NOAA RFID Fishing Line Tagging

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Contact information:
Justin Patton or David Cromhout
Managing Directors
RFID Research Center
Sam M. Walton College of Business
University of Arkansas
Fayetteville, AR 72701
479.236.5890
479.575.3460 (fax)
jpatton@walton.uark.edu
dcromhout@walton.uark.edu

CONTENTS

1 EXECUTIVE SUMMARY

1.1 Objective

The objective of this study is to determine the feasibility of RFID technology to tag deep sea fishing line, and to discover effective methods of attaching these tags. Several types of RFID technology and tags are investigated, as well as methods of securing tags to fishing line so that they will remain attached, survive the ocean environment, survive handling by fishing equipment such as winches, and remain readable when the line is found.

Characterization of the entanglement problem is expressed in thess excerpts from the initial project synopsis and statement of work:

> *"The Atlantic Large Whale Take Reduction Plan (ALWTRP) was implemented by the National Marine Fisheries Service (NMFS) under the Marine Mammal Protection Act (MMPA) to address the incidental entanglement of Atlantic large whales (right, humpback, and fin whales) in commercial fixed gear fisheries, such as trap/pot and gillnet fisheries. The ALWTRP is a key component of the NOAA mission goal to "Protect, Restore, and Manage, the Use of Coastal and Ocean Resources through an Ecosystem Approach to Management." To better understand the vertical line entanglement risks posed by fixed fishing gear, and potential biological and socioeconomic impacts of additional management measures intended to address these risks, additional information must be ascertained from entanglements between commercial fishing gear and large whales. To acquire this information, Stigall Consulting Group (SCG) will explore Radio Frequency IDentification (RFID) to mark vertical lines. This is a new use of RFID. The goal of this study is to develop an RFID tag, in consultation with the NMFS Northeast Region's Protected Resources Division (PRD) Gear Research Team, which would be able to identify the source of line recovered from entangled marine mammals*
>
> *At present, NMFS lacks important gear characterization information essential to NOAA's mission goal of management initiatives to further conserve large whale species. Results of this project offer a mechanism to collect this information.*
>
> *Conceptually, several RFID tags would be placed along the line between the surface system and gear on the ocean floor (i.e., on the buoy line) and also on lines between traps on the ocean floor (i.e., on the groundlines). Lines are often set in depths of up to 250 fathoms."*

> *"Entanglements of large whales with fishing lines continues to be a problem. Reducing entanglement aligns directly with NOAA's Mission Goal to "Protect, Restore, and Manage the Use of Coastal and Ocean Resources through the Ecosystem Approach to Management." Greater knowledge of the fishery, the part of the gear (buoy, groundline, etc) and gear's owner through fishing line marking should provide direction to entanglement reduction. To date, a line marking tag has not yet been developed that is durable, easy to attach to fishing lines, low-cost, and able to provide adequate information to assist in management of large whale interactions with fishing gear."*

1.2 Investigation

An initial visit to Ocean City to understand the treatment of the fishing line was undertaken and the feasibility of some tag designs that were woven into the fishing line was investigated. After this visit, a long term salt water immersion test was performed on several samples of RFID tags to determine if they would survive long term exposure. An RFID converter that specializes in rugged environmental RFID tag designs was contracted to produce some high durability inlay encasing samples. These designs were also immersion tested, and the inlays were again tested in the field on a return visit to Ocean City.

1.3 Findings

The RFID technology is feasibile from a performance and water survivability perspective, but a method of attaching the tags to the fishing line so that it survives the stresses of the winch and pulley on the line has not been achieved.

2 OBSERVATION

2.1 Initial Ocean City Investigation

A trip to Ocean City was undertaken on October 17, 2010 to understand the environment of the line in the ocean and on the fishing boat. Several existing tag samples were studied, and information was gathered from on-site interviews and observation of line handling processes.

2.1.1 Initial Ocean City Observations

- 7/16” Sink Line and ½” Float Line Used
- 5000lb (test) line, 1200 feet of line in a 60lb (weight) coil
- Ideal line life expectancy is 6 years or 600 pulls
- Line pulled through 2” diameter block and 4” to 1’ winch

Several types of tags were attached to fishing line at ~6 foot separation (20 tags total used). These lines were tossed overboard and hauled in multiple times. Current tags displayed several issues, outlined below under photos.

2.1.2 Tags

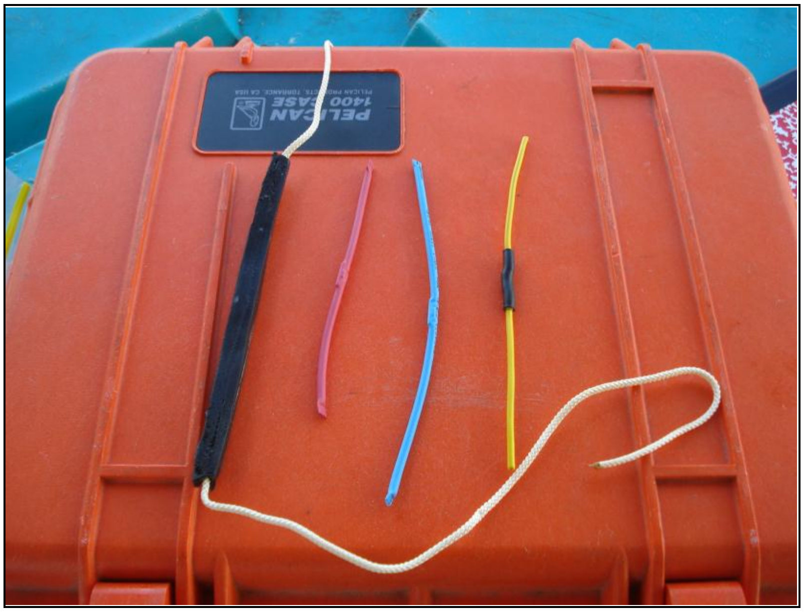


Figure 2-1 Various Weave-in Tag Types

Current tag models included long wire tags that are woven into the fishing line, as well as long rubberized tags that are tied to the line.

2.1.3 Tagging Issues

Tags were somewhat difficult to weave into the fishing line because of the tight weave in the line. Rubberized tags with string were observed to not be feasible with the line winch.

Figure 2-2 Example of Woven Tag Inserted into Line

Figure 2-3 Tag Woven into Line Traversing a Line Guide

The woven tags were cast overboard, and hauled back in several times. No tags were lost in the ocean. Several issues were observed with the tags becoming jammed or entangled in the winch, or being pulled partially loose from the line after passing through the winch.

Figure 2-4 Tag Fouling in the Winch Pully

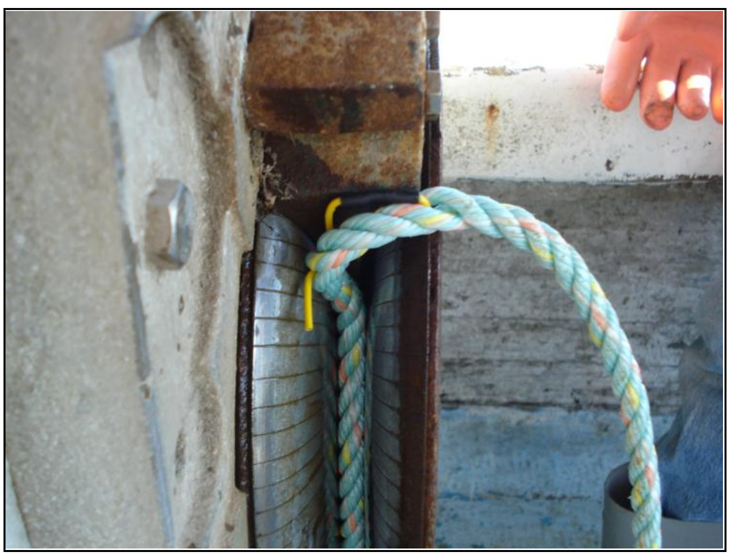


Figure 2-5 Tag Fouling in the Winch Pulley Ejection Device

Figure 2-6 Tag Fouling Under Winch Pulley Ejection Device

The ends of the woven tags hang loose from the line, and can easily become jammed or pull free from the fising line during the hauling operation through the pulley.

2.1.4 Initial Ocean City Conclusions

The tags were not immediately destroyed and did not come loose when casting into the ocean. However, the tags were unlikely to survive multiple pulls through the winch while remaining attached to the line. Overall, this method of attachement was regarded as not being feasible and focus was shifted to an adhesive type attachement method and the following inlay immersion tests were done in preparation for this.

3 INLAY IMMERSION TESTING

3.1 Tag Testing

Several types of unconverted and unprotected RFID inlays were tested:

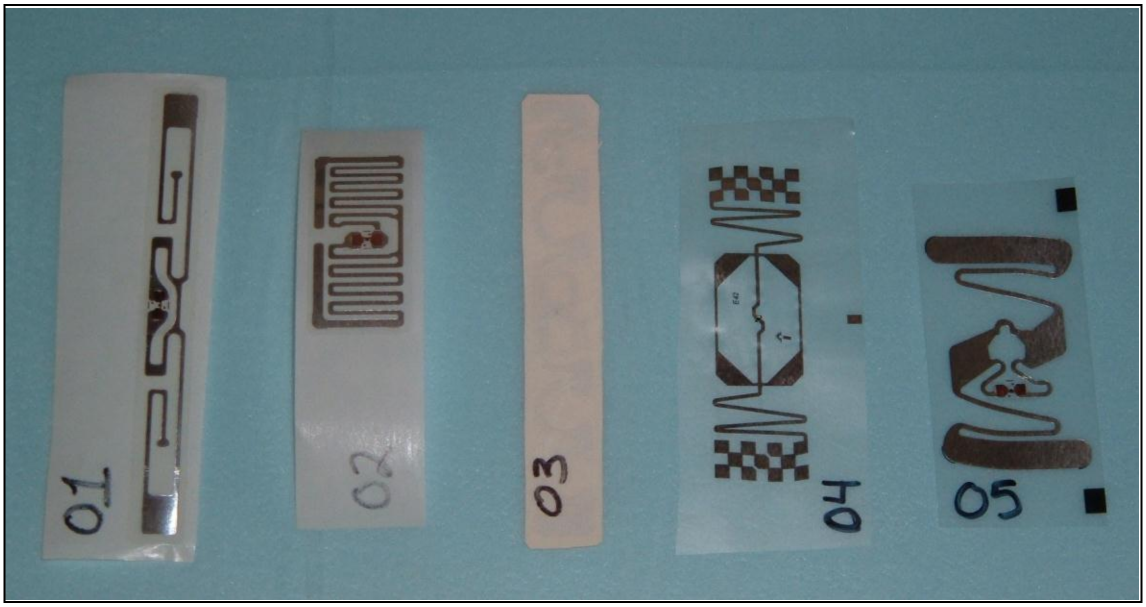


Figure 3-1 RFID Tag and Inlay Samples 1 Through 5

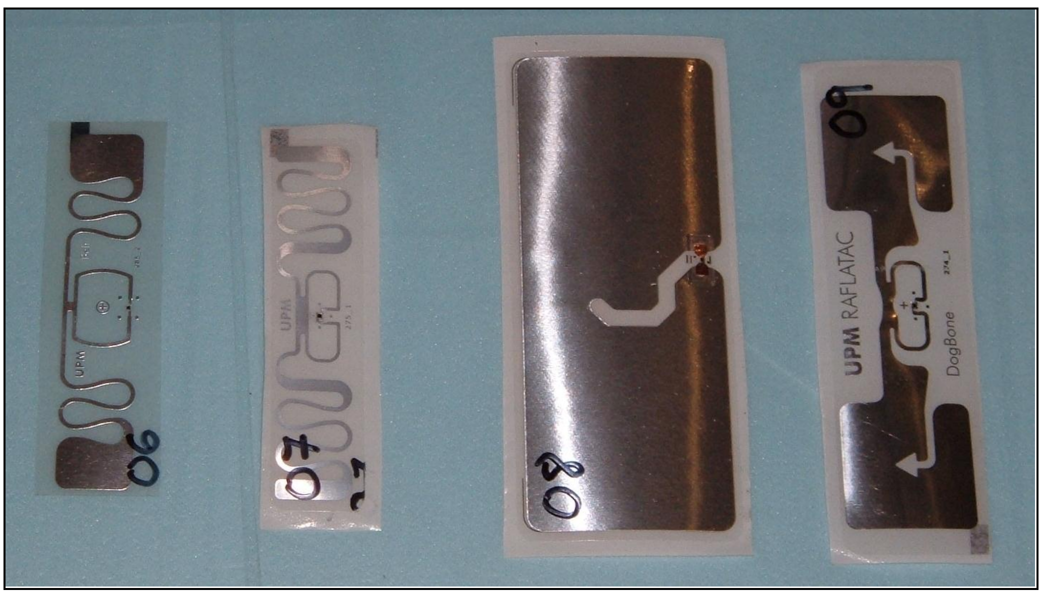


Figure 3-2 RFID Tag and Inlay Samples 6 Through 9

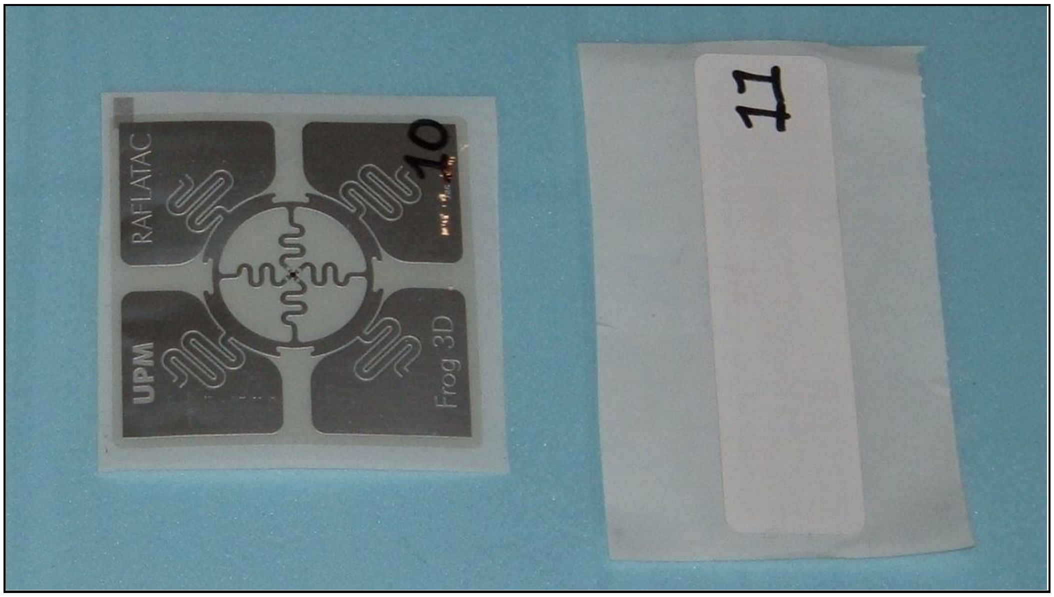


Figure 3-3 RFID Tag and Inlay Samples 10 and 11

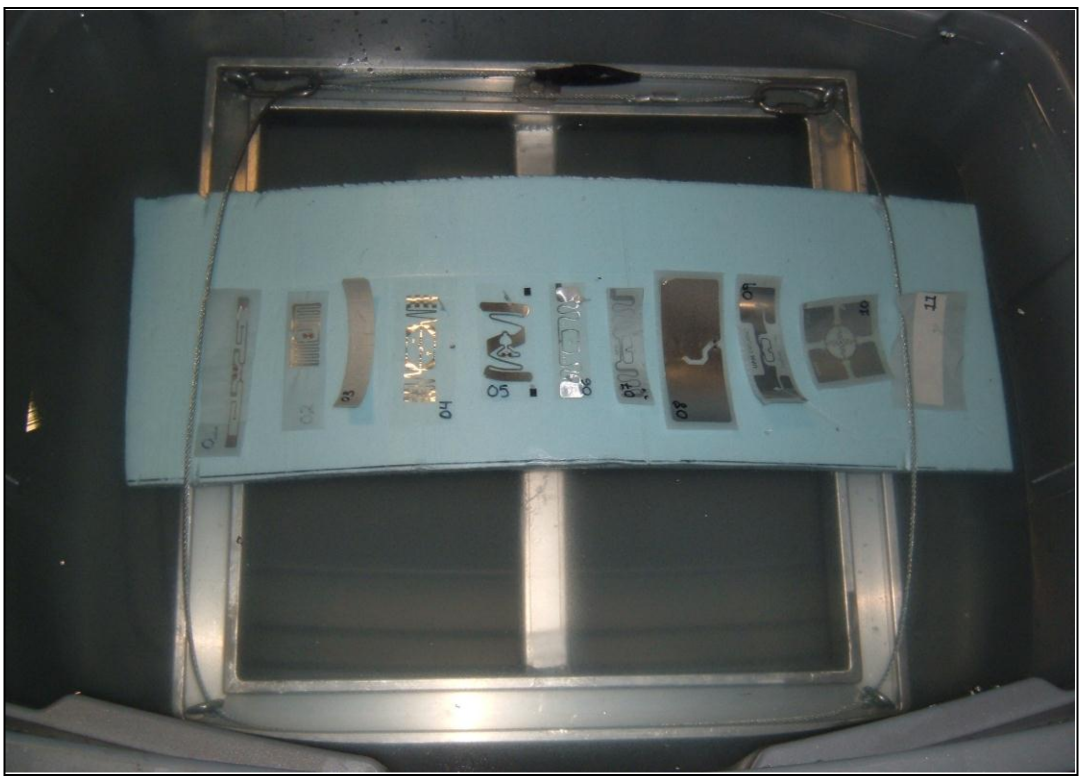


Figure 3-4 RFID Tag and Inlay Samples 1 Through 11 Submersed in Extended Saline Exposure Tank.
Salinity of 35g/1000ml (Sea Water)

These tags were immersed in a bath of 35g/1000ml saline solution. Daily testing from May 1st to September 1st showed all tags are currently still readable on retrieval.

Also, all of the prototype self fusing tags were added to the solution on June 17, 2011. These inlays remained immersed through August 20, 2011, when they were taken to Ocean City for the final field test. All of the inlays survived the immersion testing. These prototypes are pictured only in Appendix A of the report while being tested for survivability in Ocean City. They consist of a thin layer of rubbery feeling material which instantly adheres to itself, upon which the tag is placed. Appendix C contains a complete chemical description of the self fusing material from the manufacturer who developed it.

The immersion test did not include wrapping the tags in insulation for three reasons. Firstly, the open inlays tested as pictured above were undergoing protracted salinity resistance testing, and the rough treatment of manipulating them around rope and securing them with tape may have caused faults in them that might not have been indistuigishable from saline penetration failure. The same is true for the self-fusing tags immersed on June 17th. Secondly, the self-fusing material on the immersion tested tags not pictured would not have released and would have renedered those specimens useless for further testing had they survived (which they did). At the time, our intention was to preserve as many specimens as possible for the mid-term survivability testing. And thirdly, the true test of the adhesive tape was to assess it's survivability during stress testing through the fishing mechanisims of the boat. As can be seen in the photographs of Appendix A, the electrical tape used as the "start-of-test" marker became somewhat fouled during the testing, placing it's survivability in question.

Furthermore, upon arrival at the boat for the mid-term survivability testing, both the NOAA representative and the fishing vessel captain commented that electrical tape was not a practical or deployable solution since it would not sufficiently adhere to wet fishing line. The fishermen generally considered that of all commercially available tape types, electrical tape is the most durable when adhered to rope under trawling conditions and other tape types that might adhere under wet conditions were dismissed for lack of durability. A solution that adhered to both wet line and was very durable is sought. This was new information that had not been previously expressed by them.

4 SURVIVABILITY TESTING

Survivability testing was performed in Ocean City because the procurement revealed we could not afford a lab based Pulley system equivalent to what is commercially used. Not initially understanding the full cost of these pulley systems, our stated plan had been to purchase one for laboratory testing where hundreds or even thousands of repititions could be performed on tag survivability. As an alternative, we performed a mid-term survivability test trip in the field using actual pulley mechanisms. Projected capital expenditure was use transferred to travel cost for the 2nd visit to Ocean City.

4.1 Visit Summary

A return visit was made to Ocean City in August 24th and 25th, 2011. The tags that would adhere in the wet and dirty conditions of the boat were tested over 25 runs through the pulley with a heavy weight on the rope. None of the tags survived the attachment method (electrical tape was not used), and only the UHF tags survived readability testing. Electrical tape was not used since interview with fisherman determined it was not considered a feasible solution for wet, in-field, attachment, and because it is known to become separated from the rope after approximately a year of use even when applied in dry conditions. A solution that is applicable in both dry and wet conditions is sought.

4.2 Test Description

Self-fusing material was chosen to attach RFID inlays to the fishing line. Self-fusing material will molecularly crosslink when overlapped to itself, so the layers essentially become one. Self-fused tags in the test overlapped by a fraction of an inch, not providing a large self-fused area. As well, adhesion of self-fused material to the line is moderate. Different colors indicate different thicknesses.

Two types of RFID tags were used: Ultra High Frequency (UHF), nominally 915Mhz carrier using ISO 18000-6C protocol, and Near Field Communication (NFC) High Frequency, nominally 13.56Mhz carrier using ISO 15693 protocol. UHF tags, operating in the far field with standing waves, normally offer long range reads measured in meters. NFC HF tags, operating via inductive coupling, tend to be limited to less than 3cm range. These are the two major types of passive RFID and offer a good sampling of the technology currently available. NFC tags were tested in anticipation of most future mobile phones being NFC enabled. An integral HF reader in a personal mobile phone would allow NOAA personnel assured access to a fishing line reader vs requiring a special purpose UHF reader.

Due to understanding that some form of protective backing might help with tag survivability we suggested to our tag hardening partner that a face stock similar to electrical tape, but with a more aggressive self-adhesive likely could yield a scalable execution (scalable being materials and processes that could be commercially combined to provide the tags in a format that fisherman would not consider burdensome to apply to line.) The tag hardening partner assessing emerging materials suggested the self fusing material to both strong adhere to itself and at the same time provide some cushioning to the RFID inlay when exposed to extreme pressures. The tag hardening partner did indicate that additional process development work would be required to scale the process to make self fusing based RFID tags readily available to the fishing industry.

These materials are being combined with multiple longer and shorter range RFID tags, some of which would allow future applications and readability at longer range (several feet), and some of which would be short range applications that are now being made widely available in modern cell phones.

The self fusing material and face stock are transparent at RF frequencies. As a human visible indicator that an RFID tag is attached to a line, the visual spectrum contrast between the line and the tag should be sufficient to spot a tag. Many of the tags under consideration are small enough that it woud not be feasible to attach the ends, and leaving the center of the tag exposed introduces a greater possibility of damage or separation. However this attachment method can be considered for longer tag models.

The test was started with:
3 Black-backed UHF tags
4 Grey-backed UHF tags
1 Black-backed NFC tag
5 Red-backed NFC tags

Each tag was placed on the rope approximately one fathom (6 feet) apart. Approximately 78 feet of rope had tags attached and an extra 30 feet of rope was used during the test.

The rope was thrown overboard and placed under tension before being brought aboard with the winch pulley.

4.3 Definition of a Run

A "run" consisted of the rope, with a large concrete weight attached to the end, being thrown overboard. The concrete block placed on the line was not intended to simulate trap weight as much as it was intended to create sufficient line drag needed to force the rope over, around, and across any surfaces it would naturally encounter when hauling a trap. The block successfully created sufficient resistance to achieve shear forces over certain surfaces, such as the edge of the deck, and stress forces, such as needed by the pulley. The rope was then tensioned through positioning of the boat, after which the pulley and winch system was used to bring back onboard the entire length of rope containing the tags. The tags were then individually read using the appropriate reader (NFC and then UHF). The UHF reader was powered down to lowest power to ensure that only the tag under test at any single moment was read.

4.4 Test Process

Twentyfive runs were performed. The entire test took approximately 2 hours to complete. By run 21 all the self-fused tags were essentially destroyed. The cause was not obvious but was considered to be the rope dragging across the edge of the boat hull, deck rail, wench wedge, or pulley edging. This rendered all but the now-exposed UHF tags unreadable. IF some UHF tags remained intact and partially adhered to the rope at this stage, they read. This included 1 black-backed UHF tag and 2 grey-backed UHF tags.

However, due to the generally unacceptable condition in which the tags were now adhered – some dangling precariously from the rope with only fractions of an inch of antenna pinched between the backing and the rope – that individual reading was abandoned for the remaining 4 runs. Again, only the UHF tags were readable at this point, the final working NFC tag/s had been destroyed on run 21. On the final run, number 25, the remaining UHF tags were read and found operational, although, again, this is a moot point since the manner in which they remained adhered to the rope is an unacceptable deployment scenario. Therefore, at the end of the test, a single black-backed UHF tag, and two grey-backed UHF tags, while almost completely detached, remained readable.

4.5 NFC Performance

Interestingly the NFC tag's performance would deteriorate over time to a point of failure. It would take a longer amount of time to read them. This can be seen in the comments within the data table. Based on the slowing read rate for each NFC tag, their individual imminent failure could be accurately predicted; that is, the order in which they would probably stop working. This is not something typically witnessed in UHF tags. UHF tags undergoing physical endurance testing traditionally either work, or don't work from one run to the next, with no reduction in the amount of time it takes to read their identifier. One hypothesis is the NFC tag antenna stress cracked in many places from all the stretching and sharp bends, changing the conductivity of the NFC antenna, and thus its resonance tuning. Since UHF tags operate via a standing wave on the antenna, stress cracking is not as noticeable until complete antenna breakage occurs.

4.6 The Winch Pulley

The pulley system on the boat is designed to guide the rope into an ever-narrower gap thereby crimping the rope with enough force to pull a sizable load. Loads in excess of 3,000 lbs can be applied to the rope under normal working conditions. It is not uncommon for the load on the rope can outweigh the hydraulic force of the pulley motor, making the motor scream and stall since the rope is gripped too tightly to slip. A steel wedge is fixed permanently into place on the exit side of the winch pulley in order to help the rope out of the narrow, gripping wedge and onto the boat deck. As a result, there are several severe pressure points and sharp rubbing angles to which the rope is subjected on every rewind. All of these have the potential to "smear" off anything applied to the outside of the rope.

4.7 Source of Stress

It is uncertain whether the instant pressure applied by a sudden change in angle of the rope over a deck rail, pulley wheel, winch wedge (a sheer or "smear" force) tear the self-fusing material off the rope. As well the general crushing pressure of the winch pulley (pure squeezing pressure) caused the most damage to the antenna or integrated circuit that provides the RFID functionality.

4.8 Best Performance

As can be seen from the data, the red-backed tags outperformed the other methods of attachment. However, the red-backed tags suffered the same fate as the others on run 21.

4.9 Insights to Possible Workable Solution

The solution for identifying line, no matter what the method, is desired to be deployable under both dry and wet conditions. Electrical tape was dismissed as potential method of attachment due to its inability to remain adhered when applied in wet conditions, as well as its tendency to become detached after approximately a year, even when applied in dry conditions.

As well, the nature of stranded, twisted line is repeated cycles of tension and slack make adhesion of a tag difficult. Such line elongates 10% when tensioned to test strength while RFID tags can only elongate tenths of percent when in tension. Also the diameter of the line decreases a similar amount at test tension.

As a matter of interest, a marker was placed on the rope in order to indicate the start of the tagged portion. A tagless piece of black backing from one of the destroyed NFC tags was used as the marker, and wrapped electrical tape was wound around it. It out-survived the other adherence methods.

During the course of the test the physical condition of this marker remained unchanged; it was unaffected by the forces that destroyed all the tags on run 21. In light of the fact that electrical tape becomes detached over time in salt water, the condition of this marker at the end of the test might not serve any meaningful interpretation. At the most, this marker remaining intact indicates that a tapered leading and/or trailing edge on whatever is secured to the outside of the rope handles smear/sheer forces better than those without.

Additionally, there was no testable tag in this marker so it is possible that while a leading and/or trailing edge keeps the tag better insulated from smear/sheer forces, it does not protect from the crushing forces of the pressure within the narrow gap of the winch pulley which may be what causes the NFC tag performance to decay over time and eventually fail.

Full data including performance tables and photos are attached in Appendix A of this document.

4.10 Notes: Black Backed NFC Tags

Only two black-backed NFC tags would adhere to the rope under the damp conditions of the boat and rope. One of these tags was lost during submersion on the first run. The second tag became semi-detached on the first run but remained on the rope until run 5 when it fell from the rope onto the deck. It was, however, still readable. Detachment is a consequence of the self-fusing material, not the NFC tags.

4.11 Notes: Grey Backed NFC Tags

One of the grey-backed UHF tags had been submersed in sea water in the lab for the past 2 months and had lost all its adherence properties. It could not be used in this stage of the testing. This indicates the self-fusing material surface cannot be compromised by long duration exposure to salt water before being adhered to itself.

4.12 Notes: Rope

The rope used was 7/16” diameter.

5 CONCLUSIONS

5.1 Project Conclusions and Next Steps

The UHF RFID inlays are very rugged and will survive the stresses of the fishing line during both longterm water immersion and the rough handling of the line. The NFC RFID inlays didn't fare as well and are not a candidate. They were more susceptible to failure especially under the stretching extremes of the line as handled through the winch mechanism. Various attachment methods were tried, including some very rugged custom attachment designs, but currently no type of attachment and shielding was rugged enough to survive the stresses of the winch environment. Field or 'on-board' attachment of RFID tags to fishing line is not an option.

It is of interest that attachment during line manufacturing, before exposure to moisture and dirt, might be successful if done under test tension. That is, if the tag is attached while the line is elongated by test tension and the self-fusing material made at least one complete wrap of itself, then it may function when tension is released yet not suffer the effects of stretching. If this attachment process is used, the line would have to be checked to discern how much this would affect the thickness of the line for pulley considerations.

Currently the RFID technology is definitely feasibile, but a method of attaching the tags to the fishing line so that it survives the stresses of the winch and pulley have not been achieved.

Very high levels of required durability coupled with the small required footprint of fitting the tag through the winch and the capability of adding and removing tags in the field are very steep requirements for current passive RFID technology. Future research will most likely involve testing very long inlays with ends that are further apart and less likely to foul in the winch, or non-removable inlays integrated into the line itself. As, the RFID technology seems sound, but there is a lot of work required in the attachment material, further work on this topic will most likely focus on the area of material attachment rather than RF technology. Lab development of attachment methods is desired.

Current work on tagging line in environments that do not utilized handling equipment as destructive as the winch are being investiaged with the current results. Logistics and consruction applications for validating that product has not been disturbed during shipping, or the history and safety of line or rope can be addressed.

APPENDIX A

Final Testing Data

Data including performance tables as well as photos and commentary on various attachment methods and issues are attached in the following pages of Appendix A.

Data: Table 1 - Tag Reads Collected per Run from Each Tag Type

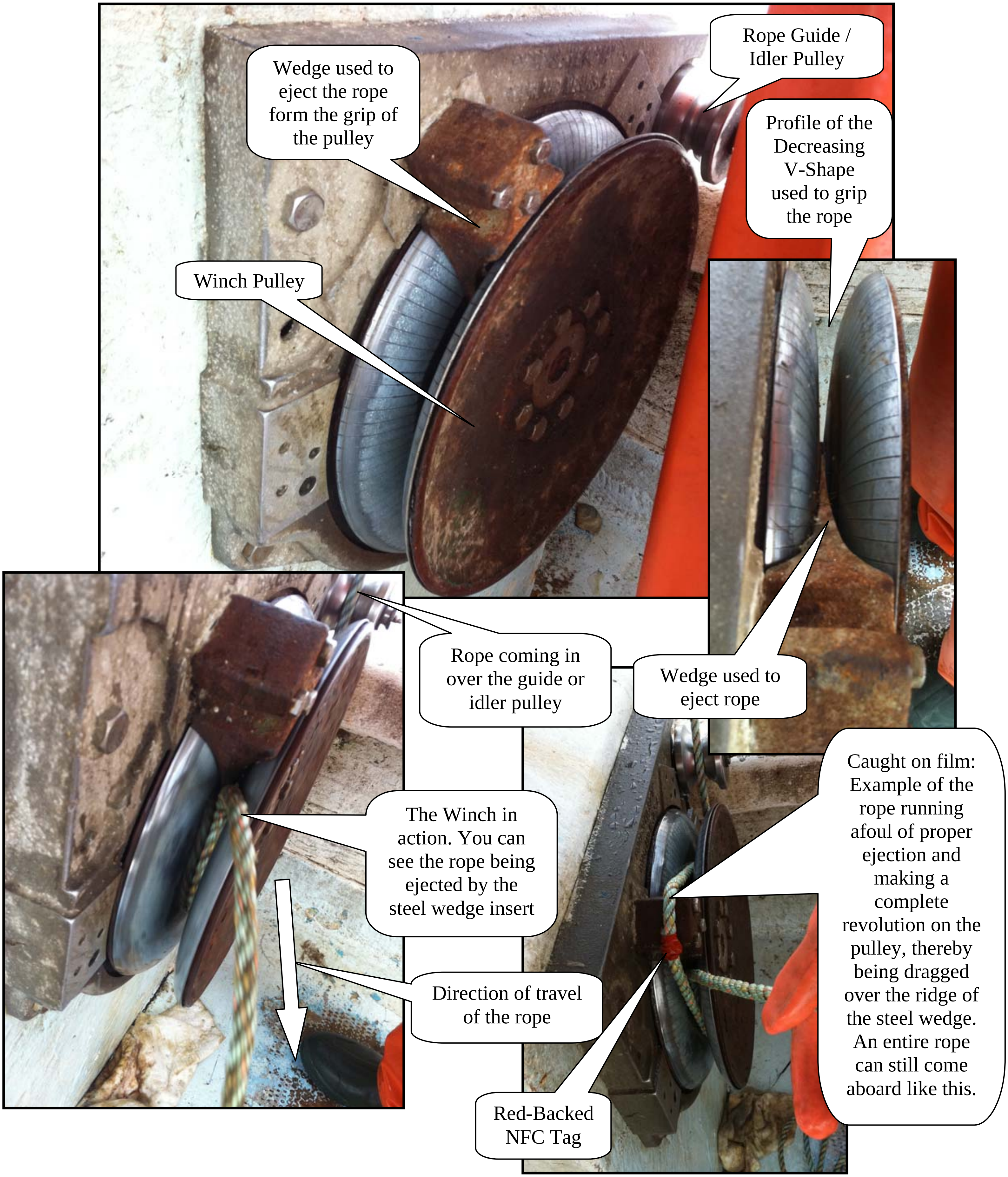
Run	Black NFC	Red NFC	Black UHF	Grey UHF
Beginning Status	2	5	3	4
	Remaining 3 unable to adhere	All tags adhered	1 destroyed during bending and 1 unable to adhere	1 unable to adhere
1	1 (1 Detached)	5	3 (All becoming detached)	4
2	1	5	3	4
3	1	5	3	4
4	1	5	3	4 (2 Becoming detached)
5	0 (1 Detached)	4 (No. 4 Dead)	3	4
6	0	4	3	4
7	0	4	3	4
8	0	4	3	4
9	0	4	3	4
10	0	4	3	4
11	0	4	3	4 (Increased degree of detachment)
12	0	4 (No. 1 Slow)	3	4
13	0	3 (No. 3 Dead)	3	4 (Increased degree of detachment)
14	0	3	3	3 (No. 4 tag gone although backing semi-attached)
15	0	2 (No. 1 Dead and 2 & 5 slow)	3 (No. 3 becoming detached)	3
16	0	2	2 (No. 3 Detached)	3 (Increased degree of detachment)
17	0	2 (No. 5 corner detached)	2	3
18	0	2	2	3
19	0	2	2	3
20	0	1 (No. 2 Dead)	2	3
21	0	0	1	2
22 (Pull test only)	0	0	1	2
23 (Pull test only)	0	0	1	2
24 (Pull test only)	0	0	1	2
25	0	0	1	2

All tag backing destroyed. Appears to have been dragged under force across the edge of some surface. Only UHF tags, where present, still operational

All tag backing destroyed - only UHF tags, where present, still operational

Table 1 - Tag Reads Collected per Run from Each Tag Type

University of Arkansas RFID Research Center – NOAA – Fishing Line Identification
Feasibility Study
Rope Winch Photographs



University of Arkansas RFID Research Center – NOAA – Fishing Line Identification
Feasibility Study
Black-Backed UHF Tag Photographs

UHF Tags Directly after Application

UHF Tags after Run 14

UHF Tag after Run 15

Same UHF Tag on Deck after Run 16

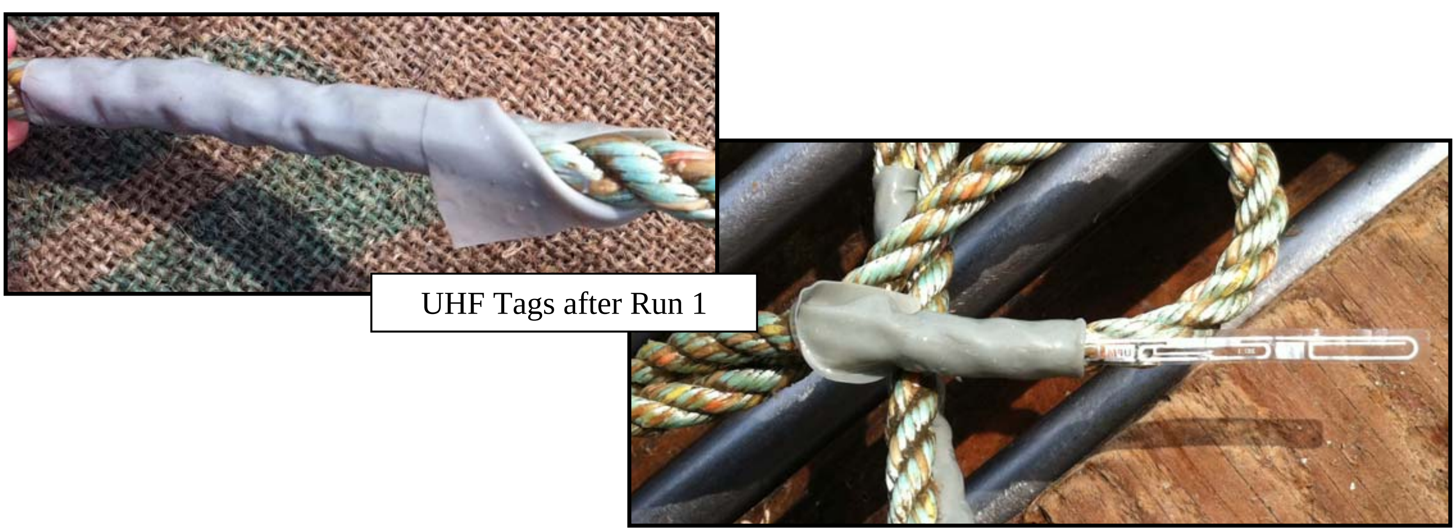
UHF Tag after Run 21

Tag still readable

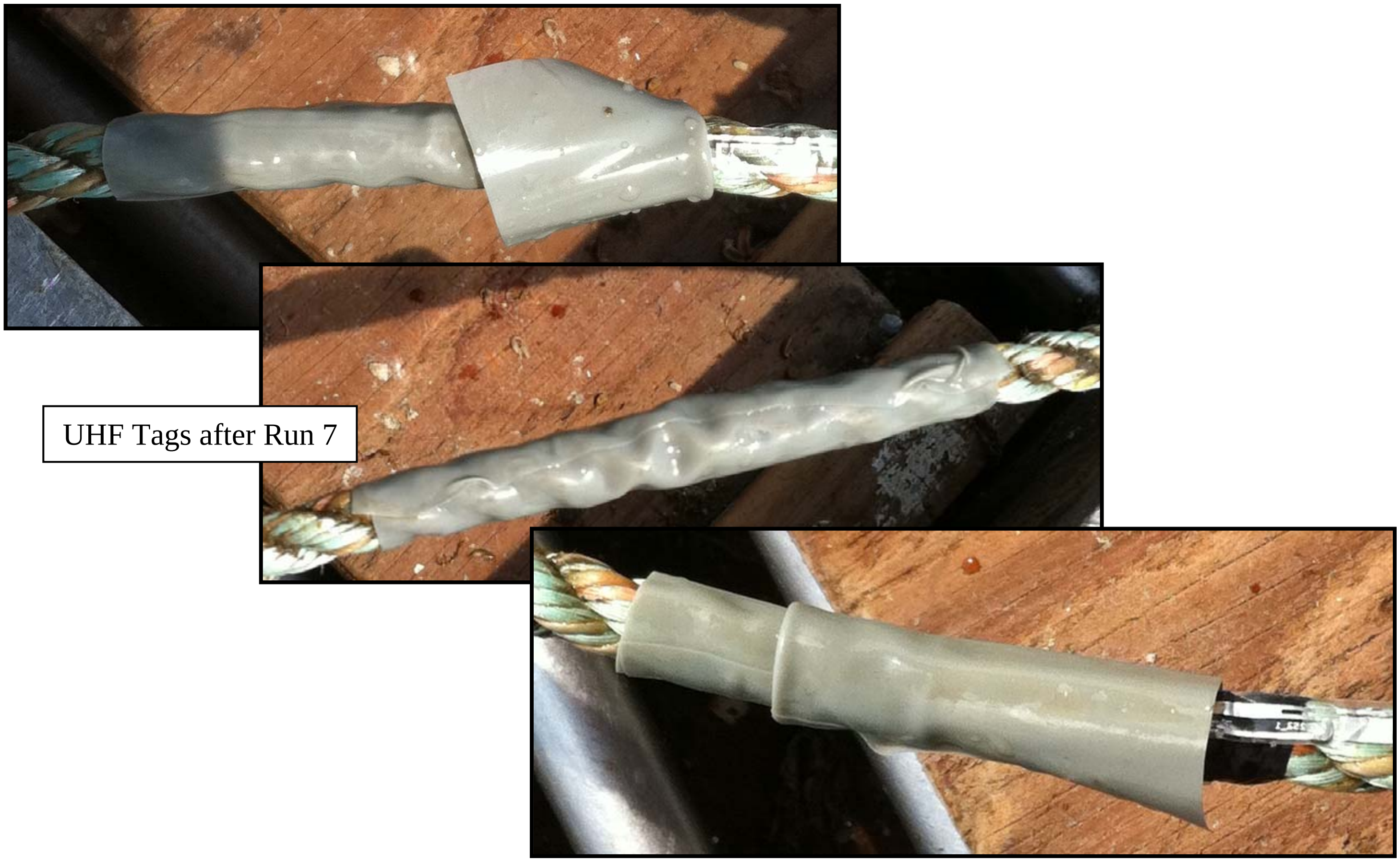
UHF Tags after Run 25 – End of Test

Grey-Backed UHF Tag Photographs

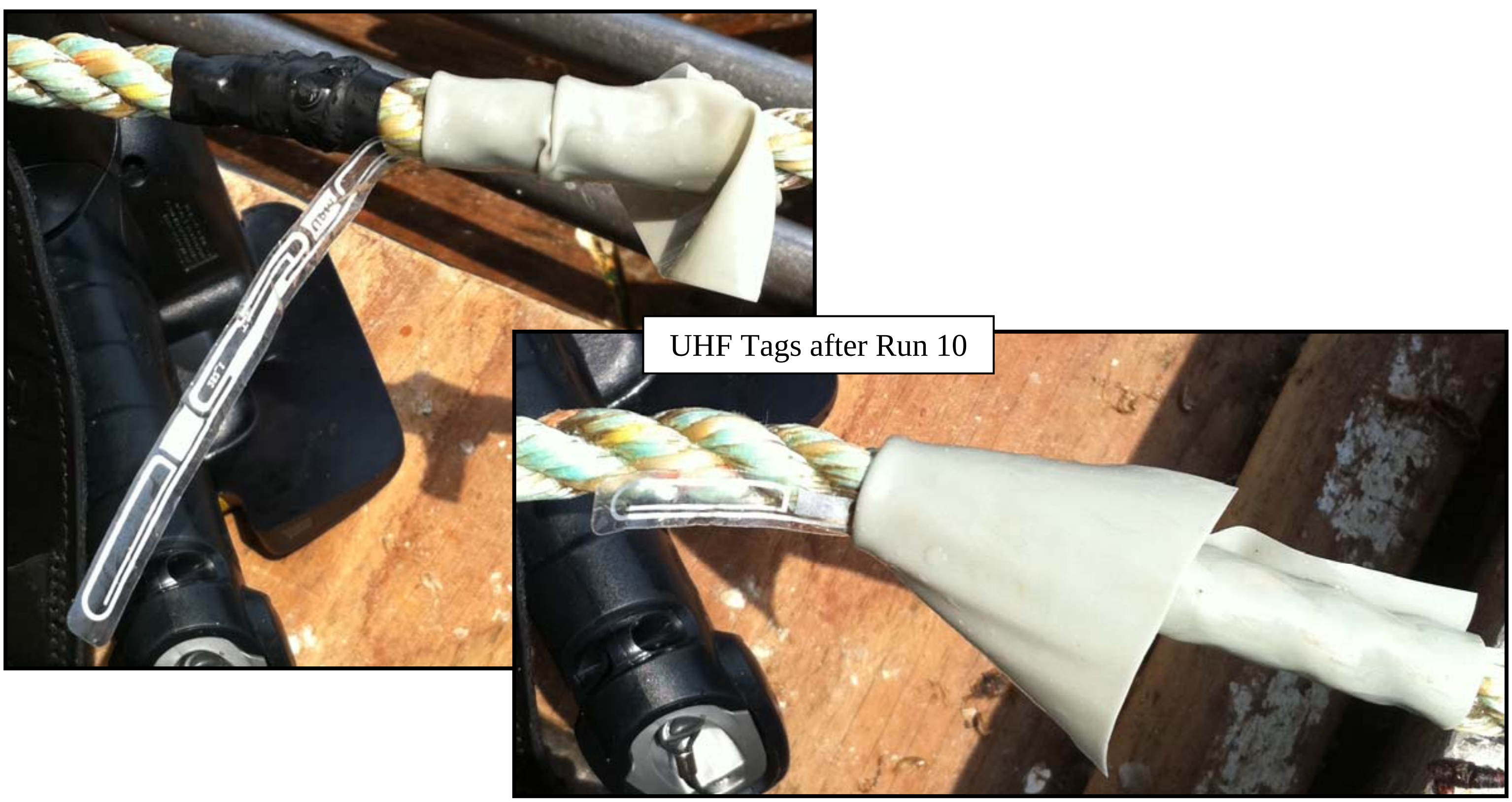
UHF Tags Directly after Application



UHF Tags after Run 1



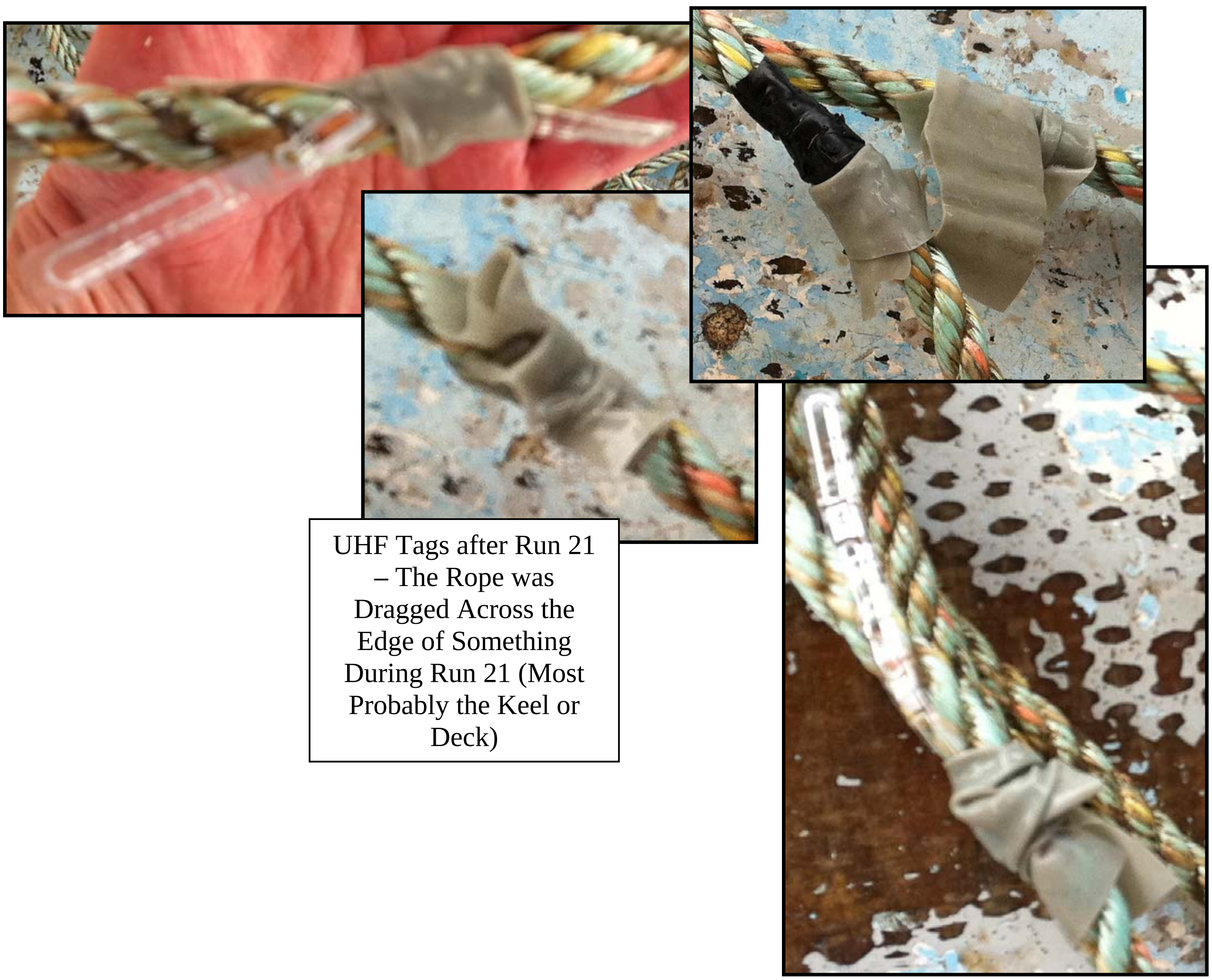
UHF Tags after Run 7



UHF Tags after Run 10

University of Arkansas RFID Research Center – NOAA – Fishing Line Identification
Feasibility Study
Grey-Backed UHF Tag Photographs

UHF Tags after Run 14



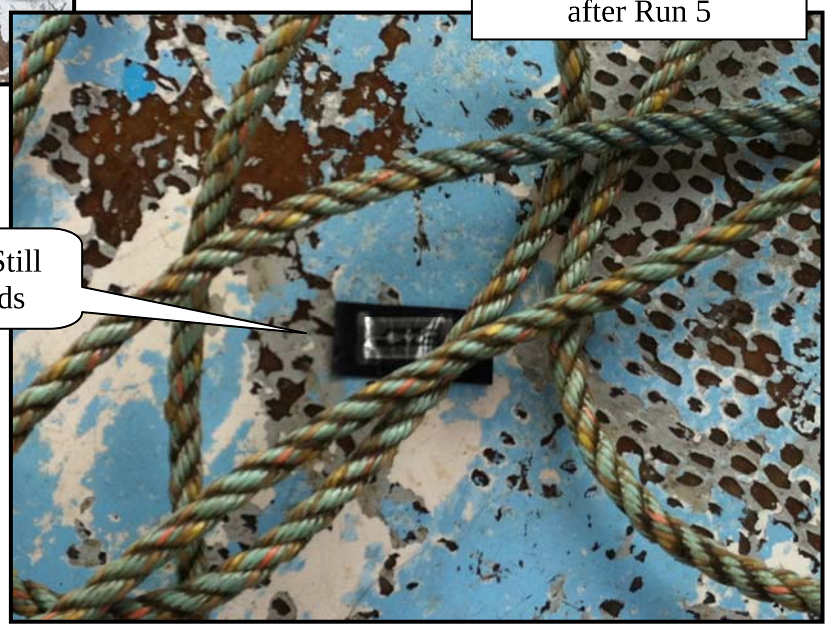
UHF Tags after Run 21 – The Rope was Dragged Across the Edge of Something During Run 21 (Most Probably the Keel or Deck)

UHF Tags after Run 25 – End of Test

University of Arkansas RFID Research Center – NOAA – Fishing Line Identification
Feasibility Study
Black-Backed NFC Tag Photographs

NFC Tag Directly After Application

NFC Tag on Deck after Run 5

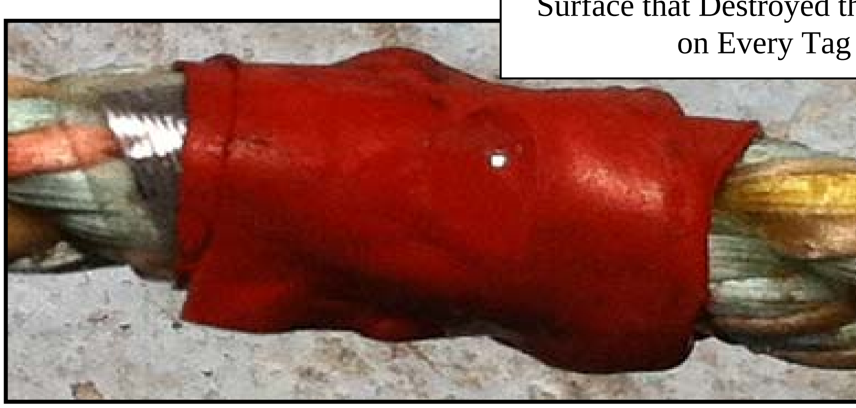


University of Arkansas RFID Research Center – NOAA – Fishing Line Identification
Feasibility Study
Red-Backed NFC Tag Photographs


NFC Tags Directly After Application – Showing Two of the Five Tags (All Similar Adhesion)

NFC Tag after Run 17 – Only Red NFC Tag Exhibiting Any Change in Backing Properties




NFC Tags after Run 21 – Run 21 Caused the Rope to Drag Across a Surface that Destroyed the Backing on Every Tag


NFC Tags after Run 25 – End of Test

Tagless Backing Wound with Electrical Tape as a Start-of-Test Marker

Tagless Backing Wound with Electrical Tape as a Start-of-Test Marker after Run 10

APPENDIX B

STUDY INSIGHT/RESULTS COMPARED TO STATEMENT OF WORK

COMMERCIAL FISHING LINE RFID TAGGING STUDY

1 AIM:

The goal of this project is to assess the feasibility of RFID (Radio Frequency IDentification) tags to track fishing line throughout the ocean in the fishing season, and to be able to identify the source of fishing line recovered from marine animals. **Goal Remained Unchanged**

2 BACKGROUND:

Entanglements of large whales with fishing lines continues to be a problem. Reducing entanglement aligns directly with NOAA's Mission Goal to "Protect, Restore, and Manage the Use of Coastal and Ocean Resources through the Ecosystem Approach to Management." Greater knowledge of the fishery, the part of the gear (buoy, groundline, etc) and gear's owner through fishing line marking should provide direction to entanglement reduction. To date, a line marking tag has not yet been developed that is durable, easy to attach to fishing lines, low-cost, and able to provide adequate information to assist in management of large whale interactions with fishing gear. RFID tags have been used for identification in logistics and other commercial sectors, but are limited in providing this greater knowledge because of the abuse the lines endure being in the ocean, being tossed around and compressed by line tension. This study will categorize the failure modes of the RFID tags under fishing abuse and discover techniques to sufficiently lengthen the life of a low cost, easy to attach, durable RFID tag. **Background Remained Unchanged**

3 OBJECTIVES:

To achieve the above aim the project has six technical objectives / areas of development-

- Assess the ability to read currently marketed passive RFID tags on a boat via standard portal reader/antenna. **No identification need was determined on board fishing boats during the 1st Ocean City trip to merit a fixed reader/antenna**
- Assess the ability to read currently marketed passive RFID tags on a boat via handheld readers **Both handheld UHF readers and the HF reader embedded in an NFC phone proved sufficient, reliable, and robust enough for boat and beach reading. UHF readers must store data and be connected to a data base, while NFC gathered data can connect to a data base if cellular service is available**.

- Assess the readability/survivability of RFID tags after going through the pulley system in a laboratory setting **Because pulley system costs far exceeded budget allocation, testing was done on boats. Such testing indicated UHF RFID tags would continue to be readable after repeated pulley pulls, while NFC HF RFID tag RF performance tended to degrade to failure quickly**.
- Access the readability/survivability of RFID tags submerged in salt water for days and weeks in a laboratory setting **Commercial, commodity UHF RFID tags remained readable when submerged in a laboratory saline solution equivalent to ocean salinity in excess of 6months with no signs of failure**.
- Assess the proper attachment of tags to the fishing line to ensure adequate reads Robust attachment proved to be the key limitation. **Trying to weave UHF RFID tags into the woven fishing line proved to be unreliable in the 1st Ocean City visit. Research was focused on adhesive attachment because electrical tape used as a depth marker was used by fishermen. However, the first execution and test of the most aggressive approach to adhesion, self fusing material, proved unable to withstand sharp bends and edges encountered on a boat. As well, attachment to wet, dirty, or both, line on a boat appeared to reduce the quality of adhesion. A proposed next test step is proposed**.
- Develop a tag or marking tape containing an RFID tag that is low-cost and easy for fishermen to attach to their lines that will withstand a year of use. **No attachment mechanism was found that allows attachment to fishing line on a boat. It is hypothesized that attachment during or post line manufacture, before exposure on a boat with the self fusing material might yield a RFID tag that stays attached for several years. As well, combining commercial RFID tags with the self fusing material would require some additional process development to scale to several hundred thousand per year.**

4 TECHNICAL APPROACH / STEPS:

Design tests that will quantify the performance and failure modes of tags on fishing line during fishing gear hauling and during actual application of tags on fishing line currently in use. Specific testing procedures will be determined after water and pulley testing environments are created. Ultimately, hardening techniques will be developed enabling the RFID tags to overcome the failure modes of salt water submersion, line tension, pulley compression, and deck impact.

1. Initial tests on readability/survivability/failure modes of existing RFID inlays will be developed and conducted based on testing methods developed specifically for the study after observation of the fishing process at sea. **Done per 1st Ocean City visit and early in-lab salinity tests**

2. Initial testing on readability/survivability/failure modes of existing attachment methods for existing RFID inlays will be conducted based on testing methods developed specifically for the study after

observation of the fishing process at sea. **Done per 1st Ocean City visit**

3. Testing on readability/survivability of hardened RFID inlays and attachment methods will be conducted based on the previously developed testing methods These hardened RFID inlays will be tags developed in cooperation with the RFID tag vendor community to meet specifications determined by testing of currently available tags, the developed testing methods and observation of the fishing process at sea. **Hardening and aggressive adhesive development done with William Frick Co.**
4. Final at-sea test of the hardened tags that pass laboratory readability/survivability testing **Done per 2nd Ocean City visit**

5 METHODS:

Investigators will travel to observe commercial fishing at sea and will observe current fishing line handling processes. Based on these observations, testing methods will be specially developed in order to quantify the survivability of hardened tags, durability of the hardened tag attachment process, and the ability to read the tags using RFID readers. These testing methods will simulate fishing line handling conditions at sea. Equipment similar to that on fishing vessels will be purchased in order to perform these tests. Currently available tags will be tested with these methods, and the points of failure will be noted. Currently available tag attachment methods such as tape, adhesives, or other methods will be tested with these methods, and the points of failure will be noted. Based on the results of testing, specifications for a prototype hardened tag will be created. These specifications will be used to obtain prototype hardened tags from the RFID tag vendor community. These hardened tags will be tested using the methods developed for this project. Based on the results of the prototype hardened tags, a specification for a final, functional tag will be created. The final tag will be submitted for testing on fishing line in use at sea. A final report will be prepared detailing the specifications of the functioning hardened tags, as well as any testing data proving the at-sea worthiness of the final tag. **Done per above except:**

-in-lab simulation with realistic pulley systems was unaffordable with the requested budget, leading to only on-boat pulley testing

-content for a final specification for a commercial RFID tag to attach to fishing line was not discovered due to the harsh handling occurring in fishing with the allotted time and budget. Potential, positive next steps to discover such content were provided.

6 DELIVERABLES:

1. Report including specific read information and survivability information on all tags tested as well as various attachment methods **Included**
2. Report describing RFID tag life ending causes **Included**

3. Recommendation of tags that meets requirements for survivability and readability **UHF RFID tags appear strong candidates, but more exposure testing is required to discover the years before failure**
4. Recommendation of tag attachment methods that meets requirements for survivability and readability **Shortcoming of tested approaches and potential next step provided**

7 MILESTONE SCHEDULE:

Activity	Weeks from Funding
Background Study	2
Existing Tag Lab Tests	6
Create Hardened Tag Prototypes	8
Test Hardened Tag Prototypes	21
Assess Results and Propose Final Design	25
Test Prototype Hardened Tags in Field	30
Complete Report	36

8 BROADER IMPACT AND FUTURE SCOPE:

1. Future tag and hardware development for nautical use **Provided**
2. Insight into future RFID use cases in a nautical environment **Provided**

9 EVALUATION CRITERIA

Applicant Qualifications

Stigall Consulting Group (SCG) has been engaged by various suppliers of Passive RFID tags since 2001. SCG has been engaged to develop emerging applications since 2001 by UPM Raflatac, the world's largest supplier of passive RFID tags. Mr. Stigall has worked with several specialized RFID tagging hardening partners. Mr. Stigall has contacts at several academic RFID labs that can be contracted for repetitive testing at relatively low cost. All SCG's experience and partner network connections are available to advise and prototype potential solutions for fishing line tagging.

9.1 Outreach and Education

SCG and the involved partners will be willing to present the research results in suitable venues.

APPENDIX C

Self Fusing Material Specifications

WILLIAM **FRICK**™ & COMPANY

Innovations in Identification

(847) 918-3700 • FrickFax: (847) 918-3701

PRODUCT INFORMATION SHEET

Product Description

Silicone Rectangular Tape

PRODUCT INFORMATION

	MIL Specification: A-A-59163	
Design / Construction	**Value**	**Tolerance**
Thickness	.020"	+/- .002"
Width	1.00"	+/- .020"
Length	36 ft.	+/- 6.00"
Tape Colour	Orange / Red	N/A
Guideline Colour	None	N/A
Physical Properties	**Value**	**Specification**
Tensile Strength (PSI)	1100	700 Min. ASTM D412
Elongation (%)	360%	300 Min. ASTM D412
Inclined Mandrel Tack Test (inch.)	0.25	ASTM D2148
Bond Strength (1 inch. width, pounds)	5.5	2.0 Min. ASTM D2148
Dielectric Strength (Volts/mil)	575	400 Min. ASTM D149
Reinforcement Material	N/A	
Interleave Material	.002" thk. Mylar	
Product Operating Temperature	-90 Deg. C to +260 Deg. C	
Product Shelf Life	Two Years	

Note: Shelf life is defined as the duration of time for which the product will meet the physical requirements outlined above. It does not guarantee the product's usefulness in all applications.

COMPOUND INFORMATION

Physical Properties	**Value**	**Test Method**
Tensile Strength (PSI)	1200	ASTM D412
Elongation (%)	550	ASTM D412
Tear Strength (lb/in)	130	ASTM D624 Die B
Durometer, Shore A Points	50	ASTM D2240

FLAME RETARDANCE INFORMATION

Flame Test Method	FAA 60 Sec. Vertical	
Flame Test Information	**Value**	**Tolerance**
Flame Time (seconds)	N/A	N/A
Glow Time (seconds)	N/A	15 sec. Max
Char Length (inches)	N/A	6" Max.

FUEL RESISTANCE INFORMATION

Fuel Test Information	**Value**	**Test Method**
Volume Change After 24hr Immersion @ 73F	N/A	ASTM D471 Ref. Fuel C
Hardness Change After 24hr Immersion @ 73F	N/A	ASTM D471 Ref. Fuel C
Elongation Change After 24hr Immersion @ 73F	N/A	ASTM D471 Ref. Fuel C
Tensile Change After 24hr Immersion @ 73F	N/A	ASTM D471 Ref. Fuel C

The data presented in this document represents typical values for the production material. This data should not be used to write, or in place of, material specifications.

William Frick & Company 2600 Commerce Drive • Libertyville, Illinois • 60048 | **www.fricknet.com**