosure box have engineered barriers to greatly minimize, if not entirely prevent, in leakage of gasses from the winch box space.

It should be noted that the winch box will never be at a higher pressure than the electrical box on ventilated tanks. On non-ventilated tanks, the winch box may, at most, be 0.1 inch of water higher pressure higher than the electrical enclosure. The acceptance test of the equipment required pressure and vacuum testing of the winch box and electrical enclosure box to confirm the seal integrity of the boxes.

If the device is left in a tank for extended time periods, it is suggested that the electrical and winch enclosures be checked for presence of combustible gasses prior to energization of electrical equipment.

6.2 Deployment Device Mast & Arm

All areas within and without the deployment mast and arm (the portion in the tank vapor space) are considered a Class I, Division 1, Group B classified area.

6.3 Neutron Probe

The area surrounding the neutron probe is considered a Class I, Division 1, Group B location.

6.4 Miscellaneous Equipment Adjacent to Deployment Device

This space is considered a non-classified location, once the deployment device is fully installed and the riser bolts have been torqued. Although this space is immediately adjacent to the winch box, it is separated by the sealed NEMA 4X winch box, sealed riser gaskets, and sealed decontamination equipment. Plausible leak paths from the tank space (riser, winch box, etc.) have engineered barriers to greatly minimize, if not entirely prevent, outward leakage of gasses.

It should be noted that the tank space will never be at a higher pressure than the atmospheric pressure on ventilated tanks. On non-ventilated tanks, the winch box pressure will fluctuate with changes in barometric pressure. Depending on the dynamics of barometric pressure swing, the winch box pressure may reach a higher pressure than the non-classified space surrounding the winch box. As noted above, the acceptance test of the equipment requires pressure and vacuum testing of the winch box to confirm the external seal integrity.

7.0 Equipment Compliance with Hazard Classification

7.1 Deployment Device Upper Enclosure(s)

7.1.1 Winch Enclosure

There are no electrical components besides cabling that passes through this space. All electrical cabling passing through this space is intrinsically safe. There had been a camera winch and associated wiring in this space as well, however the winch and cabling have been permanently removed. See Appendix A for confirmation of circuit intrinsic safety. (BUSSELL, TBD Action)

7.1.2 Electrical Enclosure

This box is considered a non-classified location. This box contains intrinsic safety barriers for the neutron probe and inclinometer. None of the electrical equipment in this box must comply with requirements of any classified location.

For information only, this box also contains a line driver board, electronic compass, circulation fan motor, and an open frame thermostat. Also, the box contains the thermostat switch and an abundance of wiring and terminal strips.

However, if the device is left in a tank for extended time periods, it is suggested that the electrical enclosure be checked for presence of combustible gasses prior to energization of electrical equipment.

7.2 Deployment Device Mast & Arm

There are no electrical components besides an inclinometer, inclinometer cabling, and neutron probe cabling that pass through this space. All electrical cabling passing through this space is intrinsically safe, again see Appendix A.

The inclinometer is a simple apparatus, containing a wire wound pot immersed in a silicon oil bath.

7.3 Neutron Probe

This device could not be made intrinsically safe, as it contains a high voltage neutron detector bias power supply (650 VDC -- current limited to less than 1 milliamp). However, the cabling to and from the neutron probe has been made intrinsically safe (meeting the intent of NEC Article 504). The intrinsic safety was obtained by placing FM approved intrinsic safety barriers on the probe inlet power wires, and also providing a custom isolation network within the probe itself to prevent backfed power in the event of a fault. See Appendix A for a more detailed discussion.

Therefore, the neutron probe system was encased in an explosion proof housing. The housing was not destructively tested, rather the design was extensively critiqued against UL-1203. The results of this critique is contained in Appendix C.

The neutron probe case (and connector) has been determined to meet the intent of UL-1203, based upon the evidence from Appendix C. The neutron probe case and connector are adequately designed as an explosion proof housing.

7.4 Miscellaneous Equipment Adjacent to Deployment Device

This space is considered a non-classified location, once the deployment device is fully installed and the riser bolts have been torqued. Electrical equipment in the immediate vicinity of a riser should not be energized until tank containment is reestablished/sealed.

For reference, SMMS equipment required in this space will include a headset intercom, and a video monitor.

8.0 References

1. SST Hazardous Classification document, Huckfeldt
2. SY-101 Haz. Class.Doc., Huckfeldt
3. Magison, Ernest C., "Electrical Instruments in Hazardous Locations," 3rd Edition, Instrument Society of America.
4. Engineering Work Plan for Surface Moisture Measurement (WHC-SD-WM-WP-300 Rev. 0)
5. Bossert, John A., "Hazardous Locations Guide for Design, Testing, Construction, and Installation of Equipment in Explosive Atmospheres," 1995, Canadian Standards Association.
6. ANSI/NFPA 70, "National Electrical Code - 1993"
7. ANSI/ISA-RP12.6-1987, "Installation of Intrinsically Safe Systems for Hazardous (Classified) Locations."
8. Class Number 3610, "Approval Standard - Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1 Hazardous (Classified) Locations", October 1988
9. ANSI/UL 1203-1988, "Standard for Explosion-Proof and Dust-Ignition-Proof Electrical Equipment for use in Hazardous (Classified) Locations."
10. SMMS Drawing Tree - H-14-100457

Appendix A: Bussell intrinsic safety circuit write up, inclinometer and probe wiring, barriers regarding neutron probe power in & zener diode network protected faulted power back from probe.

Appendix B: Bussell catalog cut sheets and test reports submitted to ETL, explosion proof thing, rest of ETL package

Appendix C: Study of Probe housing compliance to UL-1203

Appendix D: SAIC and PNL Explosion Pressure Calculations

Appendix E: SMMS Structural Evaluations for Normal Operating and Handling Conditions

A.1 Introduction

Figure A1 shows a block diagram of the SMMS and the demarcation between intrinsically safe portion of the system and the non-intrinsically safe portion of the system. The SMMS has two electrical components in a tank, the probe assembly and the inclinometer. The probe will be discussed below in detail. The inclinometer is a wire wound potentiometer and is immersed in silicon oil for dynamic response purposes. Therefore the inclinometer is a simple apparatus and is intrinsically safe with the appropriately chosen intrinsic safety barrier.

Intrinsic safety parameters were selected for the SMMS on the basis of their entity safety parameters. Entity safety parameters are those parameters that define the maximum open circuit voltage, maximum short circuit current, maximum allowed capacitance, and maximum allowed inductance in the intrinsically safe apparatus, e.g. the inclinometer. Manufacturers seek approval for their intrinsic safety barriers using entity approval concept. Listing by entity parameters allows interchangeability between manufacturers and permits intrinsically safe system to be easily qualified by verifying the correct relationship between entity safety parameters of an intrinsically safe apparatus and an intrinsic safety barrier. Figure A2 the relationship between entity safety parameters between the intrinsically safe apparatus, e.g. inclinometer, and the associated apparatus, i.e. intrinsic safety barrier and attached instrumentation. Tables A1 to A3 shows the figure safety parameters of the intrinsic safety barriers.

A.2 Inclinometer

The inclinometer is pendulum based inclinometer with potentiometer output. The potentiometer is a wire wound potentiometer and has an inductance of 75 to 80 microhenries (see attached inductance calculations). The inductance of wire wound is insignificant to inductance limits in the entity parameters of its intrinsic safety barrier, 47 millihenries. A piece of modified 0.187 diameter stainless steel well logging cable is used to connect the inclinometer to Elcon Instruments, Inc. model 1072 intrinsic safety barrier. [The outer cable jacket was removed to make 0.187 diameter stainless steel cable more flexible.] The stainless steel wrapped well logging cable was selected because of its abrasion resistance. A sealed jam-nut type bulkhead fitting is used to pass the cable through the bulkhead from the mechanical side of the enclosure to the electrical side of the enclosure.

A.3 SMMS Neutron Probe

The SMMS neutron probe consists of a probe housing containing four printed circuit boards and three boron-10 neutron detector tubes. Each of the four electronic boards are 2.875 inches in diameter and are described below in order as they are located the probe, bottom to top. The voltage supplied to the probe is provided through two intrinsically safe circuits. One intrinsically safe circuit provides 14 mA of current at 16 V for the high voltage power supply. The other intrinsically safe circuit provides 31 mA of current at 15 V for the probe amplifier power supplies.

Table A1
Entity Safety Parameters for Intrinsic Safety Barriers for Neutron Probe Power Supply
(High Voltage and Low Voltage)
Stahl 9351/10-14-10

V _{oc} Maximum Open Circuit Voltage from IS Barrier (V)	V _{max} Intrinsic- ally Safe Apparatus Maximum Allowed Voltage (V)	I _{sc} Maximum Short Circuit from IS Barrier (mA)	I _{max} Intrinsic- ally Safe Apparatus Maximum Allowed Current (mA)	C _a IS Barrier Maximum Allowed Circuit Capacitance (μF)	C _{total} Circuit Total Capacitance (μF)	C _{cable} Cable Capacitance (100 ft x 60 pF/ft) (μF)	C _i Intrinsic- ally Safe Apparatus Capacitance (μF)	L _a IS Barrier Maximum Allowed Circuit Inductance (mH)	L _{total} Circuit Total Inductance (mH)	L _c Cable Inductance (100 ft x 0.2 μH/ft) (mH)	L _i Intrinsic- ally Safe Apparatus Inductance (mH)
19	20	330	<330	0.24	<0.026	0.006	<0.02	0.18	0.02	0.02	0

Notes:

¹Inductance and capacitance per foot are assumed to be 60 pF/ft and 0.2 μH/ft.

²The effective inductance presented to the cable from probe is effectively zero because of the three series diodes in series in the isolation networks for the power supplied. No reverse current will flow through these diodes when the inductance in the probe current is interrupted.

Table A2
Entity Safety Parameters for Intrinsic Safety Barrier for Neutron Probe Pulse Output
Stahl 9002/77-150-300-00

C h a n n e l	V _{oc} Maxi- mum Open Circuit Volt- age from IS Barrier (V)	V _{max} Intrin- sically Safe Appa- ratus Maxi- mum Al- lowed Volt- age (V)	I _{sc} Maxi- mum Short Cir- cuit from IS Barri- er (mA)	I _{max} Intrin- sically Safe Appa- ratus Maxi- mum Allowed Current (mA)	C _a IS Barrier Maxi- mum Allowed Circuit Capaci- tance (μF)	C _{total} Circuit Total Capaci- tance (μF)	C _{cable} Cable Capaci- tance (100 ft x 60 pF/ft) (μF)	C _i Intrin- sically Safe Appa- ratus Capac- itance (μF)	L _a IS Barrier Maxi- mum Al- lowed Circuit Induc- tance (mH)	L _{total} Circuit Total Induc- tance (mH)	L _c Cable Induc- tance (100 ft x 0.2 μH/ft) (mH)	L _i Intrin- sically Safe Appa- ratus Induc- tance (mH)
I	14.5	13	138	< 290	0.85	< 0.016	0.006	< 0.01	1.6	0.02	0.02	0
II	14.5	13	138	< 290	0.85	< 0.016	0.006	< 0.01	1.6	0.02	0.02	0

Notes:

¹The intrinsic safety barrier is dual channel passive barrier. One channel is terminals 1 to 3 and the other channel is terminals 2 to 4.

²Inductance and capacitance per foot are assumed to be 60 pF/ft and 0.2 μH/ft.

Table A3
Entity Safety Parameters for Intrinsic Safety Barrier for Inclinometer
ELCON 1072

V_{oc} Maximum Open Circuit Voltage from IS Barrier (V)	V_{max} Intrin- sically Safe Appara- tus Maximum Al- lowed Voltage (V)	I_{sc} Maxi- mum Short Circuit from IS Barrier (mA)	I_{max} Intrin- sically Safe Appara- tus Maximum Al- lowed Current (mA)	C_a IS Barrier Maxi- mum Al- lowed Circuit Capaci- tance (μ F)	C_{total} Circuit Total Capaci- tance (μ F)	C_{cable} Cable Capaci- tance (100 ft x 60 pF/ft) (μ F)	C_i Intrin- sically Safe Appara- tus Capaci- tance (μ F)	L_a IS Barrier Maxi- mum Al- lowed Circuit Induc- tance (mH)	L_{total} Circuit Total Induc- tance (mH)	L_c Cable Induc- tance (100 ft x 0.2 μ H/ft) (mH)	L_i Intrin- sically Safe Appara- tus Induc- tance (mH)
13.1	Not Appli- cable	26	Not Appli- cable	1.1	0.07	< 0.06	< 0.01	47	< 0.03	0.02	< 0.01

Notes:

¹ Inductance and capacitance per foot are assumed to be 60 pF/ft and 0.2 μ H/ft.

A.3.2 Detector Tubes

The two sizes of boron-10 lined detectors tubes are used in the probe. The detectors are 0.5 inches in diameter and 2.5 and 2.75 inches long. The detector tubes are hermetically sealed and are filled with a fill gas consisting of Argon and Carbon Dioxide. A internal anode wire runs the length of detector tube and is electrically connected to an anode tube. The detectors in the SMMS probe are polarized with 650 VDC. The bottom detector assembly contains a solid state temperature sensor. The temperature sensor is molded plastic package and is embedded in an aluminum block. Wiring to temperature sensor is sleeved with heat shrink tubing to provide additional electrical insulation and to provide protection against abrasion resistance.

A.3.3 Preamplifier Board

The purpose of the preamplifier board is to convert the current pulses or charge pulses (5×10^{-13} coulombs per pulse) to a voltage signal. The preamplifier board has three charge sensitive amplifiers and three high voltage bias resistors, 10 Megohms, for the detectors. A dc blocking capacitor, 3 kV rating, isolates the front end of each charge amplifier from the detector bias voltage. All high voltage components are mounted on insulated terminals which have a voltage rating of 1500 V. Additionally the front end of the charge sensitive amplifiers is clamped to

ground with back-to-back diodes and a 1 kilohm resistor provides current limiting for the front end field effect transistor. Power is provided to this board from the low voltage power supply on high voltage/low voltage power supply board, via the line driver board. The preamplifier board has a solid internal ground plane. Figure A3 shows the schematic for the preamplifier board. The preamplifier board contains significant energy storage components in the form of high voltage capacitors, a 0.1 microfarad capacitor charged to 650 VDC. The discharge path for this capacitor is through the voltage regulator bleeder network on the high voltage/low voltage power supply board, 100 Megohms to ground. Thus the bleed off time constant is 10 seconds or about 60 seconds to discharge to 1% of initial value.

A 0.060-inch thick stainless steel plate is located between the preamplifier board and the line driver board. The primary purpose of this plate is to provide electrostatic shielding between the line driver output signals and the charge sensitive amplifier inputs. During prototype testing it was found that the output pulses from the line driver outputs were coupled into the charge sensitive amplifier inputs. The plate is grounded to the case of the probe through metallic contact through metal spacer and mounting screws. The pulse signal from each charge sensitive amplifier is connected to line driver board through RG-174 coaxial cable. The shields of the coaxial cables are terminated to ground on each board. These coaxial cables are well separated from high voltage terminals on the preamplifier board and the high voltage lead wire from the high voltage/low voltage power supply board. The dielectric in the RG-174 coaxial cable is rated for 1100 V.

Figure A1. SMMS Connection Diagram

Figure A2 Entity Safety Parameter Concepts

A.3.4 Line Driver Board

The purpose of the line driver board is to provide additional linear amplification for neutron detector counting pulses. The amplification stages combine the pulses from detectors 1 and 2 into positive and negative going pulses to permit transmission of linear pulses from the two detectors over one coaxial cable. Pulses from detector 3 are inverted and transmitted over on a second coaxial cable. In addition to amplification of the counting pulses, two temperature signals are combined with the counting pulses in the form of a DC voltage level that varies from 4 to 6 V above ground for a temperature range of -100 to +100 degrees Celsius. The output pulse amplitude of the two line driver amplifiers are set to 1.25 V (positive and negative going pulses) with a 5×10^{-13} coulomb charge input to charge amplifiers (100 mV through a 5 picofarad capacitor). Potentiometers are provided to adjust the pulse amplitude for each detector. The line driver board is powered from the 12 VDC power supply located on the high voltage/low voltage power supply. Figure A4 shows the the schematic for the line driver board. The second solid state temperature sensor is located on this board.

Two RG-174 coaxial cables connect the two counting signal outputs of the line driver board to isolation board. The cables is routed up through a slot in the high voltage/low voltage power supply board. High voltage components are well separated from these two cables by spacing and a grounded metal spacer.

A.3.5 High Voltage/Low Voltage Power Supply

This printed circuit board provides the 650 VDC bias voltage for the three neutron detectors and the 12 VDC power supply voltage for the electronic circuit boards. The high voltage is boosted from the 14 to 15 V provided to the high voltage power supply from the intrinsic safety barrier located at the top of the mast. A commercial DC-DC converter is used to convert a regulated DC voltage to a high voltage. The DC-DC converter is epoxy potted in a deep-drawn steel housing. A potentiometer mounted on this board to provide an adjustable range from 550 to 725 VDC. By changing a resistor (unsoldering and soldering required) the range of output of the high voltage supply can be varied from about 500 to 1500 VDC with approximately 200 V range of voltage adjustability. High voltage components are mounted on insulated terminals above the printed circuit board. The insulated terminals are rated for 1500 VDC. Figure A5 shows the circuit schematic of the high voltage/low voltage power supply board. High voltage silicone rubber insulated lead wire, rated for 5 kV, is used to connect the output of the high voltage power supply to the preamplifier board.

Like the preamplifier board, this board also contains significant energy storage components in the form of high voltage capacitors, a 0.1 microfarad capacitor and a 0.01 microfarad capacitor charged to 650 VDC. The discharge path for this capacitor is through the voltage regulator bleeder network on the high voltage/low voltage power supply board, 100 Megohms to common. Thus the bleed off time constant is 10 seconds or about 60 seconds to discharge to 1% of initial value. Load test on output of high voltage power supply show that the high high voltage power supply is current limited. The maximum steady short current obtained from the high voltage supply is about 600 microamperes while the intrinsic safety barrier provides 90 mA of current to the high voltage power supply.

The low voltage power supply, + 12 V, is also located on this printed circuit board. The circuit components are located on the bottom of printed circuit board along with the regulator for the high voltage power supply. The printed circuit board contains a ground plane in the center of board. The insulation of hook-up wire used to distribute the low voltage power to line driver board, and preamplifier board is rated for 600 V per Mil-W-16878E. This military standard requires high potential testing to 2,000 V. The wiring for the low power supply is very well separated from the high voltage lead wire to the preamplifier board. Power is provided to the high voltage/low voltage power supply from the isolation board via two twisted pairs. The twisted pairs are soldered in two sets of thru holes on the high voltage/low voltage power supply board from the high voltage components.

Figure A3 Preamplifier Schematic

NOTES:

1. J1, J2, J3 = TWO CIRCULAR PADS W/ .030" DIA PLATED THRU HOLES.
2. J4 = TWO CIRCULAR PADS W/ .040" DIA PLATED THRU HOLES.
3. PDI = CIRCULAR PAD W/ .030" DIA PLATED THRU HOLE.
4. MAINTAIN .050-.060" CLEARANCE BETWEEN PINS-1 AND OTHER FOILS.
5. WTG HOLES SHALL BE 10-32 CLEARANCE WITH .030" RELIEF ON GND AND POWER PLANES (THREE PLACES EACH PCB).

SAIC/NPD		
Title		
MOISTURE PROBE PREAMP SCHEMATIC		
Size	Document Number	REV
A	307113	A
Date:	January 17, 1996	Sheet 1 of 1

Figure A4 Line Driver Schematic

A.3.6 Isolation Board

The isolation board is located 1/2 inch above a 0.060-inch thick metal stainless steel plate. Another 0.060-inch thick stainless steel metal plate is located 1/2 inch above the isolation board. These two metal plates are grounded through the mounting screw and metal spacers to probe enclosure. Wiring from the probe electronics passes through a hole in the bottom plate and is soldered into four pairs of thru holes on the bottom side of the circuit board. Wiring to probe connector passes through two sets of holes in the top plate and is connected to probe connector. The metal plates have rubber grommets in the holes where wiring passes through. Four isolation networks are constructed on this printed circuit board. A solid copper ground plane surrounds each of the isolation networks on both sides of the printed circuit board.

A.3.6.1 High Voltage/Low Voltage Power Supply Input Power Isolation Network

The isolation board contains the isolation networks to limit the amount of energy that can flow into the coaxial cables and power supply cable if a fault takes place in the SMMS probe. The power supply isolation network consists of three series connected diodes and redundant voltage limiting 20 V 1-watt zener diodes. Each of the three series connected diodes has a peak inverse voltage of 1000 V. The basis for this protection scheme is to prevent current flow from probe back into cable and clamp the voltage with redundant zener diodes. These diodes effectively isolate the cable from any inductance in the probe by preventing current flow out of the probe. An additional feature of this configuration is reverse voltage protection of probe electronics. The maximum voltage that can be supplied from the Stahl 9351/10-14-10 barriers is 19 V. The zener diodes will not begin to conduct until the voltage at the probe connector reaches about 22 V because of voltage drops of three series connected diodes (0.6 to 0.8 V drop per diode)

A.3.6.2 Pulse Output Isolation Network

The output pulses from the line drivers are isolated from the cable with a 50 ohm 2-watt metal film resistors and two sets of 15 V zener diodes. The 50 ohm resistors were selected on the basis of an open circuit voltage 15 V. The ignition current for a resistive circuit with cadmium metals is 1 A. After derating by 2/3 (qualification by analysis derating factor) and 1/1.5 (energy derating factor), the current is 444 mA. The minimum resistance value then is 12 V/444 mA or 27 ohms. The value of 50 ohms was chosen because it matches the impedance of the line driver to the impedance of the coaxial cable. A metal film resistor was chosen for this application because of requirements of intrinsically safe apparatus approval standards such as FM Class 3610 [A2]. Metal film resistor have a high probability of failure in the most desirable mode, open circuit mode (95% fail in open circuit mode and 5% fail in short circuit mode) [A1]. Redundant 15 V 1-watt zener diodes were chosen to limit the voltage on both ends of the 50 ohm resistor to 15 V. The desirable failure mode for these zener diodes is to fail shorted. Zener diodes fail in the shorted mode half of the time, (50% fail open) [A1]. The probability that at least one of the one of two zener diodes will fail shorted is 0.75. It should be noted that the output of the low voltage power supply is 12 V. The voltage at this isolation network will only exceed 12 V when there is:

- (1) failure of low power supply - maximum voltage is limited by the intrinsic safety barrier 19 V open circuit; and

(2) a fault from the high voltage power supply to a circuit component - maximum voltage limited by 15 V zener diodes and other circuit components, capacitors (70% to 80% of time fail shorted), and integrated circuits [A1].

The largest peak current through the zener diodes on the cable side of 50 ohm resistor from the probe is about 100 mA. The current through these zener diodes will decay as the voltage as the power supply capacitors decay. This value is based upon 18 V being applied on probe side of the 50 ohm resistors. The zener diodes on the circuit side of the 50 ohm resistor were placed there to limit the voltage and absorb the initial voltage surge if the 650 V power supply should fault to the 12 V power supply. Faults from the intrinsic safety barriers, Stahl 9002/77-150-300-00 are limited to a short circuit current of 138 mA and a maximum open circuit voltage of 14.5 volts dless for voltage levels upto 250 VRMS applied on the non-intrinsically safe side of the barrier. The maximum voltage available on the non-intrinsically safe side of the barrier is 24 VDC. The zener diodes can tolerate this condition indefinitely with no damage.

A.3.6 Probe Connector

Two power supply pairs and two coaxial cables from the isolation board are connected to the cable head through a military cable connector. The dielectric rating of the connector is 1300 V. The two power supply pair have pin and socket inserts for each conductor and the coaxial cables have coaxial cable inserts.

A.3.7 Grounding and Bonding

The probe housing is bonded to the shield wires of the two shield wires of the two 18 AWG wires. The shield wires are bonded to the cap of the probe enclosure and to ground bus for the intrinsic safety barrier located in the mast head. The probe housing is not externally grounded other than these shield wires except through the contact through the arm during installation and during interim storage during the tank. When the probe is suspended in the head space of the tanks these ground wires provide only bonding path for the probe. The ground resistance through the waste in the bottom of the tanks can vary greatly from the megohm range to a few ohms depending on the moisture content of the waste. The resistance of the two shield wires is less than 2 ohms.

The probe cable jacket is a semiconductive plastic that will drain the electrostatic charge induced as a result of being rolled off of the winch, passing down through the mast, and rolling over the shoe assemblies at the end of the arm. The semiconductive plastic is LNP Engineering Plastics Stat-Kon-ME¹. The surface resistivity is 10^2 to 10^4 ohms/square and 10^3 to 10^4 ohms-cm.

¹LNP Engineering Plastics and Stat-Kon-ME are trademarks of LNP Engineering Plastics.

SAIC/MPD	
TI: SI	
MOD STURE PROBE INTRINSIC SAFETY COMPONENTS	
SI ze Document Number	REV
A	-
Date: 7/10/96	Sheet 1 of 1

Figure A6 Interface Board Schematic (located in mast assembly in non-classified location).

DESIGN CALCULATION

WHC-SD-WM-DA-202 REV 0

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ of _____ Appendix **A**
 (4) Building _____ (5) Rev. _____ (6) Job No. _____ Page **12** of **19**
 (7) Subject Inductance of Incl. nometer Potentiometer
 (8) Originator JH Russell JH Russell Date 5/1/96
 (9) Checker _____ Date _____

(10) Alternate Method of Calculating inductance of Incl. nometer:

From Gray, Frederick W. Inductance Calculations
 Working Formulas and Tables Special Edition, ISA,
 p 153

Equation 122a

$$L = 0.00254 F d_2 N^2$$

F = tabulated value
 in table 40

d_2 = coil diameter
 in inches

N = total number of
 turns

L = inductance in
 μ microhenries

$$\text{Length of coil} = 1100 \text{ Turns} \times 0.0007 \text{ in} = 0.770 \text{ in}$$

The diameter of coil is to the center line of the windings

$$\text{Diameter of mandrell} = 0.044 \text{ inches (copper)}$$

$$\text{Diameter of wire} = 0.0007 \text{ inches}$$

$$\text{Diameter of coil} = 0.0447 \text{ inches}$$

$$\text{To use table 40} \quad r = \frac{\text{diameter of coil}}{\text{length of coil}} = \frac{0.0447 \text{ in}}{0.770 \text{ in}}$$

$$= 0.05805$$

BEST AVAILABLE COPY

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ of _____
 (4) Building _____ (5) Rev. _____ (6) Job No. _____
 (7) Subject Inductance of Inclination Potentiometer
 (8) Originator JHBussell JH Russell Date 5/1/96
 (9) Checker _____ Date _____

(10)

$$L = \frac{(r N)^2}{9r + 10l}$$

$$= \frac{(r N)^2}{9r + 10Nd}$$

r = mean radius of coil in inches

l = length of coil in inches

Nd

d = wire diameter in inches

N = number of turns in coil

L = inductance in microhenries

Formula from

Wulsh, Ronald A. Electromechanical Design Handbook, 2nd Edition, McGraw-Hill, Inc. p 6021

Winding Data

Mandrell: 0.024 inch (copper)

Number of Turns: 1100 Turns

Wire Diameter 0.0007 inches

$$L = \frac{((0.0224)(1100 \text{ Turns}))^2}{9(0.0224 \text{ in}) + 10(1100 \text{ Turns})(0.0007)}$$

$$= \frac{607.1296}{0.2016 + 7.70}$$

$$= \underline{76.8 \text{ microhenries}}$$

BEST AVAILABLE COPY

DESIGN CALCULATION

WHC-SD-WM-DA-202 REV 0

Appendix 14

- (1) Drawing _____ (2) Doc. No. _____ (3) Page _____ of _____
 (4) Building _____ (5) Rev. _____ (6) Job No. _____
 (7) Subject Inductance of Inclincimeter potentiometer
 (8) Originator JH Russell JBR Date 5/1/96
 (9) Checker _____ Date _____

(10)

TABLE 40. DESIGN DATA. SINGLE-LAYER COILS

$$r = \frac{\text{diameter}}{\text{length}}$$

r	k	F	β	γ	r	k	F	β	γ
0	9.87	0	0	=	0.25	8.90	2.225	0.556	35.6
0.01	9.83	0.098	0.0010	983	.26	8.86	2.304	.599	34.1
.02	9.79	.196	.0039	489	.27	8.83	2.384	.644	32.7
.03	9.74	.292	.0088	325	.28	8.79	2.462	.689	31.4
.04	9.70	.388	.0155	243	.29	8.76	2.540	.736	30.2
.05	9.66	.483	.0242	193.2	.30	8.72	2.617	.785	29.1
.06	9.62	.577	.0346	160.3	.31	8.69	2.693	.835	28.0
.07	9.58	.671	.0470	136.9	.32	8.65	2.769	.886	27.0
.08	9.54	.763	.0611	119.2	.33	8.62	2.844	.939	26.1
.09	9.50	.855	.0770	105.6	.34	8.59	2.919	.993	25.2
0.10	9.46	0.946	0.0946	94.6	0.35	8.55	2.993	1.048	24.4
.11	9.42	1.037	.1140	85.7	.36	8.52	3.067	1.104	23.7
.12	9.38	1.126	.1351	78.2	.37	8.49	3.140	1.162	22.9
.13	9.35	1.215	.1580	71.9	.38	8.45	3.212	1.221	22.2
.14	9.31	1.303	.1825	66.5	.39	8.42	3.284	1.281	21.6
0.15	9.27	1.390	0.2086	61.8	0.40	8.39	3.355	1.342	20.97
.16	9.23	1.477	.2363	57.7	.41	8.36	3.426	1.404	20.38
.17	9.19	1.563	.2656	54.1	.42	8.32	3.496	1.468	19.82
.18	9.16	1.648	.2958	50.9	.43	8.29	3.565	1.533	19.28
.19	9.12	1.732	.3292	48.0	.44	8.26	3.634	1.599	18.77
0.20	9.08	1.816	0.363	45.4	0.45	8.23	3.703	1.666	18.29
.21	9.04	1.899	.399	43.1	.46	8.20	3.771	1.735	17.82
.22	9.01	1.982	.436	40.9	.47	8.17	3.838	1.804	17.37
.23	8.97	2.063	.475	39.0	.48	8.14	3.905	1.874	16.95
.24	8.94	2.144	.515	37.2	.49	8.10	3.972	1.946	16.54
0.25	8.90	2.225	0.556	35.6	0.50	8.07	4.037	2.019	16.15

Since the purpose of this calculation is to bound the inductance of the inclinometer

$$F = 0.577 \quad \text{for } r = 0.06$$

$$L = 0.00254 (0.577) (0.0447) (100 \text{ turns})^2$$

$$= \underline{79.3 \text{ micro henries}}$$

BEST AVAILABLE COPY

A.4 References

- A1 _____, "Electronic Reliability Data - A Guide to Selected Components," Institute of Electrical Engineers, 1981.
- A2 "Class Number 3610, Approval Standard - Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1 Hazardous (Classified) Locations", October 1988

Appendix B Bussell catalog cut sheets and test reports submitted to ETL,
explosion proof thing, rest of ETL package.

(LOCATED IN PROJECT FILES H5-09, 2920 GEO WASH WAY/55)

APPENDIX C

Comparison of Probe Housing to UL-1203

C.1 Probe Enclosure

The enclosure for the probe is constructed from 3-inch schedule 40 stainless steel pipe and machined bottom assembly. The machined bottom assembly and the 3-inch schedule 40 pipe are welded together using a full penetration welding process similar to the welding process used for high pressure piping. The welds were visually inspected and radiographed. Inspection records are available in the 306E work package, available from D.B. Graves. After the welding was completed the end of the probe was machined down at the bottom 4.23 inches from 0.21 to 0.13 inch sidewall thickness. The transition of between the thicker and thinner wall section is over a 1-inch of probe length (5° taper). Table C1 shows the surface and volume data for probe enclosure and table C2 shows a summary of construction requirements from UL-1203. The requirements in table 6.1 of UL-1203 is satisfied (0.067 inches thickness of sheet steel). The housing is designed for 500 psi pressure, five times the peak explosion pressure of hydrogen in a spherical chamber. Calculations performed by Pacific Northwest National Laboratory and SAIC indicate the maximum peak explosion pressure in the housing is about 440 psi Appendix D]. Structural analysis of the probe enclosure concludes that that design of enclosure is acceptable for the 500 psig pressure expected during worst case internal explosion. [Appendix E, page 5]

The cable strain relief and seal assembly is attached to the probe housing with a nut with two sets of 3.375-16 UNC-2B threads. The two sets of threads allow the cable strain relief and seal assembly to be installed without rotating it more than 1 turn (relative to the probe housing) while the nut is rotated more than 8 turns. The probe cable in the cable strain relief and seal assembly consist of three basic components; a compression cable strain relief nut at the top of the assembly, cap assembly, and cone shaped wedge. The outer jacket of the probe cable is removed exposing the Kevlar² fiber. After the cable has been threaded through the cap assembly, the cone shaped wedge is slid up under the Kevlar fiber in the tapered through hole in the cap assembly. When the cone shaped wedge is in the proper location, the through hole is filled with Emerson & Cummings Stycast 1266 epoxy. Pull tests performed on the cable assembly fabricated as described above have breaking strengths greater than 2600 pounds-force. (See pull test report in Appendix B).

More than 8 rotations are required to fully seat the nut. Thus the requirements defined in UL-1203 section 7.28 is satisfied. The clearance between the cable strain relief and seal and the probe housing is 0.002 to 0.003 inches. This clearance is not designed or intended to meet the requirements of UL-1203 in sections 7.25 to 7.34 (0.0015 inches clearance). Equilibrium and temperature tests indicate that the internal components of the housing will operate about 6° C above the ambient temperature. (The nominal power dissipation in the housing is 710 milliwatts.) Thus the maximum housing temperature will be less than 100° C when the probe is operated in a 90° C ambient temperature.

Table C1 Probe Housing Dimensional Data	
Internal Volume	180 cubic inches
Total Surface Area	220 square inches

²Kevlar is a trademark of E.I. deMours Dupont Corp.

Table C2 Summary of Explosion Proof Enclosure Design Requirements per UL-1203	
Section/Paragraph	Requirement
Table 4.1	Nema Type 7 enclosure
5	Material: Iron, steel, copper, cast brass, bronze, aluminum There are limitations on use copper and aluminum [see section 11.16 in UL-1203 for portable equipment which calls for bronze or brass]
6, Table 6.1	Minimum Thickness: 0.093 inches for maleable iron 0.125 inches for cast iron 0.067 inches for sheet steel
7.28	Joining Threads: (coarser than 20 threads/inch) Non tapered 8 fully engaged threads class 1 fit 7 fully engaged threads class 2 fit 6 fully engaged threads class 3 fit Tapered (use pipe threads although not specified) 5 full engaged threads
11.16	Portable equipment: Material specified for portable equipment is brass, bronze, or aluminum The basis for this to prevent sparking from striking (if this is an issue)
11.1 to 11.3	Conduit Threads: If a conduit fitting is used as part of the cable seal, e.g. close nipple, then the enclosure must be threaded for the proper size with 5 full threads of engagement. Provisions must also be made for a conduit stop or provide space for an insulating bushing.
11.24 -11.28	Packing Gland for cable seal
16	Hydrostatic Pressure Testing The explosion pressure for hydrogen is 102 PSI. Use a safety factor of 5. Apply 510 PSI water and verify that case does not rupture or distort. Test applied for 1 minute.

C.1.1 Impact Spark Resistance of Housing

The housing is fabricated from stainless steel. Stainless steel is one of the better impact spark resistant materials. Tests cited in the literature indicate that stainless steel is spark ignition is difficult to obtain austenitic stainless steel even when grinding specimens on grinding wheel [C2].

C.2 References

- C1 ANSI/UL-1203-1988, "Standard for Explosion-Proof and Dust-Ignition Proof Electrical Equipment for use in Hazardous Locations."
- C2 Letter, RN Johnson to RE Bauer, "Selection of Spark-Resistance Tube Material for Use in Tank 101-SY," Dated December 20, 1990.

Science Applications International Corporation
An Employee-Owned Company

April 9, 1996

Westinghouse Hanford Company
Richland, WA 99352
Attention: Mr. Jim Bussell

Subject: Overpressure calculations for SMMS probe body

Reference: Task #25, SW6-SWV-370248

Sir:

Attached are the overpressure calculations performed by Dr. Ali Dabiri. The maximum pressure expected from a hydrogen burn at 1 atm. is 440 psi. This is calculated for a Chapman-Jouguet detonation, Figure 7.9, from Shapiro, "Dynamics and Thermodynamics of Compressed Fluid Flow, Vol. 1".

Also attached is a letter from PNL, Mr. Perry Meyer, verifying that this is an upper limit number, with 370 psi being a lower bound value.

Sincerely Yours,

A handwritten signature in dark ink, appearing to read "Fred P. Johansen", is written over a horizontal line.

Fred P. Johansen, PE
Program Manager

Max Pressure from Hydrogen Ignition in SMMS Probe Body

$$T_1 = 520^\circ R = 61^\circ F$$

$$\Delta T_o / T_1 = 6 \quad \Delta T_o = 6 \times 520 = 3120^\circ R$$

$$= 2661^\circ F$$

$$= \underline{1460^\circ C}$$

$$\Delta T_o / T_1 = 7 \quad \Delta T_o =$$

$$= 3640^\circ F$$

$$= 3181^\circ C$$

$$= \underline{1749^\circ C}$$

For hydrogen $T_o = 2045^\circ C$

$$\Delta T_o = 2045 - 20 = 2025^\circ C = 3677^\circ F = 4136^\circ R$$

$$\frac{\Delta T_o}{T_1} = \frac{4136}{520} \approx 8$$

From Fig 7.9 of Shapiro Book [Dynamic & Thermodynamics
of Compressible Fluid Flow Vol. #1]

$$\frac{P_{o2}}{P_1} \approx 30$$

$$P_1 = 14.7 \text{ psi}$$

$$P_{o2} = 440 \text{ PSI}$$

of the mechanism by which a wave starting from rest ultimately reaches the stage of detonation.^{6,7} The enormous flame propagation speeds in a detonation wave are possible because the detonation is a combination of an adiabatic compression shock and a subsequent slow burning. The shock precedes the flame zone and raises the temperature and pressure of the unburned gas to such high values that the kinetics of the chemical reaction are augmented to the point where the flame zone propagates rapidly enough to keep pace with the shock front.

Fig. 7.9. Thermally-choked combustion waves ($M_2 = 1$), for $k = 1.4$. Solid curves show maximum flame speed M_1 for slow combustion, and minimum flame speed M_1 for detonation. The latter is the detonation Mach Number always observed in experiments. Dashed curve shows, for detonation with $M_2 = 1$, the stagnation pressure ratio for an observer at rest with respect to the unburned gas.

THE CHAPMAN-JOUQUET RULE. The observed fact that $M_2 = 1$ for a detonation wave is often called the *Rule of Chapman and Jouquet*. In order to find the corresponding detonation speed M_1 , we set $(T_0/T_0^*)_2$ equal to unity, and substitute for $(T_0/T_0^*)_1$ in Eq. 7.26 the value given by Eq. 7.16. Carrying out these operations, and simplifying, we obtain

$$\left(\frac{T_{02} - T_{01}}{T_1} \right)_{M_2=1} = \left(\frac{\Delta H}{c_p T_1} \right)_{M_2=1} = \frac{(1 - M_1^2)^2}{2(k+1)M_1^2} \quad (7.27)$$

The two values of M_1 which may be found from this equation correspond to the maximum flame-front speed for slow combustion and the

A-75

THE RECOVERY FACTOR

211

minimum speed for detonation. These speeds are plotted in Fig. 7.9 as a function of the energy parameter $\Delta H/C_p T_1$.

One measure of the potentialities for damage of a steady detonation wave is the rise in stagnation pressure experienced by an obstacle over which the wave passes. Denoting by p_{02} the stagnation pressure of the burned gas in a coordinate system where the unburned gas is at rest, it may be shown that

$$\left(\frac{p_{02}}{p_1}\right)_{M_1=1} = \frac{1 + kM_1^2}{k + 1} \left[1 + \frac{k-1}{2} \left(\frac{M_1^2 - 1}{1 + kM_1^2} \right)^2 \right]^{\frac{k}{k-1}} \quad (7.28)$$

This ratio is also plotted in Fig. 7.9 for a Chapman-Jouguet detonation. In the usual hydrocarbon detonation, T_1 is about 520°R, $\Delta T_0/T_1$ is about 6, and the speed of sound is about 1000 ft/sec. From Fig. 7.9 it may be seen that the flame-front speed is then about 5500 ft/sec and the stagnation pressure increases to about 25 atmospheres. The temperature after an adiabatic shock traveling at 5500 ft/sec is found from the adiabatic normal shock tables to be about 3000°F; thus, as indicated previously, there is considerable preheating effect available for increasing the flame speed to values necessary for detonation.

The temperatures in an atomic explosion are said to be measured in millions of degrees. If $\Delta T_0/T_1$ is assumed to equal 10⁴ for such an explosion, Fig. 7.9 indicates a wave speed of the order of magnitude of 200,000 ft/sec and a stagnation pressure of the order of magnitude of 40,000 atmospheres!

7.5. The Recovery Factor

When a fluid flows through a pipe having an insulated wall, the temperature at the wall (called the adiabatic wall temperature, T_{aw}) is neither the average stagnation temperature T_0 nor the average static temperature T of the stream. In a gas flow the adiabatic wall temperature usually lies between T and T_0 . The factors influencing T_{aw} and theoretical methods for predicting its value are discussed in detail in Volume II, Chapters 27, 28, and 29. For the present we shall introduce some elementary considerations and shall summarize some experimental results of value for practical computations of pipe flow.

Physical Mechanism of Frictional Heating. The temperature assumed by an insulated wall, past which flows a high-speed gas stream, is controlled by complex phenomena in the boundary layer. Fluid layers far from the wall deliver viscous shear work to layers near the wall. The consequent temperature rise of the inner layer is necessarily accompanied by heat conduction through the fluid away from the wall,

BEST AVAILABLE COPY

BattellePacific Northwest Laboratories
Battelle Boulevard
P.O. Box 999
Richland, Washington 99352
Telephone (509)

375-6694

September 5, 1995

Troy Stokes
WHC
PO Box 1970
MSIN H5-09
Richland, Washington 99352

Dear Troy:

Jim Fort and I have reviewed the hydrogen-air combustion calculation performed by A. Dabiri per your request. We found his calculated combustion pressure of 440 psi to be approximately the theoretical upper limit which is obtained by assuming stoichiometric detonation (~30% H₂ by volume). This represents the highest achievable pressure, and is, therefore, suitable for use as a conservative design pressure.

In addition to reviewing Dabiri's methodology, we performed two separate analyses to verify his result. The first of these utilized an undocumented educational software package which solves the theoretical equations to predict the detonation products. The program, EQLBRM, is an educational PC software written in 1988 by Prof. David Pratt of the University of Washington.

The second method was based on experimental results for H₂-air combustion. The data of Lewis & Friauf as reported in "Principles of Combustion" by K. K. Kuo, 1986, Wiley & Son's, page 260 was used, together with the theoretical equations, to determine the detonation stagnation pressure.

For both of the methods, different reactants and buffers were considered which correspond to various stoichiometries. Combustion pressures ranging from 370 - 410 psi were computed for stoichiometric conditions. The lower value is from software program and the upper value is based on the experimental data. The resulting pressure from rich or lean detonation is lower.

Please note that 440 psi is an extremely conservative value. If it is found to be difficult to design the canister to handle these pressures, lower, more realistic values could be provided since detonation is very unlikely (experimentally determined lower detonation limit is 18% H₂ by volume). More realistic pressures would be derived assuming adiabatic burning of pre-mixed H₂-air using realistic values for H₂ concentrations.

September 5, 1995
Page 2

Please let me know if you have any questions concerning our findings.

Sincerely,

A handwritten signature in dark ink, appearing to read 'P. Meyer', followed by a horizontal line.

Perry A. Meyer
Research Scientist

PAM/kr

cc: James M. Bates
James A. Fort
File/LB

Westinghouse Hanford Company

Appendix E
Page 1 of 32

From: Spent Nuclear Fuel Evaluations
Phone: 376-4193
Date: April 4, 1996
Subject: SMMS Structural Evaluation for Normal Operating and Handling Conditions

To: D. B. Graves L6-01

cc:	B. L. Coverdell	H5-57
	P. R. Deichelbolher	S7-12
	W. G. Farley	S7-71
	S. K. Farnsworth	H5-57
	C. E. Hanson *	H5-09
	L. S. Krogsrud	R3-08
	R. P. Omberg *	R3-85
	G. A. Ritter	H0-38
	T. I. Stokes	H5-09
	G. F. Vargo Jr.	H5-09
	SLH File/LB	

* without attachment

- References:
- (1) Memo, S. L. Hecht to D. B. Graves, "SMMS Structural Evaluation for Accident Conditions", November 28, 1995.
 - (2) T. I. Stokes, et al, Handout: 60% Design Briefing - Surface Moisture Measurement System (SMMS), October 4, 1995.
 - (3) Hanford Plant Standard - SDC-4.1, Standard Arch-Civil Design Criteria - Design Loads for Facilities, Rev 11, September 6, 1989.
 - (4) ASME BOILER & PRESSURE VESSEL CODE - SECTION III. Rules for Construction of NUCLEAR POWER PLANT COMPONENTS,
 - (5) Hanford Site Hoisting and Rigging Manual, RL-92-36, Rev. 0, 1992

The attached analysis addresses the structural integrity and related requirements of the Surface Moisture Measurement System (SMMS) deployment assembly and the Hanford Site high-level waste (HLW) tanks component(s) to which it interfaces with during normal operations and handling. Structural assessment for design basis accident conditions (with the exception of the postulated detector hydrogen explosion, which is addressed, herein) were previously provided in reference 1. In the evaluation of the SMMS for structural integrity, it is required that the calculated stresses/strains for normal conditions comply with required or industry standard limits and safety factors. Additionally, the calculated deformations are required to

D. B. Graves
April 4, 1996
Page 2

Appendix E
Page 2 of 32

be within limits as to meet functional requirements of the SMMS and tank systems. This should preclude any damage to the SMMS assembly and interfacing tank components. The results of the attached analysis show that the SMMS assembly and interfacing tank riser will maintain their structural integrity under the normal operating and handling conditions, addressed herein. A summary of these analyses, along with a discussion of loadings, assumptions and acceptance criteria, are given below.

DESIGN LOADINGS/EVENTS AND ASSUMPTIONS

The SMMS deployment device is classified as a Safety Class 3 component. The interfacing tank riser is classified as a Safety Class 2 component. The natural phenomena design loads, evaluated herein, for these Safety Class components is the 80 MPH wind loads (per HPS-SDC-4.1, Standard Arch-Civil Design Criteria; Design Loads for Facilities - Ref. 3). Normal loadings considered are operational, operational wind, and installation loads. Normal operation arm motion loads are conservatively address by considering a postulated off-normal accident condition the where the arm actuator cable system is overloaded (by roughly a factor of 10) to failure. Each of these loadings, with corresponding stresses and allowable limits, are addressed. The assembly is assumed to be at a uniform constant temperature, with the maximum expected temperature not exceeding 150 F. Analyses are based on description given in Reference 2 and Drawings H-14-100459, 100460, 100461.

ACCEPTANCE CRITERIA

Allowable values of calculated stresses and or strains used in the evaluation given herein are those given in the American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code - Section III; Nuclear Vessels⁽⁴⁾. Other criteria are utilized in cases where they are more appropriate than the ASME code. For example, for crane lifting, the criteria given in the Hanford Site Hoisting and Rigging Manual⁽⁵⁾ are employed. These are cited in the particular application. As ductile construction material are used in the design, and the loading is not cycled a significant number of times, peak stress and associated fatigue damage are not generally considered. Deformations are evaluated as to their impact on the functional requirements of the SMMS device and the tank riser system interface requirements. Material properties, upon which allowables are based, are taken as minimum values, unless certified material property data exist for the actual metal or component used. Generally, most components are constructed of 304 or 316 stainless steel (SS), unless otherwise specified.

LOADS, STRESSES AND DESIGN MARGINS (SUMMARY)

In the attachment, evaluations are made as to the loading, stresses and structural integrity of the SMMS deployment device under various loading conditions. Loads are calculated when necessary for respective conditions. Stresses are determined for the critical locations and are compared against allowable limits.

D. B. Graves
April 4, 1996
Page 3

Appendix E
Page 3 of 32

Normal Operation and Handling Conditions

These loading conditions include those which are expected and are designed to. These include normal operations and normal, expected, handling loads. Structural integrity evaluation for these conditions is per criteria given in ASME B&PV Section III, for Design Conditions, unless otherwise stated. The components are to remain intact and totally functional and continue normal operations after these loading conditions are experienced.

Wind Loading (see attachment pages 2-4)

The design wind load, for safety class 2 and 3 components are those loads associated with 80 and 70 mph winds^[3], respectively. The Tank Farms have placed 15 mph wind speed operating limits on crane lifts, so as crane lifts are not allowed during higher wind speeds. It is currently expected, that during SMMS operations, if higher than allowed wind speeds are expected, or experienced, the SMMS device will be lowered and positioned in a parked location. This parked position is expected to be approximately at the appropriate tank riser interface. Hence, two different design conditions were considered. These are: (1) a maximum 80 mph load in the parked position, and (2) an operating wind load, which can be at any crane controlled vertical location. This operating load is assumed to be twice, the crane operating limit (to account for gusts), or 30 mph.

80 mph wind at parked position

While the SMMS device need only be designed for a 70 mph wind (safety class 3), the analysis assumed a wind speed of 80 mph, as it is the required design conditions for the interfacing riser. Here it is conservatively assumed that the line from the crane does not provide any horizontal resistance.

The maximum (orientation dependent) wind load or drag on the enclosure box was calculated at 242 lbs. This produces a maximum bending stress on the SMMS mast (at the riser system interface) of 4,840 psi. This primary bending stress is well below the 30,000 psi ASME Section III allowable limit. For the riser, a maximum stress of 14,900 psi is predicted at tank dome interface. As the allowable stress limit for this condition is 24,000 psi, an acceptable condition exists.

30 mph wind at any operating position

The SMMS deployment device was assumed to be at the highest elevation which can transmit a bending moment to the riser system. Any horizontal constraint from the crane is conservatively neglected.

The maximum (orientation dependent) wind load or drag on the enclosure box was calculated at 34 lbs. This produces a maximum bending stress on the SMMS mast (at the riser system interface) of 8,600 psi. This primary bending stress is well below the 30,000 psi ASME Section III allowable limit. For the riser, a maximum stress of 4,940 psi is predicted at tank dome interface, well below the allowable stress limit of 24,000 psi.

D. B. Graves
April 4, 1996
Page 4

Appendix E
Page 4 of 22

Handling Loads - Horizontal-to-Vertical Lift (see attachment pgs. 5-10)

The SMMS deployment device is transported to and within the tank farm in a horizontal position. This relatively flexible 35-39 ft. long assembly is then lifted to a vertical orientation, so it can be lowered into the waste tank riser. To do this lift requires the use of one or more crane(s).

A finite element analysis (FEA) was used for the analysis of the main structure(s) for the proposed horizontal lift conditions. The FEA model, shown in figure 1 and 2 of the attachment, is comprised of beam elements. The pipe sections are modeled exactly for bending characteristics, whereas the control box regions were modeled primarily to represent the masses at these location only. Hence, stresses at these, non pipe, locations, are erroneous, as they are not expected to be significant. Pseudo areas and densities were used to account for the mass distributions. Loading was induced via gravitational body forces (1 g) and displacement boundary elements were applied to simulate lift conditions ($U_y = 0$).

Four different cases were considered. These were two different proposed lifting configurations for each geometric type, i.e., long and short. Lifting points are assumed to be at: 1) just above the slot on the mast, and 2) at the enclosure box. Two cases consider a lift from the lifting arms only, whereas, the other two cases assume an additional lift point at the enclosure box region, at the top of the box. Results of these analyses, showed that the maximum principal stress, σ_1 , or the absolute value of the minimum principal stress, $|\sigma_3|$, in the pipe was in the worst cases predicted at 13,850 psi (see fig. 2 in attachment). The allowable principal stress, per the rules given in the Hanford Site Hoisting and Rigging Manual⁽⁵⁾, is $S_u/3$. For the 304L SS pipe, with $S_u = 42.8$ ksi (from mat'l certs), the allowable principal stress is 14,270 psi. As the calculated stresses are less than the allowable value, the proposed lift scenarios are acceptable.

The crane attachment lifting arms were also evaluated. Maximum loads were assumed, i.e., no lift force at the top of the enclosure box. For the horizontal position, the predicted maximum principal stress on the lifting arm is 5,010 psi, well below the allowable limit of 10,000 psi. The attachment bolts have a predicted maximum shear stress of 17,160 psi. This too, is below the allowable shear stress of 20,000 psi for the high strength bolts. For the vertical lift position, the bolts are now in tension, and here $\sigma_1 = 13,100$ psi, considerably less than the 40,000 psi limit. For bending, the arm is in the weak direction (due to holes) and the predicted $\sigma_1 = 9,740$ psi, which is below the 10,000 psi limit.

Arm Actuation Loading (see pages 11-24 in attachment)

For normal operation, the loading, via cable force, is low (< 100 lbs) and not expected to be a problem. However, a potential conservative bounding accident conditions scenario is postulated. Here, upon an operator lifting the arm to the full up position, via cranking on cable winch, the torque limiter/winch system fails and allows the cable system to reach a load of 1100 lbs (for the current torque limit setting, the maximum cable force is less than 1030 lbs) and subsequently the cable is assumed to instantaneously go slack, which is highly unlikely, and allows the arm to fall. This

conservative assumption should more than qualify the system for normal operation, provided all components other than the cable shear pin remain intact. This accident is referred to in the report and attachment as either the "cable system accident" or "cable accident".

The full load conditions assumes failure (of the cable system), hence the evaluation is made to assure the failed SMMS device can be removed from the HLW tank, intact. Just prior to the postulated cable system failure, the maximum load is reacted by the component in the load path. The arm stop in the up-position reacts the load (via couple) so that the 1 inch 316SS axle develops an average shear stress (double shear) of 8,210 psi. The failure strength of the axle in shear is 15,000 psi. The bending moment developed at the arm elbow cause a bending stress in the mast pipe of 23,800 psi, which is below the minimum yield strength of the mast material (42.7 ksi). The cable lift arm on the SMMS arm assembly, in the maximum loaded up-position, will develop a maximum bending stress of 23,900 psi, an acceptable value considering a minimum yield strength of the 304SS material of 30,000 psi.

Once the cable system fails, the arm accelerates downward, due to gravitational potential energy (PE) and stored elastic strain energy in the deflected arm. This available potential energy of 5,600 in-lbs becomes kinetic energy (KE) and impacts the stop on the mast elbow joint. The calculations show that the mast will plastically deform and absorb the KE in plastic work (or strain energy), before the elbow stop system fails (.5 in dia pin shearing). This prediction included an elastic-plastic FEA on the lower mast system (see fig 5 in the attachment). Predictions showed that a permanent set of 0.7 inches, over the lower 57 inches of the mast, would be required to absorb the KE. The calculated plastic deformations occur in the upper 14 inches of the slotted section of the mast. Analysis shows that it would require up to approximately 200 lbs of additional withdrawal force to pull the 0.7 inch bent 3.5 inch mast through a 4 inch riser, which is doable. A maximum effective stress of 44,320 psi and corresponding equivalent plastic strain of 2.5% were predicted. The failure strain for this material is 46%, hence there is a large margin to failure.

Off-Normal Accident Conditions (Explosion within the Detector Housing) (see page 25 in attachment)

This postulated accident condition was not addressed in Reference 1, and hence is provided herein. It is postulated that a spark from the detector electrical system ignites entrapped hydrogen gas within the detector housing, causing a peak pressure of 510 psi. It is desirable to show that the housing will retain structural integrity, and hence the event will not propagate to the tank environment.

A maximum primary hoop stress of 6,510 psi was calculated to the thinnest cylindrical section. The bottom flat-head (1/8th inch plate) was calculated to have a maximum bending stress (based on fixed boundary conditions) of 57,300 psi. As the thickness of the cylindrical section is the same as the end-plate, the maximum discontinuity bending stress in the cylindrical tube should be slightly lower than that predicted for the flat-head. Since these stresses are lower than the minimum ultimate strength of 75,000 psi for the 302/304SS material, design is acceptable.

D. B. Graves
April 4, 1996
Page 6

Appendix E
Page 12 of 32

CONCLUSION

The SMMS deployment device and interfacing tank components were shown to be structurally acceptable for design loading (normal and anticipated) conditions. The minimum Safety Factor on allowable stress was determined to be 1.03 (Design Margin = 0.03 or 3% over designed). Calculated deformation were found to be acceptable, so as to assure that the SMMS deployment device will function as intended or can safely be removed from a tank.

Computer Runs

Input and output files of the SUN4 (SPARC) ALGOR FEA runs made for the SMMS analysis are stored on a compressed UNIX TAR file, smms.tar.Z. This file can be found on the Hanford Common File System (CFS), in directory /v92627/fem.

S. L. Hecht, Principal Engineer
Spent Nuclear Fuel Evaluations

Reviewed by:

B. L. Coverdell, Advanced Engineer
Analytical Services

Attachment

ANALYTICAL CALCULATIONS

Page 1 or 26

Subject SMMS STRUCTURAL ANALYSISOriginator S.L. HECHTDate 3/96Checker B.L. CorbettDate 4-5-96ATTACHMENTSMMS STRUCTURAL EVALUATION FOR NORMAL
OPERATING AND HAND LINE CONDITIONSCONTENTSPAGESWIND LOADING2-4HANDLING (LIFTING) LOADS5-10ARM ACTUATOR LOADING11-24DETECTOR HOUSING MOUNT25MATERIAL CERTIFICATION26

BEST AVAILABLE COPY

DESIGN CALCULATION

WHC-SD-WM-DA-202 REV 0

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ Appendix E
 (4) Building _____ (5) Rev. _____ (6) Job No. _____ Page 8 of 32
 (7) Subject SMMS
 (8) Originator S.L. HUNT [Signature] Date 3/96
 (9) Checker BIP Date 4-5-96

(10)

WIND LOADS

80 MPH in PAKAD POSITION (SAFETY CLASS 2)

$$D(\text{drag}) = C_D A_p V_f^2 / 2 \quad \text{on Box } 42" \times 41" \text{ cross section}$$

$$C_D = f(R_o)$$

$$R_o = V_f d / \nu$$

$$\nu = 0.000143 \text{ ft}^2/\text{sec}, \quad \rho = .00251 \text{ lb-sec}/\text{ft}^2$$

$$d = 42/12 = 3.5 \text{ FT}$$

$$V_f = (80 \text{ mi/hr}) (1.47/3600) (5280 \text{ ft/mi}) = 117 \text{ ft/sec}$$

$$R_o = (117)(3.5) / 0.000143 = 2.9 \times 10^5$$

$$L/d \approx 1, \quad C_d = 1.18 \text{ [1]}$$

$$A = (42)(41) / 144 = 11.96 \text{ FT}^2$$

$$D = (1.18)(11.96)(.00251)(117)^2 / 2 = 242 \text{ lbs.}$$

THE MAXI INTERACTS WITH THE FIRST "RIGID"
 RESTRAINT - i.e. THE TOP OF THE SPRAY RING WHICH
 IS APPROX 12" BELOW BOX. THE MAXIMUM MOMENT
 MAXI IS:

$$M = \left(\frac{42}{2} + 12 \right) (242) = 7,990 \text{ in-lb}$$

$$\sigma_b = \frac{Mc}{I} = \frac{(7,990)(1.75)}{2.37} = 7,840 \text{ psi}$$

$$\tau_a = P/A = \text{negligible}$$

$$\sigma_{\text{allow}} = 1.5 S_{ut} = (1.5)(20,000) = 30,000 \text{ psi}; \quad \text{o.k.}$$

1. HUGHES & BRIGHTON, THEORY & PROBLEMS OF FLUID DYNAMICS,
 STRAUM'S, 1967

2. ASME B19.1 Code Section III

BEST AVAILABLE COPY

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ Page 9 of 32
 (4) Building _____ (5) Rev. _____ (6) Job No. _____
 (7) Subject SHMS
 (8) Originator SLH SLH Date 3/96
 (9) Checker BIP Date 4-5-86

(10)

THE STRESS ON THE RISEN 4" SHP' 40 IS

ASSUME M_{MAX} AT SOIL-RISEN INTERFACE $d = 9\frac{1}{2}$ FT MAX

$$M_{MAX} = (242)(9.5)(12) = 27,600 \text{ IN-LB}$$

$$I_{RISEN} = \frac{\pi}{64} (D_o^4 - D_i^4) = \frac{\pi}{64} (4.5^4 - 4.026^4) = 7.23 \text{ IN}^4$$

$$\sigma_{MAX} = \frac{Mc}{I} = \frac{(27,600)(2.25)}{7.23} = 8,590 \text{ PSI}$$

CONSIDER MAX. MOMENT AT TANK-DOME RISEN INTERFACE (VERY CONSERVATIVE). THIS IS AT A ADDITIONAL 7 FT

BELOW GRADE (TOTAL 21 FT) HERE

$$M_{MAX} = (242)(21.5)(12) = 61,900 \text{ IN-LB}$$

$$\text{AND } \sigma_c = \frac{Mc}{I} = \frac{(61,900)(2.25)}{7.23} = 19,400 \text{ PSI}$$

ALLOWABLE PER ASME Sec III DIV I NB 2200

$$R_{SEAL} = D, \text{ ASTM A53 } R_{50} = 30 \text{ ksi}, S_u = 48 \text{ ksi} \quad [2]$$

$$S_m = 48,000 / 3 = 16,000$$

$$\text{ALLOW } (T_c + P_b) = (1.5)(S_m) = 24,000$$

$$(P_c + P_b)_{ALLOW} > \sigma_b \Rightarrow \text{DESIGN IS OK}$$

3. METAL'S HANDBOOK, Vol 1 9th ed. ASM 1975

BEST AVAILABLE COPY

(1) Drawing _____ (2) Doc. No. _____ (3) Page _____ Appendix E
 (4) Building _____ (5) Rev. _____ (6) Job No. _____ Page 12 of 22
 (7) Subject SHMS
 (8) Originator SLH MM Date 3/76
 (9) Checker SLC Date 4-5-96

(10)

CONSIDER MAX OPERATING WIND $\approx$ 2×15 MPH = 30 MPH.

$$\text{Here } R_e = (30/80)(2.9 \times 10^5) = 1.09 \times 10^5$$

$$C_d \text{ same as before} = 1.18$$

$$\text{Then } D = (30/80)^2 (242) = 34.16 \quad (14\%)$$

AS THE SHMS DEVICES IS INSTALLED/REMOVED, CONSERVATIVELY

CONSIDER NO HORIZONTAL SUPPORT FROM THE CRANE.

FOR THE MAX. MOM. THE MAXIMUM DISTANCE (MOMENT ARM)

$$\text{IS } 38 \text{ in} + \text{length of moment arm} = 380 \text{ in}$$

$$M_{\text{MAX}} = -F_d L = (34)(380) = 12,920 \text{ in-lb}$$

$$S_{\text{MAX}} = \frac{M_L}{I} = \frac{12,920(1.75)}{2.89} = 7,820$$

AT THE SLOT REGION THIS CAN INCREASE BY $\approx 10\%$

TO 8,600 PSI.

$$\text{THE ALLOWABLE} = 1.5 S_u = (1.5)(20,000) = 30,000$$

DESIGN IS OK.

ON RISE!

$$\text{MAX. MOMENT ARM} = 347 + \left(\frac{-346.77}{12} \right) = 467 \text{ in}$$

$$M_{\text{MAX}} = (34)(467) = 15,880 \text{ in-lb}$$

THIS IS CONSIDERABLY LESS THAN THE 17,900 in-lb

MOMENT EVALUATED FOR THE 80 MPH. DESIGN IS OK.

$$\left(S = \frac{15,880}{47,900} \right) (17,900) = 7,940$$

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E

Page 11 of 32

Page 5 or 20

Subject SMMSOriginator SLHDate 3/96Checker BJPDate 4-5-96LIFTING LOADS

CONSIDER BOTH HORIZONTAL AND VERTICAL POSITIONS DURING CRANE LIFT

HORIZONTALOVERALL SMMS DEVIATION RESPONSE VIA FEA
OTHER COMMENTS = LIFT ARMS (PGS 5-9.)VERTICALALL FEAS AT LIFT ARMS
(PGS 9-10)FEAALGOR⁴⁵ FEM (See Figures 1 & 2)

BEAM ELEMENTS

Pseudo Density & Mass Props (4) Box Weight

(16) Simply Support

CONSIDER STANDARD AND EXTENDED LENGTH
TWO LIFT CONDITIONS AT BOX (See below)

CASES AND RESULTS

<u>Geom & Loading</u>		<u>Max. disp. (in)</u>	<u>Stress (psi)</u>
1.A	SHORT { 3 POINT LIFT	2.32	10,740
1.B	{ 2 POINT LIFT	3.84	13,850
2.A	LONG { 3 POINT LIFT	2.43	10,740
2.B	{ 2 POINT LIFT	4.17	13,850

BEST AVAILABLE COPY

BD-6400-060.1 (07/93)

ANALYTICAL CALCULATIONS

Page 6 of 25

Subject SMMSOriginator SLH MMDate 2/96Checker BJRDate 4-5-96

$$\text{ALLOWANCE} = S_y / 3$$

$$S_y = 42,700 \text{ (CENT'S)}$$

$$S_{all} = 42,700 / 3 = 14,270 \rightarrow \text{OK}$$

RESULTS FOR CASE 1B IS SHOWN IN
FIG. 2.

A. S.L. HECHT, ALGOR COMPUTER CODE QA, WHC-SD-EN-CSWD-321,
AUG. 1991

B. ALGOR LINEAR STRESS & VIBRATION ANALYSIS PROCEDURE, REF.
MANUAL, JULY 1992 ALGOR INC. PITTSBURGH, PA.

BEST AVAILABLE COPY

75 -rw-r--r-- 1 root

75948 Jul 14 1994 libM77.so.2.0

ALGOR-V
STRESS-01
disp Opt

Hidden 1
Light
*Post

Aux post
General
lgnd boX
*Smoothed
Max abs

Bitmap
Do dither

[Esc]

Beam-Truss

13848.5
12694.5
11540.4
10386.4
9232.37
8078.33
6924.28
5770.23
4616.18
3462.14
2308.09
1154.04
2.3e-10

BEAM-TRUSS ANALYSIS DEVICE - 1 G HORIZONTAL TEST
1.00E+00 1.00E+00 1.00E+00

FIGURE 2

Help 2Undo
3Inp 4Snap
5Cur 6Swic
7Big 8Menu
9Top 0Draw

Dither method = Beam: Worst (Stress)
Display Max=2.32831e-10, Min=13848.6

[Auto range] [No frills]

File: lift_horz S=M LC 1/ 1 Vu= 1 X=-4.4295 Y=52.8920 Z= 0.0000

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E

Page 15 of 32

Page 9

Subject SMM'SOriginator SLHDate 3/96Checker BLEDate 4-5-96CHECK LIFTING ARMS.

IN VERTICAL
 ASSUME TOTAL WT TAKEN BY ARMS (2), SO THAT EACH
 ARM SKE $1150/2 = 575$ LBS, FOR HORIZONTAL USE
 WT FROM FEA $= 920/2 = 460$ LBS
 CONSIDER THE LONGER OF THE TWO

HORIZONTAL POSITION

$$\frac{1}{2} L^3 \Rightarrow S = \frac{Q_0 - Q_1}{6}$$

$$S = \frac{2^3 - 11.5^3}{6} = 0.771 \text{ in}^3$$

$$\sum M_A = 0 \quad (3) \quad F_B = 460 \quad (11.4)$$

$$F_B = 21,750$$

$$\sum F_y = 0 \quad F_A = -1750 + 460 = -1,290$$

$$M_{\text{MAX}} = (3.9)(460) = 3,860 \text{ in-lb}$$

$$S = M/S = 5,010 \text{ psi}$$

$$\frac{S_y}{3} = \frac{50,000}{3} = 10,000 \text{ OK}$$

BOLT ARE $7/16 = 20 \text{ UNC} : A_{ST} = 0.193 \text{ IN}^2$ GR 88, $S_y = 120 \text{ KSI}$

$$A_c = \frac{\pi}{4} (1.3602)^2 = 0.192 \quad T = \frac{F_B}{A_c} = \frac{1,750}{0.192} = 17,160 \text{ psi}$$

$$T_{\text{ALLOWABLE}} = (S_y/2)/3 = (120,000/2)/3 = 20,000 \text{ psi}$$

$T_{\text{ALL}} > T \Rightarrow$ design is OK

VERTICAL POSITION - FULL WEIGHT

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E
Page 16 of 32

Page 16 of 32

Subject CMRIS
 Originator SLH MP Date 3/96
 Checker BEP Date 4-5-96

$$\sum M_A = 0: 4.84 F_B + 1.84 = (575)(13.2)$$

Assume 3rd IL RIGID:

$$F_B = \frac{4.84}{1.84} F_B$$

$$\text{So Tan } 1.84 F_B + \left(\frac{4.84}{1.84}\right)(4.84) F_B = 7,590$$

$$F_B = 520.9, F_C = \left(\frac{4.84}{1.84}\right)(520.9) = 1,390$$

$$\sum F_y = 0: F_A = 575 - 520.9 - 1390 = -1,385$$

$$\text{Axial Load on Bolt } A_T = 0.1063 \text{ N}^2$$

$$\sigma = \frac{1,390}{11063} = 13,100 \text{ psi}$$

$$S_{ALL} = S_y/3 = 120,000/3 = 40,000 \text{ psi} \quad S_{ALL} > \sigma \rightarrow \text{OK}$$

Max. Moment on BAK

$$= (575)(8.4) = 4,830 \text{ in-lb}$$

At point of max. moment on there is a hole 1 ARM. TOPS
REQUIRE S, I

$$S_{required} \text{ by } \frac{M}{S} = \frac{(937.45)(.25)(1.125)}{1} = 275$$

$$S = S_{Bolt} = S_{Holes} = 7.7 - 275 = 496$$

$$G_M = M/S = 4,830/496 = 9,740 \text{ psi}$$

$$\text{ALLOWABLE} = S_y/3 = 100,000 \rightarrow \text{OK}$$

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Page 12 of 25

Subject SMMSOriginator SLHDate 3/96Checker BZEDate 4-5-96

at A $F_x^a = F_c \cos(\theta + \phi) = 1100 \cos(57 + 20) = -247.16$
 $F_y^a = 1100 \sin(77) = -1070.16$

at B $F_x^b = W \sin \phi = 96 \sin(20) = -32.716$
 $F_y^b = -96 \cos(20) = -90.16$

at C F_x^c only

$$F_x^c = W_p / \sin 20 = 28 / \sin(20) = -82.16$$

Reaction at Pivot "O"

$$F_{x_0} = 247 + 32.7 + 82 = +362.16$$

$$F_{y_0} = -1070 + 90 = -980.16$$

$$M_o = (-1070)(33) + 90(40) = -31,700 \text{ w-lb}$$

couple length $d =$

$$d = \sqrt{1.72^2 + 2^2} = 2.66$$

$$F = (31,700) / 2.66 = 11,900$$

$$F_{\text{in lb couple}} = F = W/d = 31,700 / 2.66 = 11,900.16$$

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Page 13 of 25

Subject SMH
 Originator SLH APR Date 3/76
 Checker RJP Date 4-5-96

MOMENT ON MOUNT PIPE (sat, $S_y = 42.7 \text{ ksi}$)

$$I = (2.89)(.9) = 2.6 \quad (\text{see pg.})$$

$$\sigma_c = \frac{Mc}{I} = \frac{(31,700)(1.95)}{2.6} = 23,800 < S_y \quad \text{OK}$$

CABLE LIFE AER SYSTEM

$$M_{MAX} = (1100)(1.25 - 1.625) = 3,490 \text{ in-lb}$$

$$S = \frac{bh^2}{6} = \frac{(1.6)(1.2)^3}{6} = .144 \text{ in}^3$$

$$\sigma = M/S = 23,900 < S_y_{min} (30,000) = \text{OK}$$

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E

Page 20 of 32

Page 1

Subject SMMS
 Originator SLH AKK Date 3/96
 Checker KLP Date 4-5-96

SHOCK IS AXIAL
 CONSERVATIVE ASSUMED ALL F_x, F_y REACTIVE AT 1" PIN

 $F_{max} = \sqrt{(11,700 + 980)^2 + 360^2} = 12,900 \text{ lbs}$
 $\therefore 1" \text{ PIN in double shear}$

$$\tau_{avg} = \frac{F}{A} = \frac{12,900}{(2)(\pi/4)(1)^2} = 8,120 \text{ psi}$$

$$S_{ys} = \frac{1}{2} S_y = 15,000 \text{ psi for 316 SS at RT}$$

$$\therefore S_{ys} > \tau_{avg} \rightarrow \text{OK}$$

CASE B

ASSUME THE CABLE FAILS AND THE ARM IS
 RELEASED AND FAIL TO REACT AT THE ELBOW STOP.

USE ENERGY METHODS:

PE BEFORE CABLE FAILURE =

due to gravity = height

$$PE = WH$$

weight concentrated at c.g. at 40"

$$h = 40(1 + \sin 20) = 53.7 \text{ in}$$

$$PE_g = WH = (96)(53.7) = 5,150 \text{ in-lbs}$$

due to elastic energy stored in deflected arm

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E
Page 21 of 32

Page 15

Subject SMMLOriginator SLHDate 3/96Checker BLEDate 4-5-96 $P_{Le} = W = \int F \cdot ds$: elastic system - linear

$$\therefore W = F S_{max} / 2; S = F/k, \therefore W = F^2 / 2k$$

CANTILEVER BEAM

$$k = \frac{3EI}{L^3}; I = \frac{\pi}{64} (d_o^4 - d_i^4) = \frac{\pi}{64} (3.5^4 - 3.09^4) = 2.89 \text{ in}^4$$

$$k = (3)(30 \times 10^6)(2.89) / 33^3 = 7240 \text{ lb/in}$$

From previous $F = F_g = 1070$

$$P_{Le} = F^2 / 2k = (1070)^2 / (2)(7240) = 80 \text{ in-lb}$$

ADDITIONALLY BENDING OF THE MAST FROM THE
TRANSMITTED MOMENT ALSO ADD. TO ELASTIC
SPRING BACK - WEIRPANG OF THE ARM

HERE ASSUME MINIMUM ^{EFFECTIVE} MAST LENGTH (BELOW RISER)
WHICH IS CONSISTENT WITH CONSERVATIVE TREATMENT

(SEE PG.)

$$\text{HERE } \theta = \frac{M_o L}{EI} = \frac{(31,700)(57)}{(20 \times 10^6)(2.89)} = 2.09 \times 10^{-2}$$

$$\delta_y = L\theta$$

$$\text{and } P_{E2} = F \delta_y / 2 = F L \theta / 2$$

$$= (1070)(33)(2.09 \times 10^{-2}) / 2 = 368 \text{ in-lb}$$

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E
Page 22 of 32

Page 16

Subject SMANOriginator SLHDate 3/96Checker BLEDate 4-5-96

$$PE_{TOTAL} = PE_{grav} + PE_{e_1} + PE_{e_2}$$

$$= 5,150 + 80 + 370 = 5,600 \quad 12-16$$

THE POTENTIAL ENERGY IS THEN CONVERTED INTO KINETIC ENERGY (KE) AND IS REACTED BY THE AVIATOR STOP SYSTEM. IN OCCUPYING A SECTION OF THE WINGS (CONSIDERATIVELY ASSUMED SHORTLY 4.00M) THIS ELASTIC REACTION CAN BE DETERMINED

By

$$F = \sqrt{2(KE)K}$$

where F is the force at the CG acting to the arm

$$K \text{ at CG is } K = \frac{3EI}{L^3} = \frac{(3)(20 \times 10^5)(2.89)}{(40.75)^3} = 285 \quad 15-16$$

(CORRELATION MUST BE SLIGHTLY LESS)

$$\therefore F = \sqrt{(2)(5,600)(285)} = 1,790 \quad 15-16$$

THE MOMENT AT THE BLBOW IS:

$$M_0 = (1,790)(40) = 7.16 \times 10^4 \quad 12-15$$

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E

Page 22 of 32

Page 1

Subject SIMMSOriginator SLHDate 3/96Checker RIPDate 4-5-96

THIS IS REACTED BY A COUPLE OF AXIAL-STOP PIN

$$d = \sqrt{32.722} = 3.19 \text{ in}$$

$$F = M/d = 22,800$$

THE STOP PIN (1/2 IN - 316 AL) IS THE WEAK LINK

$$A_{\text{pin}} (\text{double stem}) = 2 \frac{\pi}{4} (.5)^2 = .393$$

ASSUMING A AVAILABLE $S_u = 85 \text{ KSI}$, AND TRESCA FAILURE CRITERIA, THE PIN WILL FAIL AT A F. FORCE OF

$$F_{\text{fail}} = a S_u / 2 = (.393)(85,000)/2 = 16,700 \text{ IN-LBS}$$

THE PIN WILL SHEAR, HOWEVER, LOADING, AND ENERGY WILL BE TRANSMITTED TO THE MALT

$$\text{Hence } F_{\text{max}} = \frac{(16,700)(1,790)}{22,800} = 1,260 \text{ LBS}$$

THE MAXIMUM MOMENT AT THE RISER INTERFACE IS

$$M_{\text{max}} = F L = (1,260)(40.57) = 122,000 \text{ IN-LBS}$$

THE MAX BENDING STRESS (S_b) AT THIS LOCATION IS

$$S_b = \frac{M c}{I} = \frac{(122,000)(1.75)}{2.89} = 74,000 \text{ PSI}$$

$$S_b > S_y (42.7 \text{ KSI})$$

$\therefore$ The malt will plastically deform.

BEFORE PIN SHEARS -

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E

Page 24 of 32

Page 10 of 25

Subject SMMSOriginator SCHDate 3/76Checker TSJPDate 4-5-76

EVEN IF THE PIN FAILED (WHICH IS SHOWN NOT TO HAPPEN) THE ENERGY GOING INTO THE MAST - AND A UPPER-BOUND FOR PLASTIC DEFORMATION CALC. IS

$$E = \left(\frac{16,700}{21,800} \right)^2 (5,600) = 3,018 \text{ IN-IBS}$$

A FINITE ELEMENT ANALYSIS (FEM) DUE TO DETERMINE THE RESPONSE TO THIS CONDITION.

CRITICAL IS THE AMOUNT OF ENERGY FOR THE MAST, SO AS TO DETERMINE IF IT CAN BE WITHDRAWN FROM THE TANK.

THE FINITE ELEMENT MODEL (FEM) ANALYZES A 1/2 SECTION OF SYMMETRY OF THE LOWER ST. MCHS OF THE MAST. THIS INCLUDES THE 1/2 INCH SLIT RUNNING ALL BUT THE BOTTOM INCH. THE MODEL IS SHOWN IN FIGURE [1]. THE FEM USES THE ABAQUS ABAQUS PROGRAM AND USES 3D SHELL WITH 4 NODE AND DENSITY 252 X 2 INTEGRATION.

VAR-MECS WITH 81-LINER STRESS-STRAIN ELASTO-PLASTIC MATERIAL MODEL WAS USED, WITH $S_y = 42,700 \text{ PSI}$, $E_y = 98 \times 10^3 \text{ PSI}$ (VANDERGRAD), $\nu = 0.3$ (VANDERGRAD), $\sigma_u = 150,000 \text{ PSI}$ (VANDERGRAD), $\sigma_{u, \text{max}} = 150,000 \text{ PSI}$ (VANDERGRAD), $E_t = 98 \times 10^3 \text{ PSI}$ (VANDERGRAD), $\sigma_{u, \text{max}} = 150,000 \text{ PSI}$ (VANDERGRAD), $\sigma_{u, \text{max}} = 150,000 \text{ PSI}$ (VANDERGRAD).

LOADING WAS APPLIED AS NODAL FORCES TO GIVE THE SHEAR AND MOMENT AT THE BEAM JOINT. LOADS WERE TAKEN SO AS THE FIRST STEP IS JUST A YIELD AND SUBSEQUENT STEPS WERE IN 2.5% INCREMENTS OF THE LOAD TO FIRST YIELD.

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E

Page 25 of 22

Subject S MMSOriginator SLHDate 3/96Checker BEPDate 4-5-96

RESULTS ARE SHOWN IN FIGURES 3 & 5.
 FIGURE 3 GIVES THE RELATIONSHIP BETWEEN THE
 APPLIED LOAD AND THE PLASTIC STRAIN ENERGY IN
 THE PIPE. THE LOAD IS SHOWN AS A PERCENT
 OF THE FULL LOAD CALCULATED ON A ELASTIC BASIS,
 (E.), $P_H = 1,793 \text{ F-16 in } M = 7.16 \times 10^4 \text{ in-16 } \& H_0$
 ELBOW. AS ALGOR DOES NOT DIRECTLY
 CALCULATE THE PLASTIC STRAIN ENERGY, THIS
 WAS DONE BY HAND BY SUMMING THE ENERGY
 IN ELEMENTS IN WHICH PLASTIC STRAIN WERE
 CALCULATED, (E.)

$$E_p = \sum_{i=1}^n \left(\frac{\sigma_i - \sigma_y}{2} \right) (E_o^i) (V_i); \text{ where } V_i \text{ is the volume of the element}$$

THE ONSET OF PLASTIC DEFORMATION OCCURS AT
 25% OF THE LOAD. THE TOTAL AVAILABLE

ENERGY (KE-INCH) WAS PREVIOUSLY DETERMINED
 TO BE 5,600 IN-16. AT THIS VALUE,

THE CORRESPONDING LOAD IS 32% OF THE
 MAXIMUM OF $M = 2.69 \times 10^4 \text{ in-16}$, $F = 1,793 \text{ lbs}$.
 THIS IS AT A VALUE WHICH IS BELOW THE
 STRENGTH OF THE 1/2 INCH PIN.

THE ENERGY WILL GO INTO PLASTICALLY DEFORMING
 THE MASS.

6. ALGOR ACCURACY REFERENCE MANUAL, ALGOR INC., PITTSBURGH
 1987.

BEST AVAILABLE COPY

FIGURE 4

PLASTIC DEFORMATION - SMMS CABLE ACCIDENT

◆ ALEOR-V
STRESS-DI
disp Opt

Hidden I
Light
*Post

Aux post
General
Iynd box
*Smoothed
Max obs

Bitmap
Do dither

[Esc]

SMMS CABLE ACCIDENT - LOWER MAST SECTION
MAXIMUM LOAD AT 6600 IN-LBS PLASTIC STRAIN ENERGY

(DEFORMED SHAPE FACTOR = 100)

Von Mises

	44371.3
	40862.7
	37834.1
	33815.5
	30297.0
	26778.4
	23259.8
	19741.3
	16222.7
	12704.1
	9185.57
	5667.00
	2148.43

FIGURE 5

1Help 2Undo
3Inp 4Snap
5Cur 6Swic
7Big 8Menu
9Top 0Draw

Dither method = Von Mises [Stress]

Min=2148.43, Max=44371.3

[Auto range] [No frills]

File:smst_pl2 S=N 26/ 51 Vu=U7 X=-25.477 Y=-26.845 Z=17.6615

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E

Page 29 of 32

Subject EMMSOriginator SLHDate 3/96Checker BJPDate 4-5-96

FIGURE 4, GIVE THE RELATIONSHIP BETWEEN, ϵ_p and PERMANENT DEFORMATION (S) AT THE END OF THE MAST. FOR $\epsilon_r = 5600$ IN-15,

$\delta_p = 0.7$ INCHES. AS MOST OF THE PLASTIC DEFORMATION OCCURS WITH THE TOP OF MAST (SEE FIG.)

(E, 10 INCHES TO 14 INCHES ON SLOT SIDE. CONSIDER A "POG-LRG KINK", SO THAT THE ANGLE OF THE BEND (AT 57") IS

$$\theta = \sin^{-1}\left(\frac{0.7}{57}\right) = 0.70^\circ$$

THE DIAMETRIC CLEARANCE BETWEEN THE MAST (35.00") AND THE 4" RISER ($D = 4.024$)

IS .526 INCHES, LESS THAN THE 0.70 NO. INTERFERENCE IS THAN .017 INCHES

CONSIDER THE LONGEST RISER 19 FT

$$F = \frac{W}{L} \cdot \frac{F_s}{\sqrt{1 + \frac{W^2}{L^2}}} \quad I = 2.89$$

$$A = 2.23 \times 10^{-4}$$

$$F = \frac{27EI \cdot L \cdot \delta}{4b(a+2b)\sqrt{3a(a+2b)}} = 91.165$$

ASSUMING A COEFFICIENT OF FRICTION OF 1

$$F_{\text{pull}} = (1)(91) = 91.16 \neq \text{negligible to weight}$$

T. R. J. ROARK "FORMULAS FOR STRESS + STRAIN", 4th ED, TABLE III, CASE 2

BEST AVAILABLE COPY
BD-6400-060, 10/7/93

ANALYTICAL CALCULATIONS

Appendix E

Page 2 Page 22 of 32

Subject SMMSOriginator SCHDate 3/96Checker BLPDate 4-5-96

Consider Shorter Riser: $Q = 2$ in. diam. section
 $= (57)(2) = 11.4$ in.

here $S = S_p/2 = .087$ $\theta = \theta/2$ end of

from Riser Table III Case 11

$$F = \frac{48 E I \delta}{L^3}, \quad L = 11.4$$

$$F = \frac{(42)(30 \times 10^6)(2.99)(.087)}{(11.4)^3} = 294 \text{ lbs}$$

With the Reaction Force = F Then the Withdrawing Force F_w

$F_w = 1.2 F$; $N = 0.92$ Steels Steel Slide, E_w (MARKS)

$$F = (42)(2)(294) = 205 \text{ lb}$$

FIGURE 5 IS A DEFORMED (X100) CONTRAST EFFECTIVE
 STRESS/PLAST AT THE LOAD STEP (20) NEARLY THAT
 WHICH ABSORBS THE AVAILABLE ENERGY (5200 N-IN)

THE MAXIMUM σ_e IS 44,320 psi. WHICH IS
 EQUIVALENT TO E OF 0.025, WHICH IS WELL BELOW
 THE FAILURE VALUE OF 0.46.

BEST AVAILABLE COPY

ANALYTICAL CALCULATIONS

Appendix E

Page 25 Page 31 of 32

Subject SMMS - ACCIDENTOriginator SL HECHEDate 3/96Checker BJPDate 4-5-96ACCIDENT

DETECTOR HOUSING - POSTULATED EXPLOSION WITHIN

Pressure = 510 psi PEAK PRESSURE

Thin Section of cylinder

$$OD = 3.38, ID = 3.068 \Rightarrow t = .125, r_m = 1.597$$

$$\sigma_r = \frac{Pr}{t} = \frac{(510)(1.597)}{.125} = 6,510 < \sigma_y = 0.6$$

$$\text{END PLATE } F = 1.53, t = .125$$

FIXED AT ROOT

$$\text{Center } \sigma_r = \sigma_t = \frac{3Pr^2}{8t^2} (m+1) \quad m = \frac{r}{t} = 3.33 \quad \text{Ref. T. TABLE 4 - Case 6}$$

$$\sigma_r = \frac{3(510)(1.53)^2 (3.33+1)}{8(3.33)(.125)^2} = 37,900 \text{ psi}$$

$$\text{edge } \sigma_r = \sigma_t = \frac{3Pr^2}{t^2} = \frac{(375)(510)(1.53)^2}{(.125)^2} = 57,305 \text{ psi}$$

BEST AVAILABLE COPY

SANDVIK, INC. SCRANTON WORKS
P.O. BOX 1230, SCRANTON, PA. 18501 PH. 717-587-5191
PLANT LOCATION: INTERSTATE 81, WAVERLY EXIT 59

Appendix E
Page 32 of 32

CUSTOMER PURCHASE ORDER NO.	SANDVIK ORDER NO.	ITEM	SPECIAL CODE	MARKS	CERTIFICATE NO.	CERTIFICATE DATE
1111111111	771966	6178		YAYM000#72001	020199	11/12/99

SOLD TO: TUBE SALES

WESTINGHOUSE HANFORD
c/o ARHCO REC.

SPECIFICATION AND MATERIAL:

ASTM A-312, ASME SA-312

SANDVIK SEAMLESS STAINLESS STEEL ANNEALED PIPE TYPE 316 3 SCH 40 97'5"

Analysis, %

Heat	C	Si	Mn	P	S	Cr	Ni	Mn
742583	.048	.60	1.70	.007	.013	17.5	13.3	2.68

Mechanical Tests

Heat	Yield Str. psi	Tensile Str. psi	Elong. 2" %	Hydr. Pres. Test psi
742583	42,800 44,400	87,300 89,600	46 47	1960

FLATTENING TEST: OK

OK TO ASTM A-312

FEB 09 1990

For Bengt H. Berg, Quality Assurance Manager

Bengt H. Berg

(P-A-SA-1, REV. 1) dm
Supersedes P-A-1 and P-SA-1

BEST AVAILABLE COPY