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Hanford Coring Bit Temperature Monitor Development Testing Results Report

Danny Rey

Prepared by
Sandia National Laboratories
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Danny Rey

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Abstract

Instrumentation which directly monitors the temperature of a coring bit used to retrieve core samples of high level nuclear waste stored in tanks at Hanford was developed at Sandia National Laboratories. Monitoring the temperature of the coring bit is desired to enhance the safety of the coring operations. A unique application of mature technologies was used to accomplish the measurement. This report documents the results of development testing performed at Sandia to assure the instrumentation will withstand the severe environments present in the waste tanks.

Acknowledgments

Thanks to R. A. Normann of the Geothermal Research Department and E. R. Kadlec of the Instrumentation Development Department for their conceptual design of a "Downhole Telemetry System". Thanks also to T. J. Dubay, D. L. Trujillo of Instrumentation Engineering and Technology Department and M. R. Taylor of Power Electronics and Custom Controllers Department for their significant design efforts in the application of the Downhole Telemetry System.

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Development Testing Results Report

1.0 Introduction

As a part of their Tank Waste Remediation System (TWRS), Westinghouse Hanford Company (WHC) has developed equipment and methods for core sampling and subsequent assaying of radioactive wastes in storage tanks at the Hanford facility. Safety is a basic requirement of both the equipment and operational methods for this activity. To enhance safety and core sampling performance, the development of a technique for measuring coring bit temperature is desired. This measurement would augment other safety features to ensure sampling can be accomplished with minimal risk to the environment or site personnel. DOE/Richland requested that Sandia National Laboratories (SNL) team with WHC to enhance coring equipment, now at an advanced design stage, to provide this measurement. Several factors make this development challenging:

1. safety requirements are stringent,
2. the coring equipment is mechanically cumbersome, and
3. operational environments (particularly gamma radiation and particulate contamination) pose difficulties.

However, the preliminary work between WHC and SNL suggest a practical solution should result from a cooperative team effort.

Successful development of the direct coring bit instrumentation can achieve many benefits to the TWRS system, in particular supplying the coring truck with a real time indication of a safe drilling condition. This capability should reduce the reliance on present operational limits as a primary safety feature.

2.0 Theory of Operation

The Bit Temperature Monitor (BTM) is comprised of three major subsystems, the instrumented drill bit/core barrel, the Above Grapple Assembly (AGA), and the Infrared (IR) Receiver. The instrumented drill bit has the temperature sensors embedded into the bit and wired to a transformer secondary coil which is wound along the inside of a piece of drill pipe. The AGA produces an infrared signal which has a frequency proportional to the measured temperature. The IR Receiver receives the infrared signal and creates a 0 - 10 volt signal which corresponds to the temperature. The receiver signal will be provided to the data logger located on the drilling trucks which displays the measured temperature.

2.1 Instrumented Drill Bit

The Instrumented Drill Bit is a modified version of the present system to allow for the temperature measurement. Thermistors are used for the temperature sensor because of the large change in resistance as a function of temperature. The drawback to the thermistors is the non-linear temperature characteristic. The thermistors are embedded into the bit and potted using an epoxy based glass microballoon encapsulant.

The wires are routed up the core barrel and drill string and connected to the transformer secondary. The transformer secondary is wet wound onto a Nyloil material using an epoxy to wet the 38 gauge transformer wire. This assembly is inserted into a cavity machined into a section of drill pipe.

2.2 Above Grapple Assembly (AGA)

The AGA consists of five modules which connect together using 9 pin MDM connectors. The five modules include: The primary transformer coil, the electronics package, the battery package, a latching module to latch the AGA into the inner wall of the drill string, and finally the light emitting diode (LED) module which transmits the infrared light pulses. The AGA, which is approximately 16 inches long, resides inside the drill string and rides up the drill string above the grapple weight assembly when a sample is being removed. During the drilling operation, the AGA latches into detents machined in the drill pipe. These detents allow the primary and secondary coils to align and couple the thermistor resistance to the AGA. The primary coil is connected to a free running astable multivibrator to create a signal that drives the LED module. This signal varies when the thermistor resistance changes as a function of temperature.

The battery pack consists of 6 lithium LS14500 AA size battery cells manufactured by Saft Industries. The cells are configured into two batteries of three cells each for redundancy. Two independent temperature measurements are made by redundant circuitry to enhance reliability. The only non redundant circuitry is a ring counter used to switch power to each of the two channels one at a time to conserve power.

2.3 Infrared (IR) Receiver

The IR receiver detects the IR pulses transmitted by the AGA and creates a pulse train for pulse separation measurements. There are two printed circuit boards, one small PC board is located just above the mechanical stop and one larger PC board is located in the proximity switch bracket. The proximity switch bracket was redesigned to accommodate the receiver electronics.

The lower PC board contains the photodetectors and an amplifier. The signal is routed through the monoflow union to the proximity switch bracket where it is amplified further and detected by a phase lock loop. The majority of the digital logic resides in a field programmable logic device manufactured by Actel. This device separates channel 1 and channel 2 signals and measures the pulse spacing. This measurement then becomes an address to a EEPROM which contains the digital equivalent of a voltage corresponding to the pulse spacing. The EEPROM then provides the memory contents to a digital to analog converter to create the signal which is supplied to the truck data logger.

3.0 Tests Performed

The following tests were performed on the BTM hardware to ensure functionality and assure the instrumentation system would survive the expected environments.

1. **Functional Tests**
    1. a) Latch slide, lock, and power-on
    2. b) Infrared communications and temperature monitoring
    3. c) Drill string with Bend
    4. d) Drill string Wobble
    5. e) Proximity sensor, Alternate motor stop

2. **Environmental Tests**
    - a) Temperature
    - b) Pressure
    - c) Vibration
    - d) Compression
    - e) Corrosion
    - f) Ionizing radiation
    - g) Mechanical shock
    - h) IR communications through water

4.0 Functional Tests

Tests were performed to verify the functionality of the BTM at SNL in the Department 2663 laboratory, building 890, room 3204. Figure 1. shows the setup used to perform the functional tests. Several frequency measurements were made at the infrared receiver output using both a Hewlett-Packard model 54112D (S/N 2804A00346) digitizing oscilloscope and a LeCroy 9400 (S/N 86305) Dual 125 Mhz digital oscilloscope. A thermocouple and hand held meter were used to monitor the oven temperature.

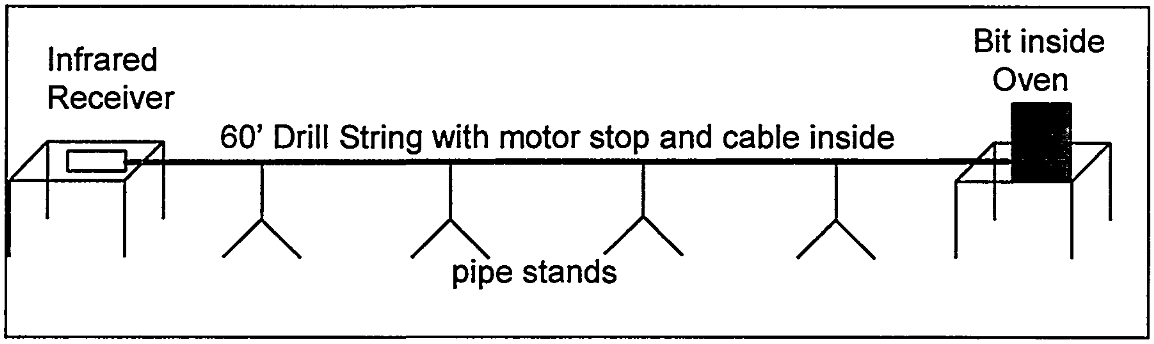

Figure 1. Functional tests lab setup

4.1 Power-on Test

This test was performed to evaluate the latching mechanism which switches battery power on when the AGA latches into the drill rod detents. The latching occurs when the AGA and grapple weight are lowered into the drill string. The purpose of the battery switch is to conserve battery power when a sample is being retrieved and no drilling is being performed. In the actual tanks, gravity allows the hardware to be lowered to the bottom of the drill string. In this test, an additional cable was used to move the AGA inside the drill string.

The latching mechanism operated correctly, but the microswitch had not been adjusted and did not switch battery power on. The microswitch operated satisfactorily after the internal mechanical adjustment was made. The total testing consisted of sliding the AGA down the drill string 15 times, rotating the AGA in the pipe 90 degrees, and repeating. A total of 60 latches were performed.

Testing showed an embedded microswitch will function as intended after the electrical switching mechanism is adjusted to the AGA latching mechanism. A latch and switch design with only one mechanism is preferred to avoid the necessity of adjustment and reduce the probability of going out of adjustment during operation. This will require a redesign of the latch which is recommended for the final unit.

4.2 Infrared Communications and Temperature Monitoring

These tests demonstrate that an infrared signal can be reliably transmitted and received over 60 feet of drill string even when the pipe has a severe bend. In the initial tests, the drill bit was inserted into a small temperature chamber with thermistors bonded to the surface of the bit. A thermocouple was also bonded to observe the temperature in the chamber. The signal amplitude was observed with no intentional bends in the drill string. Figure 2 plots the frequencies measured on both channels as a function of temperature.

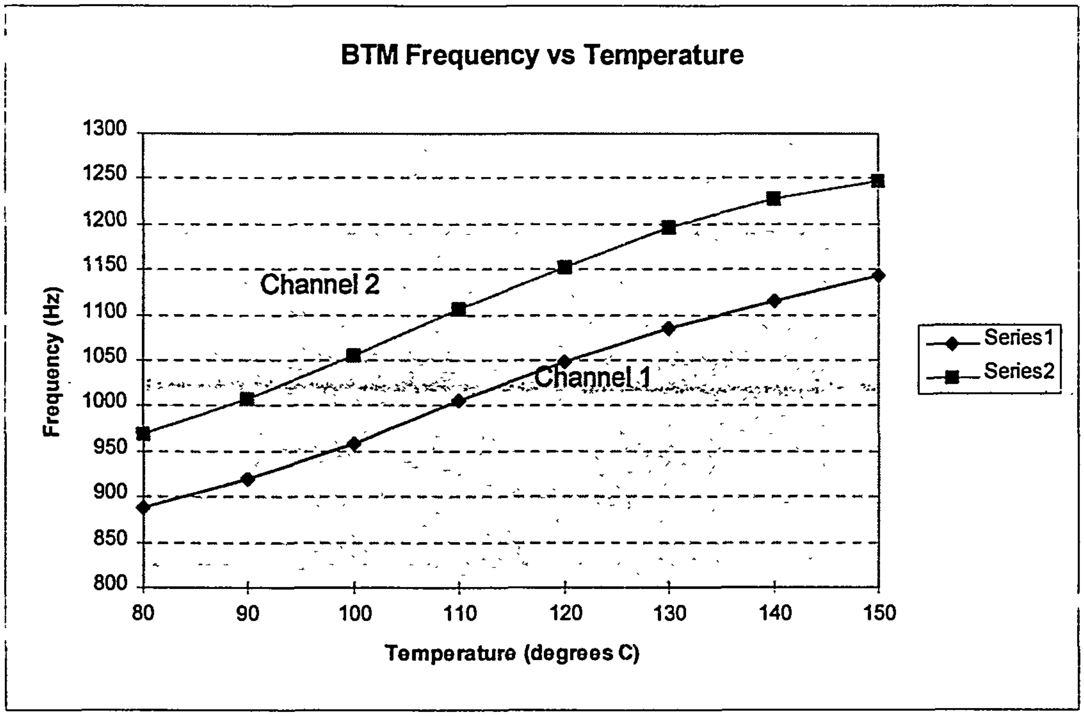

Figure 2. Channels 1 and 2 Frequency vs Temperature

For the development unit, unscreened thermistors were used and channel frequencies were not calibrated. This explains why the two curves shown in Figure 2 are not identical. The final unit will be calibrated by using thermistors that are interchangeable and have been calibrated to ± 0.5% over the temperature range 80°C to 150°C. By using interchangeable thermistors an AGA can be calibrated with a different set of thermistors than the ones previously installed in the drill bit.

4.3 Drill String with Bend

This test simulates a bend in unsupported drill string a condition that may occur when drilling is taking place. The purpose of this test is to assure attenuation in the infrared signals is not sufficient to cause the IR receiver to lose the signals. To accomplish the bend, the pipe stands were moved toward the ends of the drill string while the ends were held in place. Figure 3 shows the setup used for this test.

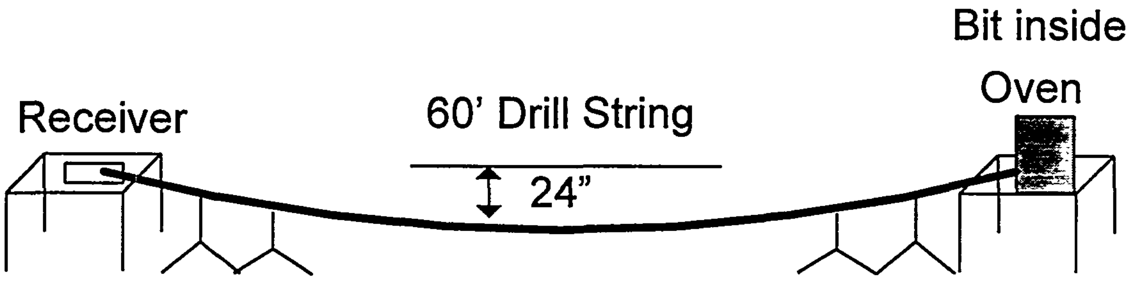

Figure 3. Setup for Drill String with Bend

With 60 feet of pipe and no bend, the receiver is still saturated and comes out of saturation with approximatly 6 inches of pipe bend. The receiver becomes saturated because of the high gain in the IR detector amplifiers. The signal output is 22.6 volts when the receiver is saturated. With 10 inches of pipe bend the signal drops to 18.7 volts and with 24 inches of bend the signal is 4.5 volts. A signal at 4.5 volts is acceptable since the signal to noise ratio exceeds 10. For this system a voltage comparator converts the IR detector amplifier output to a standard 5 volt logic signal. The comparator voltage has been set to a nominal 1.05 volts and therefore can easily detect a signal through 60 feet of pipe and 24 inch bend.

4.4 Drill String Wobble

This test was performed to determine if movement in the drill string would sufficiently modulate the IR signal to cause reception problems. The setup for this test is the same as for the pipe bend test except that the pipe is pushed down near the center and released several times. This wobbling effect will modulate the IR signal amplitude with a frequency equal to the wobble frequency. There was no effect on the receiver due to the wobble. The wobbling frequency was not measured but was arbitrarily induced by pushing down and releasing the drill pipe. The induced signal modulation provided a signal well above the 1.05 volt comparator setting. The signal amplitude would need to be less than 1.05 volts to adversely affect the receiver.

4.5 Proximity Sensor/Alternate motor stop test

The motor stop on the grapple cable is detected by the proximity sensor in the drill trucks to determine when a sample tube is near the top of the drill string when a sample is being removed. Reducing the motor stop diameter so that it can pass through the AGA as part of the normal operations is proposed. This will allow the distance from the motor stop to the top of the AGA to remain the same as in the present truck configuration without the AGA. It will also avoid having the motor stop reach the proximity detector much sooner than the previous system.

This test was performed to assure the receiver electronics did not effect the operation of the proximity sensor and that the proximity sensor did not effect the receiver electronics. In addition, the use of motor stops with smaller diameter was tested to ensure the proximity sensor operation was not affected.

Three additional motor stops were fabricated with diameters of 0.600", 0.500", and 0.400". The original motor stop diameter of 0.688" was included in the testing. All four motor stops operated satisfactorily. The parameter affecting the operation of the proximity sensor is the proximity of the sensor to the motor stop. In this case, when the proximity sensor is installed for use with a different diameter motor stop the operation is identical. The motor stop with a diameter of 0.500" was chosen because it will pass through the AGA and is the closest diameter to the original.

5.0 Environmental Tests

The Bit Temperature Monitor AGA and IR Receiver were environmentally tested to ensure proper operation in the expected environments. The subsystems performed satisfactorily in all the environments.

5.1 Temperature

The AGA and IR Receiver were tested to evaluate performance at high and low temperatures of -20°C and +85°C. The primary temperature limitation of the AGA is at high temperatures due to the lithium batteries. Lithium batteries were selected due to the high power densities available and the need to avoid changing batteries during operation. Maximum temperatures for lithium batteries is 90 - 95°C. During drilling operations the AGA is not expected to experience temperatures exceeding this maximum due to the insertion of nitrogen gas into the drill string. This nitrogen gas is not allowed to exceed 50°C (120°F) at the inlet to the drill string.

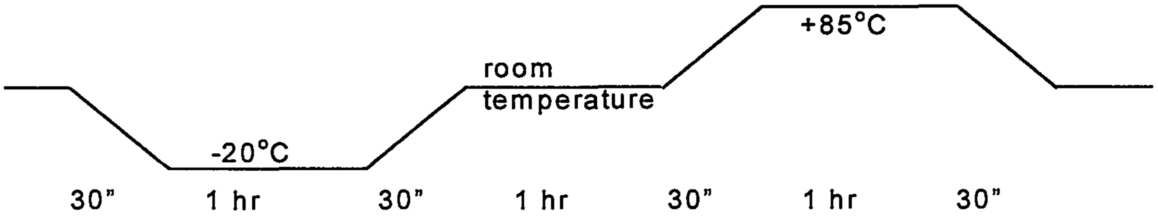

Figure 4. Temperature Profile

The AGA and IR Receiver were both tested simultaneously in a single temperature chamber. Power supplies and scopes were kept outside the chamber. The units were powered up and monitored after they had been allowed to soak at a given temperature for 1 hour. The temperature chamber was programmed to go from room temperature to -20°C or +85°C in 30 minutes. Figure 4 gives the temperature profile.

5.2 Pressure

The BTM will operate while the drill string is pressurized with nitrogen to 90 psia maximum. To assure that the pressure environment will not produce adverse effects, the AGA and Receiver were both inserted into a pressure chamber and pressurized with nitrogen. The pressure chamber used is located in SNL Technical Area III, building 6730. The units were both powered up while in the pressure chamber and monitored externally with the LeCroy scope. Pressure was increased to 135 psia and held for approximately 30 minutes. The receiver output was monitored the entire time and no problems were encountered.

5.3 Random Vibration

The BTM was tested at SNL Technical Area I Vibration Testing Facility in building 860. Both the AGA and IR Receiver were subjected to a $0.01g^2/Hz$, 20 - 2000 Hz flat spectrum. Each of the units were vibrated separately and monitored during vibration. When one unit was being vibrated the other was powered up on a table adjacent to the vibration table to allow monitoring the unit being vibrated. Signals from the AGA were reflected off the ceiling and the receiver output was monitored on the LeCroy scope during each of the tests.

A second test was performed with the AGA latched into a segment of pipe. Again the AGA signals were reflected off the ceiling and received with no adverse effects detected.

5.4 Mechanical Compression

A mechanical press located in building 890, room B63, was utilized to perform the compression test. The AGA was mounted vertically and compressed to 1000 lbs for 5 minutes. This test was repeated three times. The AGA functioned before and after each compression.

5.5 Corrosion

Originally the AGA housing was to be fabricated out of aluminum due to ease of fabrication and low cost. The aluminum would then be flame sprayed with a nickel alloy for corrosion protection. This idea was abandoned when it was discovered that the flame spraying process would not guarantee the absence of a pin hole in the sprayed AGA. This small hole in the nickel material would concentrate the corrosive material and possibly accelerate the corrosion process in the aluminum.

Appendix A is a memo from J. W. Braithwaite and N. R. Sorensen, both SNL Department 1832, describing the results of compatibility testing of candidate materials.

The objective of this test was to determine "gross" compatibility by exposing each material to the expected environment for a period of time greater than should be encountered. The expected exposure time for a single exposure is approximately 10 minutes but cumulatively this time could add up for a single AGA which is designed to operate from six months to one year. For this test most samples were exposed for 138 hours. The exceptions were an aluminum sample which was exposed for 9 minutes, two O-ring materials which were exposed for 22 hours, a teflon sheet and a polysulfide coating both exposed for 23 hours. Table 1 gives the ingredients of the solution used to test the materials. This composition was provided to SNL by WHC.

Table 1. Composition of Hanford Liquid Waste

Component	Weight %	Component	Weight %
$NaNO_3$	20.8	$NaAlO_2$	12.5
$NaNO_2$	15.8	Na_3PO_4	2.3
Na_2CO_3	0.6	H_2O	40.2
NaOH	6.2	density ~ 1.3 g/l (reported as 1.6 g/l)	

The majority of materials tested exhibited adequate resistance to chemical attack in this environment. The only materials with poor durability were aluminum and the organic coatings used to insulate the copper wires used as windings on the transformers in the AGA. A decision was made to use stainless steel as the container material instead of aluminum with a nickel flame sprayed coating. The polyurethane foam used to encapsulate the AGA batteries was found to absorb some of the material. This foam will continue to be used, but will be wrapped with an epoxy wetted Teflon™ sheet to avoid the absorption of liquids. The transformers will be wrapped with an epoxy wetted Kevlar™ or glass material to prevent the wires from being exposed. The secondary coils embedded into the drill string will be protected from the environment with a Nyloil material which also provides mechanical protection. The thermistors will be embedded into the drill bit and encapsulated with a glass microballoon(GMB)/828 epoxy mixture after being coated with polysulfide for stress relief. The GMB will be used as an encapsulant on the channels cut into the drill string for laying the wires going from the thermistors to the secondary transformer coils.

5.6 Ionizing Radiation

Appendix B is a memo for M. R. Taylor and L. F. Tafoya, both SNL Department 2314, describing results of the ionizing radiation tests performed on the AGA. The purpose of this test is to gain a measure of the ionizing radiation tolerance of the AGA. The testing was conducted in the Low Intensity Cobalt Array (LICA) facility in building 867 at SNL Technical Area 1.

A complete AGA assembly was irradiated in the facility which uses an array of 12 inch Co^{60} "pencils" arranged linearly with alternating rows of target areas. For this test a target area which provided 29.14 kRads (Si) per hour was chosen. Since the AGA is longer than 12 inches, two irradiations were performed. The AGA was irradiated for a time calculated to give 100 kRads total dose each time.

Prior to the start of the test several parameters were measured to baseline the AGA's pre-radiation performance. Each of the parameters were again measured after each irradiation. After each irradiation the current being drawn from the battery both during the transmit and non-transmit cycles of the AGA was found to be excessive. While the AGA remained fully functional, the elevated current levels were unacceptable in a battery operated system. A postmortem performed on the AGA attributed the high current levels to the installation of a non-radiation hardened integrated circuit (IC). The IC in question was a National Semiconductor version of the CD40106 Hex Schmitt Trigger which should have been a hardened Harris Semiconductor version of the same part. The IC was somehow mixed in with radiation hardened parts and the error was not detected during printed circuit board assembly. To assure other parts were not also exhibiting high current behavior, several other parts were tested and found to be within acceptable limits.

5.7 Mechanical Shock

While the AGA is in the drill string and just prior to sample tube removal during normal operations, a high probability exists that a mechanical shock will be experienced by the AGA. The grapple weight just below the AGA could spring upward when the a pin is sheared which closes a valve in the sample tube. This grapple weight may spring upward high enough to strike the bottom of the AGA. A worst case calculation shows that the grapple weight springs upward at 5 feet/second.

To perform this test a billet resembling the grapple weight was fabricated. The facility 3 inch air gun facility in building 860 was used to propel the billet into the AGA. The AGA was instrumented to measure the shock levels upon billet impact when propelled at 4 feet/second and 5 feet/second. The measured shock levels were 1700 g's and 4000 g's respectfully. The billet was propelled into the AGA at 5 feet/second three more times while the AGA was functioning with no problems detected.

5.8 Infrared Communications through water

The BTM was designed to operate in the rotary truck environment but could aid the operation of the push mode truck by allowing a slow rotation during core sampling. The environment is different in the push mode truck where water is used instead of nitrogen gas inside the sealed drill string system. To test the feasibility of using the BTM on the push mode truck the infrared communication system was tested with water inside the drill string. A plate made of Lexan™ was fabricated to hold water inside of a pipe. The infrared diodes transmitted through the Lexan™ and a length of pipe.

A baseline measurement without water showed that the receiver output had a signal equivalent to 60 feet of drill string and a 6 inch bend (approximately 21.8 volts peak to peak). Normal Albuquerque tap water was added to the drill string and the receiver output was measured each time. Table 2 shows the results of the water test. The receiver lost signal lock when more than 12 inches of water was added to the pipe. These results show that the BTM, as presently designed, will not function satisfactorily on the Push Mode Truck when water is added, but will function prior to the addition of water. An alternate BTM design using light emitting diodes which operate in the green color spectrum could possibly extend the range of transmission through water since data exists showing green light propagates much better through water than infrared. This new concept could be tested for use on the Push Mode Truck should a BTM system for that truck be desired.

Table 2. Infrared Communications through water

Water level (inches)	Signal Amplitude (volts)	Water (inches)	Signal Amplitude (volts)
baseline	21.8	12.25	2.73
1	21.7	loss of signal lock at levels given below	
3	21.7	14.5	1.05
10	7.8	17	0.38

6.0 Conclusions

Testing shows the Bit Temperature Monitor system has been designed robust enough to significantly enhance the safety and operations of the sampling systems at Hanford. Design modifications would need to be implemented prior to actual use in the waste tanks. The significant modifications include fabricating the AGA housing out of stainless steel rather than nickel flame sprayed aluminum, and wrapping the encapsulated batteries and primary transformer coils with an epoxy wetted Teflon^{TM}.

Appendix A

Materials Compatibility Test Results

Sandia National Laboratories

Albuquerque, New Mexico 87185-0340

date: January 9, 1995

to: Danny Rey, MS-0986 (2663)

from: J. W. Braithwaite and N. R. Sorensen, MS-0340 (1832)

subject: Results from Compatibility Testing of Candidate Sensor Materials

summary: *A compatibility study of candidate sensor materials with a Hanford high-level waste liquid has been completed. The majority of these materials exhibited adequate resistance to chemical attack in this environment. The only materials with poor durability are aluminum and the organic coatings used on the copper wires. Your choice to use stainless steel as the container material is supported.*

Based on your request, we have completed a preliminary evaluation of the general compatibility of several materials with the liquid portion of the high-level radioactive waste being stored in tanks on the Hanford reservation. As you described, these materials are candidates for use in various components of a thermal sensor your group is designing that will be part of a waste sampling device. The results of these evaluation are described in this memo.

The objective was to determine "gross" compatibility by exposing each material to the expected environment for a period of time greater than should be encountered and then characterizing the extent or overall type of degradation.

Experimental

Each of the candidate materials supplied was cleaned and photographed prior to exposure. A solution was prepared with the composition that you provided (see Table 1). This composition reportedly represents an aggregate for the liquid portion of the current high-level waste inventory in Hanford's single shell tanks.

One observation of note is that the reported density of this solution is not accurate. The observed value is closer to 1.3 g/l than the stated 1.6 g/l. This type of analytical error is not uncommon when concentrated solutions such as this are involved. We do not believe this type of inaccuracy would affect the results because the primary compatibility considerations are probably the solution pH and the ionic strength. The NaOH concentration was about 2 N and the solution was completely saturated as evidenced by the need to heat it to approximately 40°C to force all of the salts to dissolve.

Table 1. Composition of Hanford Liquid Waste

Component	Weight %	Component	Weight %
$NaNO_3$	20.8	$NaAlO_2$	12.5
$NaNO_2$	15.8	Na_3PO_4	2.3
Na_2CO_3	0.6	H_2O	40.2
NaOH	6.2	density ~ 1.3 g/l (reported as 1.6 g/l)	

The majority of the samples were inundated in the solution for 138 hours at ambient temperature. The exceptions included a sample of aluminum (exposed for 9 minutes) and two O-ring materials (exposed for 22 hours). During the exposure, some salts did precipitate from solution. At the conclusion, each sample was thoroughly washed, dried, and photographed. Both macro and stereo-micro photographs were taken.

Results

Observations related to the degradation characteristics of each sample that was evaluated is summarized in Table 2. This information is supported by the photographs of the candidate materials presented in Figures 1 and 2. Figure 1 shows the samples prior to exposure to the Hanford solution and Figure 2 photographs were taken after exposure. Each figure contains three sets of photographs (labeled a, b, and c). Each individual photograph is keyed to a description in Table 3 by a number in its upper right corner. An effort was made to maintain the same sequence in these photographs (e.g., #5 in each figure is of the same sample and taken with the same conditions). For this reason, corresponding sets are presented on the same page.

Conclusions and Recommendations

As expected, the only metal that showed evidence of gross incompatibility with the Hanford waste liquid was aluminum. Based on other testing being performed in our organization, your choice of Stainless Steel Type 303 as the preferred material for the final container is fully supported. It should have substantial resistance to this environment.

As demonstrated by only minor rusting in this test, the powdered iron core can probably be used even without a coating. This conclusion is consistent with the general knowledge that in alkaline solutions, iron is an adequate to marginal material of construction (depends on the concentration and temperature). Copper is also known to provide good to adequate performance in sodium hydroxide. In these tests, it is not clear if any copper was actually exposed because of the presence of platings (e.g., tin) that provided adequate protection. However, a small amount of corrosion could be very detrimental if 38 gauge wire is being used. In this case, some external protection should probably be provided.

The only other observed material incompatibility was with the organic coatings on the various copper wires. Each sample reacted slightly different. However, the integrity of the coating was compromised in every sample that, in turn, permitted exposure of the underlying metal wire to the solution. If such a wetted condition is critical for electrical purposes, a alternate family of coating materials (e.g., Teflon based) should be investigated. The polyurethane foam clearly absorbed solution, a condition that could also lead to soft shorts across the battery terminals if organic coatings on the lead wires cracked and spalled.

JWB:NRS:1832

copy to:

MS 0337	A. D. Romig
MS 0340	W. R. Cieslak
MS 0340	R. G. Bucheit
MS 0340	L. M. Maestas
1832 File	

Table 2. Qualitative Compatibility of Candidate Materials in Hanford Waste Liquid

Sample	Observations
Aluminum	rapid reaction with gas generation
IR Phototube	no degradation
Thermaleze Wire	coating cracked spirally and spalled off; wire plating protected Cu wire
SAPT Wire	significant swelling in coating with little or no cracking; remaining coating easily stripped; wire coating appeared to be unaffected
GMB	no degradation
Thermistor Wire (in GMB)	thick coating on twin leads exhibited gross cracking and coating was spalled off in many places; path could exist to thermistor due to poor coating integrity; wire plating protected wire
Nyoil	no degradation
828	no degradation
Foam	where inundated, the foam showed definite absorption of the solution with some discoloration; no attack of the foam was apparent
Copper Wire	coating effectively spalled off; wire unaffected
Kevlar and Glass Fibers	no degradation
Iron Core	cracking in and lifting of the epoxy paint; very little corrosion of iron substrate or the exposed powdered iron on other side

Table 3. Description of Photographs Prior to and After Exposure		
#	**Before (Figure 1)**	**After (Figure 2)**
1	IR phototube (low mag)	IR phototube (low mag)
3	IR phototube (high mag)	IR phototube (high mag)
5	heavy poly thermaleze wire (low mag)	heavy poly thermaleze wire (low mag)
7	heavy poly thermaleze wire (macro)	heavy poly thermaleze wire (high mag)
9	SAPT wire (low mag)	SAPT wire (low mag)
11	SAPT wire (macro)	SAPT wire (high mag)
13	thermistor in GMB potting (macro)	SAPT wire with coating peeled (high mag)
15	GMB surface (low mag)	GMB surface (low mag)
17	GMB surface (high mag)	GMB surface (high mag)
19	thermistor wire in GMB (low mag)	thermistor wire in GMB (low mag)
21	thermistor wire in GMB (high mag)	thermistor wire in GMB (high mag)
23	green nyoil (macro)	thermistor wire (high mag)
25	green nyoil (low mag)	--
27	green nyoil (high mag)	green nyoil (high mag)
29	foam and 828 samples (macro)	foam and 828 samples (macro)
31	828-square clear surface (low mag)	foam from below solution line (med mag)
33	828-round clear surface (high mag)	828-round clear surface (high mag)
35	coated foam surface (med mag)	coated foam surface (med mag)
37	38-gauge copper wire (high mag)	38-gauge copper wire (low mag)
39	kevlar and glass fiber (macro)	38-gauge copper wire (high mag)
41	kevlar fibers just below knot (high mag)	kevlar fibers just below knot (low mag)
43	kevlar fibers at knot (low mag)	glass fibers at knot (high mag)
45	glass fibers at knot (low mag)	iron core (macro)
47	glass fibers just below knot (high mag)	iron core (low mag)
49	--	O-rings: ethylene propylene on top, fluorocarbon on bottom (high mag)

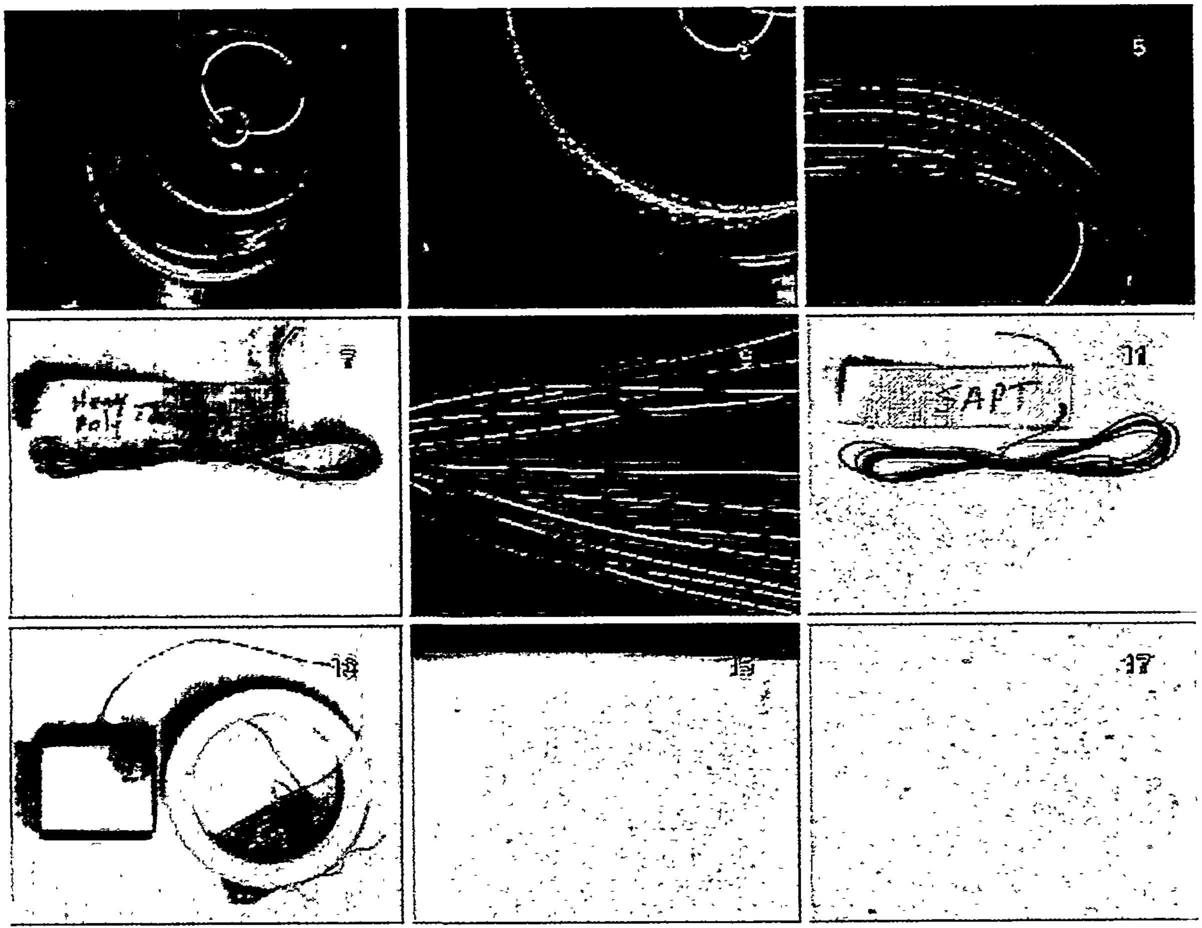

Figure 1a. Photographs 1-17 Taken Prior to Exposure to Hanford Waste Liquid

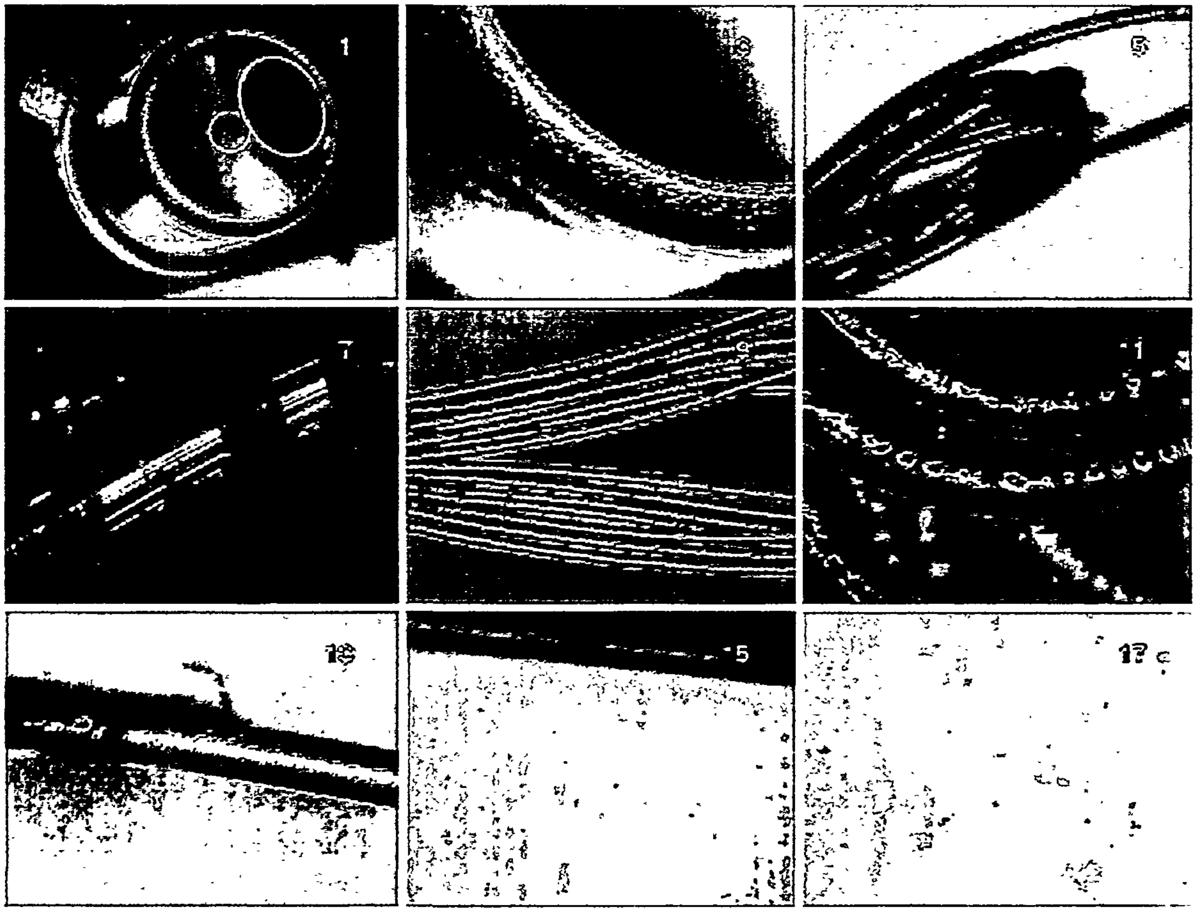

Figure 2a. Photographs 1-17 Taken After Exposure to Hanford Waste Liquid

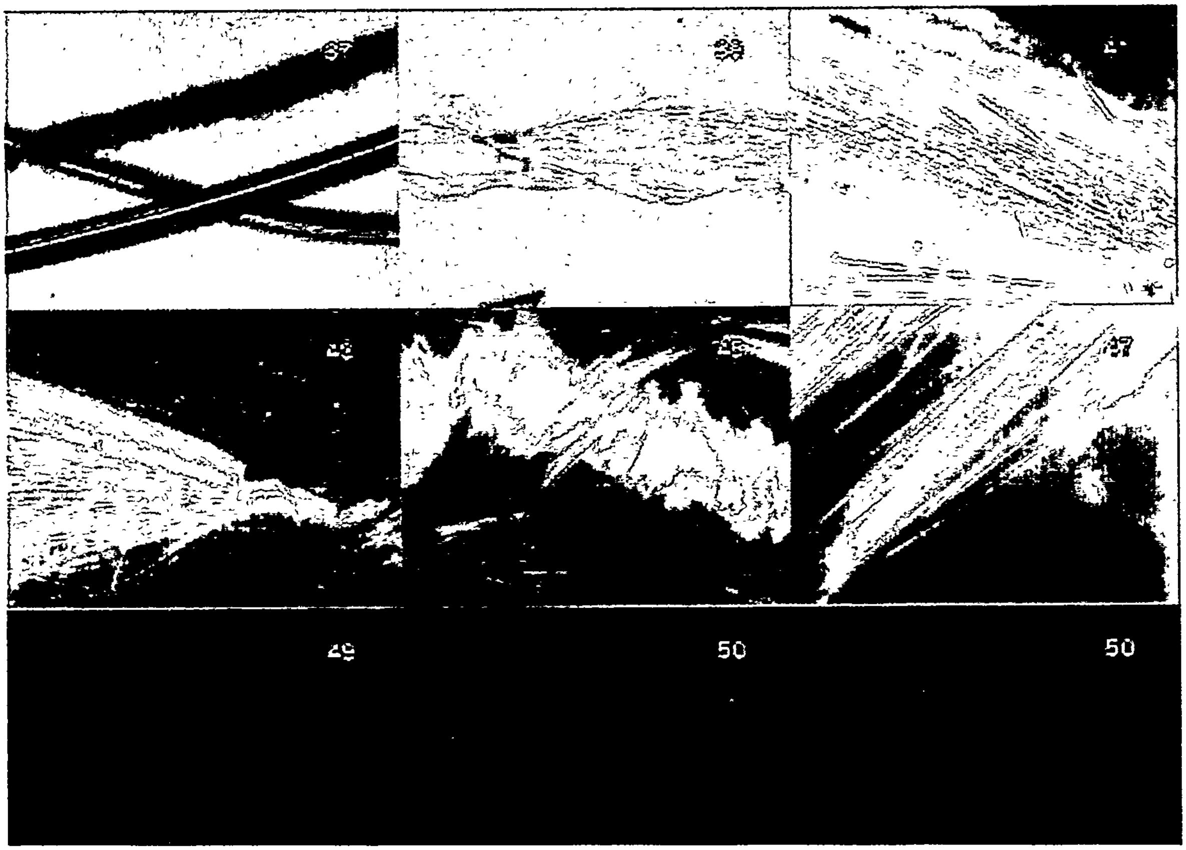

Figure 1c. Photographs 37-47 Taken Prior to Exposure to Hanford Waste Liquid

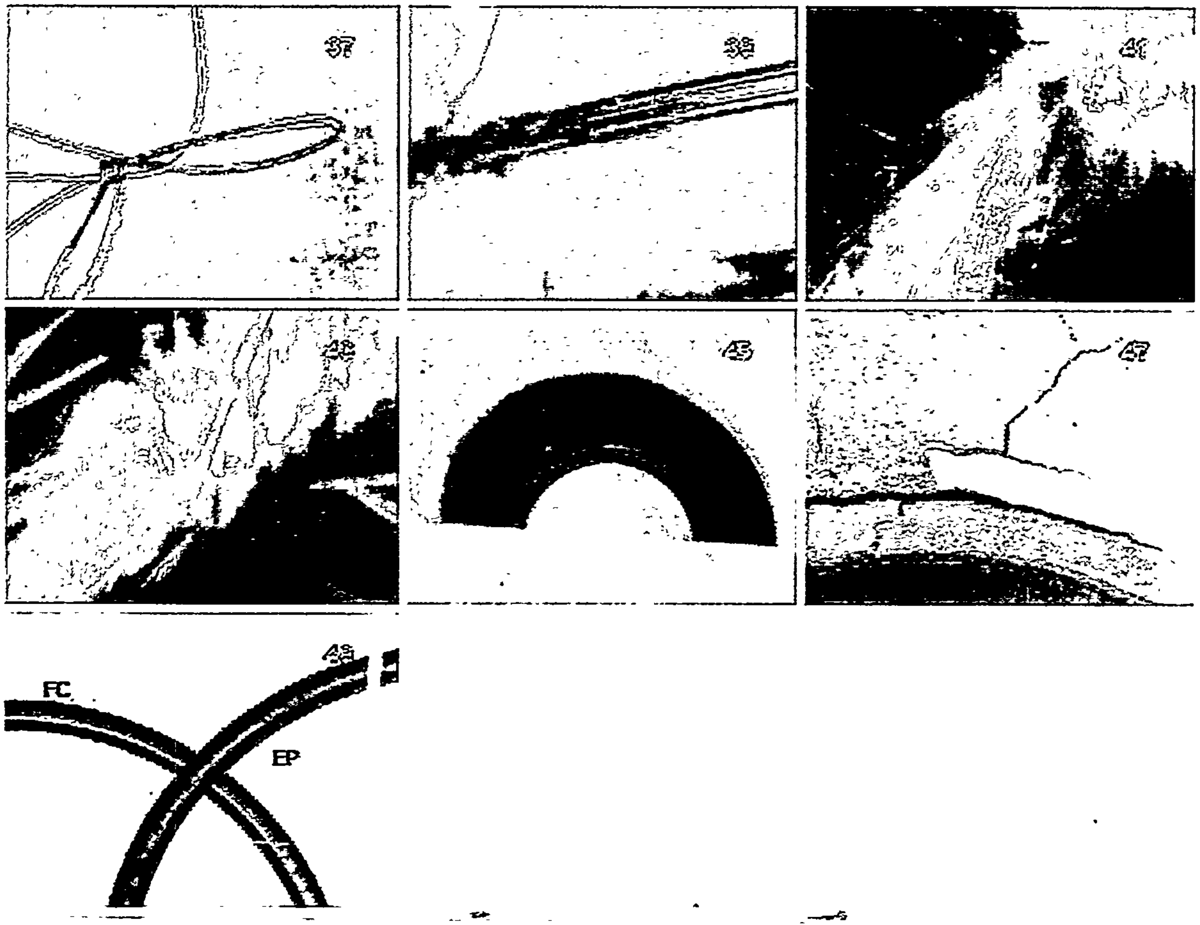

Figure 2c. Photographs 37-49 Taken After Exposure to Hanford Waste Liquid

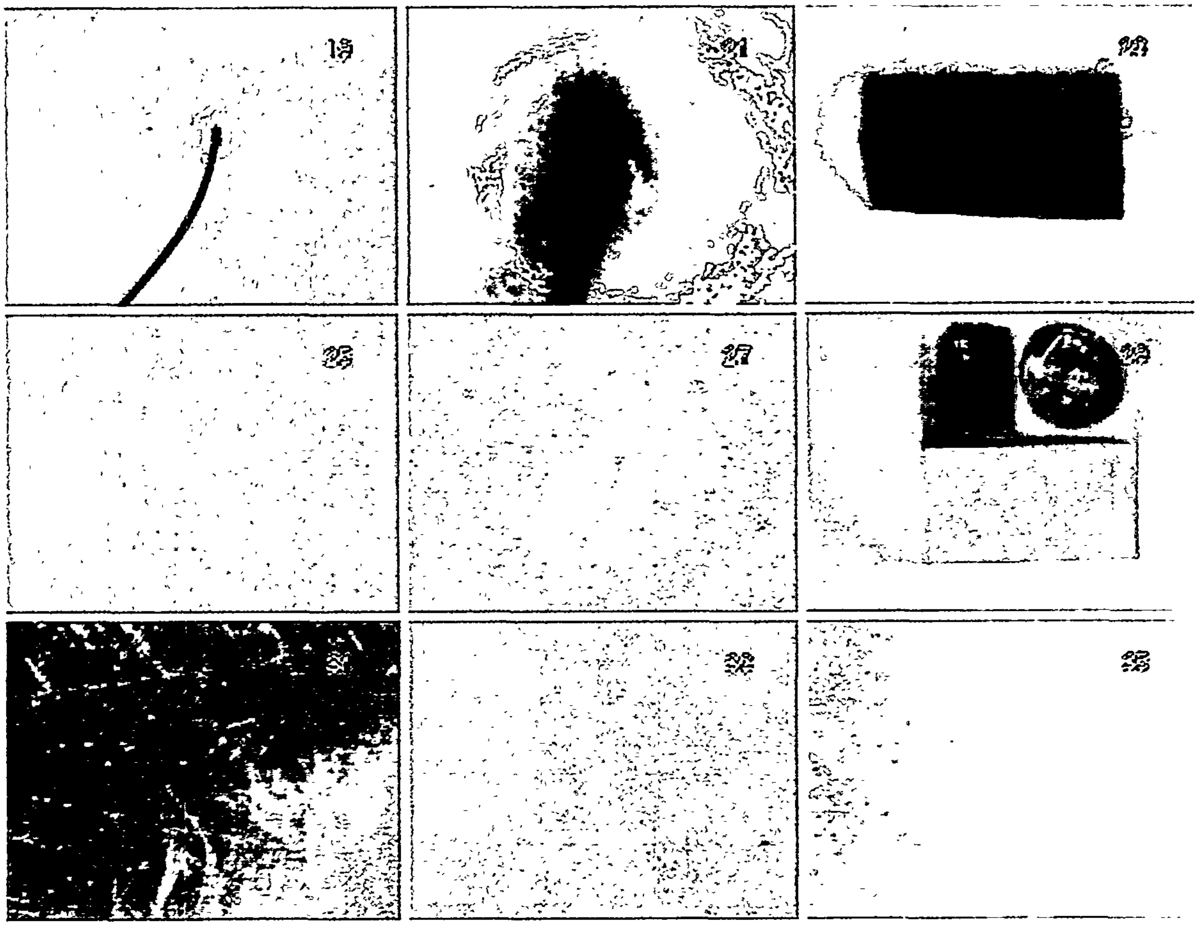

Figure 1b. Photographs 18-35 Taken Prior to Exposure to Hanford Waste Liquid

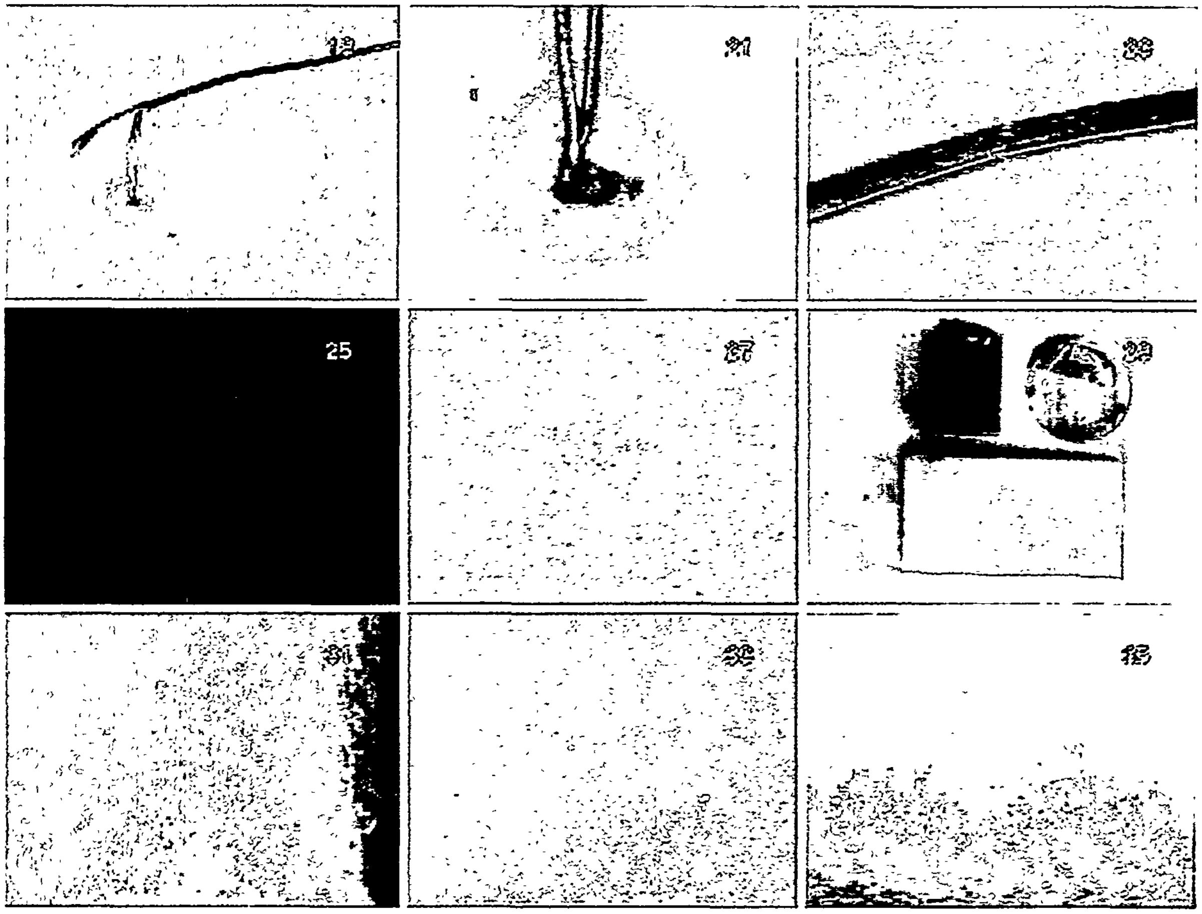

Figure 2b. Photographs 18-35 Taken After Exposure to Hanford Waste Liquid

Appendix B

Radiation Test Results

Sandia National Laboratories

Albuquerque, New Mexico 87185-0537

date: January 19, 1995

to: D. Rey, MS-0986 (2663)

M R Taylor L. F. Tafoya

from: M. R. Taylor, L. F. Tafoya, MS-0537 (2314)

subject: Radiation Test Results for the Hanford Direct Core Bit AGA

A total dose radiation test was scheduled and conducted in the Low Intensity Cobalt Array (LICA) facility in building 867 (Org 6449) on Jan.5 through Jan. 6, 1995. The test was conducted by facility operator E. Baynes of the same Org. (Org. 6449). The purpose of the test was to gain a measure of the ionizing radiation tolerance of the Hanford Direct Core Bit Above Grapple Assembly (AGA). A description of the experimental test design and results follow.

Test set-up

The LICA is an array of 12 inch Co^{60} "pencils" arranged linearly with alternating rows of target areas or "holes". Each hole accepts a sealed canister which contains the target material or unit under test (UUT). The canisters are sealed because source shielding is provided by 18 feet of water (i.e., experiments are conducted at the bottom of a water filled pool 18 feet deep). Total dose delivered for any individual hole is determined via periodic dosimetry to allow for source decay. The hole chosen for this experiment was 4B of the So. Linear Array with a measured dose rate of 29.14 K Rads (Si) per hour.

By using the LICA we were able to irradiate a complete AGA assembly (a complete assembly consists of one each of the following: XFMR Module, Battery Module, Electronics Module, Latch Module, and LED Module) with a roughly symmetric dose delivered to the full 360 ° of circumference of the AGA. The UUT canister was set up to allow air circulation for cooling and, as an added safety feature, temperature was monitored continuously during the irradiation.

The only difficulty encountered in setting up the experiment was due to the height of the Co^{60} "pencils". Since only 12 inches of target area could be maintained perpendicular to the sources at any one time, we decided to do two irradiations; one with the AGA standing in the canister LED end up, and one with the AGA standing in the canister LED end down for a time calculated to give 100K Rads (Si) total dose each. Each irradiation was instrumented with six Thermoluminescence Detectors (TLDs) arranged three each on the LED end and three each on the XFMR end of the assembly approximately 120° apart. Further, the TLD arrangement located one TLD approximately normal to the plane of each of the three circuit boards in the Electronics Module. To account for the slight non symmetry of the test fixture, the UUT canister was rotated around it's vertical axis by 90° half way through each of the two irradiations. From the 29.14K Rads (Si)/Hr. dose rate, the time required to reach 100K Rads (Si) total dose was calculated to be 3 hours 26 minutes. Thus 1 hour 43 minutes into each irradiation the UUT canister was rotated by 90°. See Figure below.

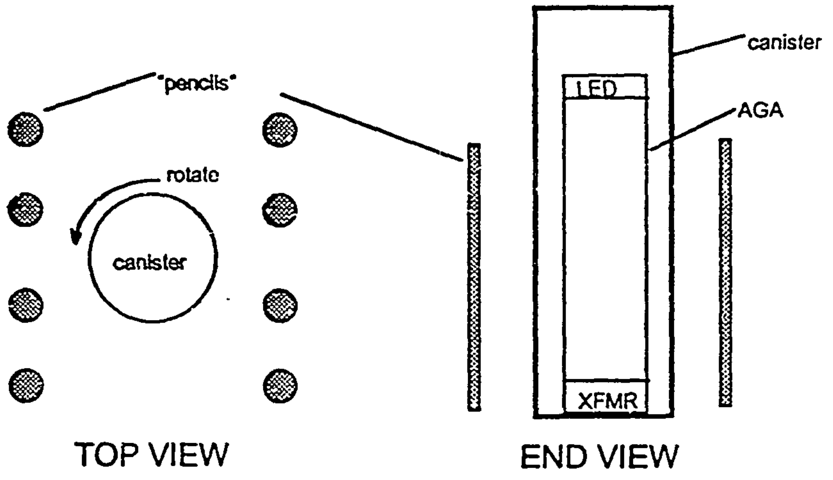

Figure 1.... Test Configuration

Prior to the start of the test several parameters were measured to baseline the unit's pre-rad performance. Those parameters were measured again after each successive irradiation. The parameters measured were Iq (the current drawn from the battery during the non transmit period of the operating cycle), Ip (the peak current drawn from the battery during either of the two transmit periods of the operating cycle), Ch1 freq. (the channel 1 output frequency with an open secondary, i.e., no secondary coil present), and battery voltage (the open circuit battery voltage measured at pin3 and pin4 of the battery pack with respect to battery common, pin6).

Test Results

Pre irradiation:

Battery voltage:

pin3-6 = 11.005V

pin4-6 = 11.001V

Iq = 228μA

Ip = 82mA

Ch1 (f) = 766Hz

Post irradiation (100K Rads (Si) total; Battery and Electronics):

Battery voltage:
pin3-6 = 10.673V
pin4-6 = 10.705V
Iq = 38.4mA
Ip = 125mA
Ch1 (f) = 760Hz

Post second irradiation (200K Rads (Si) total; Battery and Electronics):

Battery voltage:
pin3-6 = 10.870V
pin4-6 = 10.868V
Iq = 54mA
Ip = 145mA
Ch1 (f) = 760Hz

Dosimetry:

Evaluation of the TLDs by Radiation Metrology Laboratories Dept. 6522 revealed that the Battery Module and the Electronics Module both received a total dose of approximately 200K Rads (Si) in nearly equal doses of 100K Rads each. The LED Module received a total dose of approximately 120K Rads (Si) in steps of 100K Rads and 20K Rads each, and the XFMR Module received a total dose of 140K Rads (Si) in steps of 100K Rads and 40K Rads each.

Evaluation of test results

The results of testing were not as expected. We had anticipated a worst case current increase of one order of magnitude. Results showed an increase of approximately two orders of magnitude. While the AGA remained fully functional through a total dose of 200K Rads (Si), the elevated current levels were completely unacceptable. These elevated current levels could be expected to drain the battery in a very short period of time significantly degrading the expected operational life of the AGA.

The irradiated AGA was disassembled to determine the cause of the elevated current levels. The high current level was determined to be attributed to the installation of an incorrect IC. The IC in question was a National Semiconductor version of the CD40106 Hex Schmitt Trigger located in slot U1 of board #1 but should have been the hardened Harris Semiconductor version of the same part. The ICs were somehow mixed during storage (this IC was pulled from existing stock) and the error wasn't caught during the board stuffing procedure. Removal of the IC from the board and testing on a HP4145 Parameter Analyzer showed a worst case IDDQ of greater than 100mA at VDD = 5.0V indicating that a good deal of the CMOS transistors making up the IC had probably gone depletion mode. Further analysis of U1 was judged to be unnecessary at that point.

To further confidence in the analysis of the cause of the high currents, several other ICs and discrete components were removed from the Electronics Module and evaluated using the HP4145 Parameter Analyzer. Two of the five CD4015 shift registers were removed and found to have worst case IDDQs of 5µA or less at VDD = 10.0V (the CD4015s were also pulled from existing stock). Currents of this magnitude for these ICs are well within expected limits. The remainder of the components examined showed varying degrees of degradation but were all within acceptable limits further pointing to the IC in slot U1 as the only out of tolerance device.

CONCLUSION

The outcome of the irradiation test was tainted by the inclusion of a non radiation-hardened CMOS IC in the AGA Electronics Module. Had it not been for the inclusion of this non radiation-hardened IC, test results would have indicated an AGA design fully tolerant of a 100K Rads (Si) total dose radiation exposure. To further substantiate this claim we intend to repeat the experiment at some time in the future but only irradiating the circuit boards of the Electronics Module as opposed to the full AGA assembly.

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