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9978 and 9975 Type B Packaging Internal Data Collection Feasibility Testing

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EXECUTIVE SUMMARY

The objective of this report is to document the findings from a series of proof-of-concept tests performed by Savannah River National Laboratory (SRNL) R&D Engineering, for the DOE Packaging Certification Program to determine if a viable radio link could be established from within the stainless steel confines of several drum-style DOE certified Type B radioactive materials packagings. Two in-hand, off-the-shelf radio systems were tested. The first system was a Wi-Fi Librestream Onsight™ camera with a Fortress ES820 Access Point and the second was the On-Ramp Wireless Ultra-Link Processing™ (ULP) radio system. These radio systems were tested within the Model 9975 and 9978 Type B packagings at the SRNL. This report documents the test methods and results. A path forward will also be recommended.

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LIST OF ABBREVIATIONS

SRNL	Savannah River National Laboratory
ULP	Ultra-Link Processing™
GPS	Global Positioning System
AP	Access Point
dlRssi	Downlink Received Signal Strength Indicator
ulRssi	Uplink Received Signal Strength Indicator
dlSf	Downlink Spreading Factor
ulSf	Uplink Spreading Factor
dBm	Decibels per milli-Watt
IEEE	Institute of Electrical and Electronics Engineers

1.0 Introduction

The objective of this report is to document the findings of a series of proof-of-concept tests performed to determine if a viable radio link could be established from within the stainless steel confines of several drum-style DOE certified Type B radioactive materials packagings. The purpose of the radio link is to communicate sensor information such as temperature from within these types of packagings. The metallic composition of these packaging enclosures would lead one to perceive that the packaging may act as a rudimentary Faraday Cage and significantly impede the establishment of an electromagnetic radiation-based communication link.

Can a viable radio link be established from within Type B packagings, such as the Models 9975 and 9978? To answer this question, SRNL tested 2 in-hand, off-the-shelf radio systems that were developed to different IEEE standards. The first system was a Wi-Fi Librestream Onsight™ camera with a Fortress ES820 Access Point (AP) that adhered to the IEEE 802.11b/g standard. The other system was the On-Ramp Wireless Ultra-Link Processing™ (ULP) radio system which follows the proposed IEEE 802.15.4K standard currently under development. These radio systems were tested within the Model 9975 and 9978 Type B packagings at the Savannah River National Laboratory (SRNL). These packagings were used for these tests because they represent the majority of Type B drum style packagings certified by DOE (e.g., 9975) and were readily available at SRNL. This report will document the test methods and results. A path forward will also be recommended.

2.0 Type B Packages:

For the Model 9978 packaging shown in Figure 2-1, the direct signal path must pass radially through two stainless plates as well as several inches of polyurethane foam. There is also a potential for signal leakage in the axial direction between the drum, lid and the top plate because there is not a hermetic seal. For the testing described in this document, the radio was located as shown by the red star in Figure 2-1.

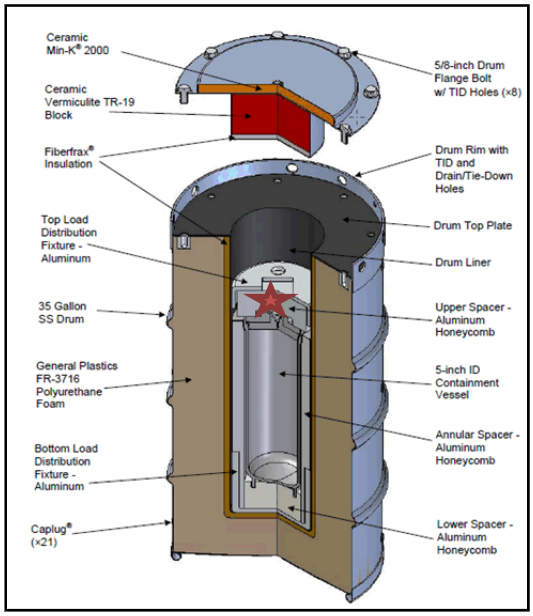

Figure 2-1. Model 9978 Type B package cross section.

For the Model 9975 packaging shown in Figure 2-2, the wireless signal must pass radially through a stainless-steel liner, ½-in of lead shielding, several inches of fiberboard, and stainless steel drum. There is also a potential for signal leakage in the axial direction through the aluminum lid of the lead assembly and bearing plate, several inches of fiberboard in the top insulation subassembly, stainless steel air shield and drum lid, . For the testing described in this document, the radio was located as shown by the red star in Figure 2-2.

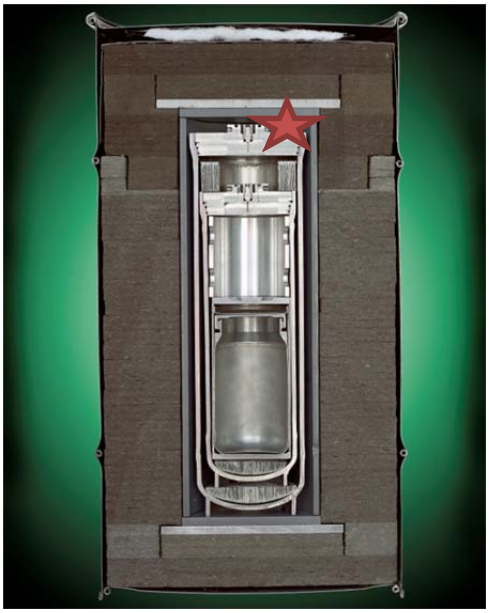

Figure 2-2. Model 9975 Type B package cross section.

3.0 Radio Equipment:

3.1 The Onsight™ Wi-Fi camera system includes the following:

- Librestream Onsight™ Camera, Model # 2000R (firmware version 4.5.6.3)
- Fortress Secure Client FIPS software (version 3.2.1.3400BB)
- Librestream Onsight™ Expert software installed on a laptop computer
- 1 Fortress ES820 Vehicle Mesh Point (firmware version 5.3.0)

Figure 3-1. Librestream Onsight™ Wi-Fi camera.

3.1.1 *Wireless Specifications:*

- IEEE 802.11 b/g
- Orthogonal Frequency Division Multiplexing Modulation
- Onsight™ Camera Transmit Power of 14 dBm and Receive Sensitivity of -82 dBm
- Fortress™ ES820 AP Transmit Power of 23 dBm and Receive Sensitivity of -97 dBm
- 7 dBi vertically polarized omnidirectional antenna on the Fortress ES820-Radio 1 (Pacific Wireless Model MA24-7N)

3.2 The On-Ramp Wireless system includes the following:

- 1 ULP Access Point, (hardware rev. 5, software rev. 3.2.17)
- 1 AP accessories including whip antenna, GPS patch antenna, and power-over-Ethernet (POE) supply
- 2 GPS prototype radio nodes each housed in a weather resistant Pelican™ enclosure
- 1 System base station pre-configured with ULP Release 1.0 demo platform

Figure 3-2. On-Ramp Wireless AP base station (left) and GPS prototype radio node (right).

3.2.1 *Wireless Specifications:*

- Proposed IEEE 802.15.4K
- Dynamic Direct-Sequence Spread Spectrum Modulation
- AP Transmit Power of 30 dBm and Receive Sensitivity of -133 dBm
- Node Transmit Power of 20 dBm and Receive Sensitivity of -142 dBm

4.0 Proof-of-Concept Test Setup:

SRNL used 2 different types of in-hand, off-the-shelf radio systems to perform proof-of-concept testing with the 9975 and 9978 packagings. The Onsight™ and Fortress Technologies Wi-Fi equipment was used primarily to get some experience on how a common and ubiquitous wireless system would perform in an enclosed metal container. This system did not have the capability to take signal strength data over a period of time. It only provided a simple display of signal strength. Furthermore, the Wi-Fi system was too large to place inside the 9975. On the other hand, the On-Ramp Wireless system was deemed more appropriate for the intended application because of its physical size and electrical characteristics. It provided a way to take signal strength data over a period of time and it fit into both packagings.

Because these packaging designs resemble a rudimentary Faraday Cage, testing was performed with the packagings grounded and ungrounded. For the tests involving an ungrounded packaging, signal strength data was collected for 15 minutes at each of the 3 indoor locations of 25, 75, and 175 feet. For the grounded tests, a ground was available outside at 17 feet, and then inside at the 75 and 175 foot locations. The base station for each radio system was set up in a laboratory space that adjoined both the indoor and outdoor test locations. Each radio system was tested while the other radio system was unpowered. Before the start of the testing, each radio was powered on and placed on top of the test packaging for 15 minutes in order to establish baseline signal strength data. The radio was then inserted inside the packaging and then the packaging assembled in stages while the radio link's signal strength parameters were monitored at the base station. Signal strength data was collected for 15 minutes before the packaging was moved to the next location. If the communication link was lost, further testing of that package and radio combination was terminated. If the link was good, the package would collect data from that location, and then be moved further away until the communication link either failed or reached the 175 foot goal location.

5.0 Onsight™ and Fortress Technologies Radio System Testing:

The Librestream Onsight™ Wi-Fi camera, shown in Figure 5-1, was tested first. The Onsight™ camera was placed on top of 9978 packaging for the baseline test which lasted 15 minutes. The camera was then placed inside the packaging and the lid was secured with bolts that were torqued to 30 foot-pounds per assembly instructions. The red star shown in Figure 5-2 shows the location of the camera. The signal strength value displayed in the Fortress ES820 connections web interface was observed at the 25 foot location for 15 minutes. The packaging was then loaded on a dolly and slowly repositioned further away from the base station until the signal was lost.

Figure 5-1. Fortress ES820 Access Point (Left) and Librestream Onsight™ Wi-Fi Camera (Right).

5.1 Onsight™ and Fortress Technologies Wi-Fi Radio System Test Results:

The Wi-Fi baseline test resulted in a signal strength reading of -54 dBm at a distance of 25 feet between the camera and the base station. Once the camera was sealed within the 9978, the signal strength fell to -81 dBm. A viable radio link was maintained from within the 9978 using standard Wi-Fi protocol to a distance of 50 feet before the communication link was lost. Unfortunately, due to the physical size of the Wi-Fi enabled camera, similar testing could not be performed with 9975 packaging.

Figure 5-2. Disassembled Model 9978 Packaging (Left) and inside view (Right).

6.0 On-Ramp Wireless Radio System Testing:

The On-Ramp Wireless prototype system and two Model 9978 packaging are shown in Figure 6-1. Two On-Ramp Wireless GPS radio nodes were used in a series of tests in which their signal strength data was collected. No temperature data was transmitted in the proof-of-concept testing. The radios and ungrounded packagings were tested at distances of 25, 75, and 175 feet. The 75 and 175 foot locations were not line-of-sight with the base station. The On-Ramp Wireless software was configured to communicate signal strength data every 15 seconds.

Figure 6-1. On-Ramp Wireless ULP system with AP base station and Model 9978 Type B packagings with 2 GPS radio nodes.

A baseline test was performed at distances of 25, 75, and 175 feet with one of the GPS radio nodes placed on top of a 9978 packaging as shown in Figure 6-1. The radio nodes were then placed inside the drums as shown in Figure 6-2. Signal strength data was collected for 15 minutes after the lid was placed on the drum body, but not secured with bolts.

Figure 6-2. The locations of the transmitters inside the 9978 packaging.

The lids were then completely secured and torqued to the prescribed 45 foot-pounds as shown in Figure 6-3. Data was collected for 15 minutes at the 25 foot location. The packagings were loaded onto a dolly and moved to a room located 75 feet away. Data was collected for another 15 minutes. The packagings were then moved an additional 100 feet further away from the base station. Data was collected at this location for 15 minutes. The packagings were then relocated back to the initial 25 foot location whereupon the radios were swapped between packagings. Data was collected for an additional 15 minutes. This completed proof-of-concept testing of the On-Ramp Wireless radio nodes in the 9978 packaging.

Figure 6-3. Radio Nodes inside Model 9978 packagings with the lids on and bolts torqued to 45 ft-lb.

Figure 6-4. Model 9975 packaging.

The next phase of testing was performed with the 9975 packaging shown in Figure 6-4. The collection of baseline data did not have to be repeated since this was accomplished in previous testing with the 9978. One of the On-Ramp Wireless GPS node radios was placed inside of the lead-shield assembly body. Data was collected for 15 minutes. Then the lead-shield assembly lid was installed and the lid bolts were torqued to 13 foot-pounds as prescribed in the assembly instructions. Signal strength data was collected for 15 minutes in this configuration. The insulation top subassembly was installed and more measurements were taken as shown in Figure 6-5. Finally, the drum lid was installed and the lid bolts were torqued to 30 foot-pounds as shown in Figure 6-6. Data was collected in this configuration for 15 minutes. The packaging was loaded onto a dolly and transported to the 75 foot location and signal strength data was collected for 15 minutes.

Another series of tests were performed without the aluminum lid installed on the lead-shield assembly. Data was taken in the following two configurations:

1. Insulation top subassembly installed and without the drum lid.
2. Insulation top subassembly and the drum lid installed and bolts torqued to their appropriate value.

Signal strength data was also taken at various distances under these packaging assembly configurations.

Figure 6-5. Model 9975 with radio node inside lead enclosure with bolts torqued to 13 ft-lbs (Left) and with the insulation top subassembly installed (Right).

Figure 6-6. Model 9975 configured with outer lid and bolts torqued to 30 ft-lbs.

6.1 On-Ramp Wireless Radio System Test Results:

Radio signal strength data with ungrounded packages was collected at distances of 25, 75, and 175 feet away from the base station. This data was used to judge the viability of the radio link. The On-Ramp Wireless ULP is a bi-directional communication device therefore; both the uplink and downlink characteristics must be within the acceptable limits. The uplink is made from the radio node to the AP and the downlink is made from the AP to the radio node. The key radio parameters include: the Downlink Received Signal Strength Indicator (dlRssi), Uplink Received Signal Strength Indicator (ulRssi), Uplink Spreading Factor (ulSf), and Downlink Spreading Factor (dlSF). Table 6-1 shows the limits for these key radio parameters. For a viable communication link, the signal strength data from the On-Ramp radios must remain below the absolute values of the limits shown in the Table 6-1.

Table 6-1. On-Ramp Wireless radio link maximum acceptable limits for data transfer.

Radio Link Limits			
dlRssi	dlSf	ulRssi	ulSf
-133	11	-142	13

Table 6-2. Baseline Test at Distances with Radio Node 106b5

Baseline Test at Distances with Radio Node 106b5								
Test Scenario	Distance (ft.)	Node Id	dlRssi	Standard Dev.(±)	ulRssi	Standard Dev.(±)	dlSf	ulSf
Baseline 25ft	25	0x000106b5	-30.534	1.533	-103.901	3.258	4	9
Baseline 75ft	75	0x000106b5	-45.420	2.149	-122.550	2.119	4	9
Baseline 175ft	175	0x000106b5	-74.417	4.353	-127.354	3.527	4	9

The baseline test data collected for radio node 106b5 are shown in Table 6-2. The dlRssi, ulRssi, dlSf, and ulSf data from the radio node are all well within the acceptable limits for a viable communication link. As expected, the signal strength parameters dlRssi and ulRssi decreased as the distance from the base station increased. Similar results were achieved with radio node 10402. Interestingly enough, radio node 10402 had a 10 dBm stronger signal than radio node 106b5 in the baseline test.

The radio signal strength data for both radios placed within the 9978 packaging are shown in Table 6-3, Table 6-4, and Table 6-5. In Table 6-3 and Table 6-4, it is evident that the signal strength parameters dlRssi and ulRssi decreased as the distance from the package and base station increased. This result was expected. However, neither radio node fell outside their signal strength limits. A viable communication link was achieved to 175 feet for both radios. Because radio node 106b5 was found to have 10 dBm less signal strength than radio node 10402 in the baseline test, the radio nodes were swapped between packagings. Table 6-5 shows the data collected at this distance. Both radio nodes produced a viable communication link. This test was only performed at the 25 foot location.

Table 6-3. Radio Node 10402 performance with Model 9978 - SN 100005.

Radio Node 10402 Performance with 9978 Type B package, SN 100005								
Test Scenario	Distance (ft.)	Node Id	dlRssi	Standard Dev.(±)	ulRssi	Standard Dev.(±)	dlSf	ulSf
On top of drum	25	0x00010402	-30.500	1.126	-104.719	2.671	4	9
Drum Lid On, No Bolts	25	0x00010402	-48.485	1.317	-123.992	1.396	4	9
Drum Lid On,Torque @ 45 ft-lbs	25	0x00010402	-61.533	1.394	-128.524	1.158	4	9
Drum Lid On,Torque @ 45 ft-lbs	75	0x00010402	-87.517	2.733	-128.224	1.830	4	9
Drum Lid On, Torque @ 45 ft-lbs	175	0x00010402	-106.765	3.072	-127.889	2.264	4	9

Table 6-4. Radio Node 106b5 results with Model 9978 - SN 100028.

Radio Node 106b5 Performance with 9978 container SN 100028								
Test Scenario	Distance (ft.)	Node Id	dlRssi	Standard Dev.(±)	ulRssi	Standard Dev.(±)	dlSf	ulSf
On top of container	25	0x000106b5	-30.398	1.240	-103.899	2.981	4	9
Lid On, No Bolts	25	0x000106b5	-53.219	1.605	-128.602	1.166	4	9
Lid On, Torque @ 45 ft-lbs	25	0x000106b5	-74.481	5.655	-126.628	3.951	4	9
Lid On, Torque @ 45 ft-lbs	75	0x000106b5	-69.473	1.864	-128.806	1.238	4	9
Lid On, Torque @ 45 ft-lbs	175	0x000106b5	-94.789	2.775	-128.559	2.508	4	9

Table 6-5. On-Ramp Wireless Radios swapped between the two Model 9978 Type B packages.

Radios Swapped between 9978 Type B packages								
Test Scenario	Distance (ft.)	Node Id	dlRssi	Standard Dev.(±)	ulRssi	Standard Dev.(±)	dlSf	ulSf
9978 (SN 100028)	25	0x00010402	-61.742	3.916	-128.052	2.071	4	9
9978 (SN 100005)	25	0x000106b5	-70.293	4.486	-128.072	2.596	4	9

A final series of radio tests was performed in a 9975 packaging. Only 1 of these packages was available for the proof-of-concept testing. The results are shown in Table 6-6. As you can see from the table, several tests were performed at the 25 foot location. The signal strength parameters dlRssi and ulRssi decrease as the packaging is assembled and they approached their limits. The packaging was loaded onto a dolly and transported toward the 75 foot location. The link was lost in transit. The packaging was dis-assembled and the lead-shield assembly lid was removed. The packaging was then re-assembled for testing without the lead-shield assembly lid. The packaging was then loaded onto a dolly and again transported toward the 75 foot location. The link was maintained up to 50 feet. Several attempts were made to re-establish the link by bringing the packaging closer to the base station, but were not successful. Even 10 feet from the base station and the radio node sitting on top of the packaging, a viable link could not be re-established. The power on the node had to be cycled off and then on to work properly again. The inability to re-establish the communication link is an issue and must be addressed in future testing. The On-Ramp Wireless radio nodes used in the testing were prototypic devices.

Table 6-6. Radio node 10402 results with a Model 9975 Type B package.

Radio Node 10402 Performance with 9975 Type B Package								
Test Scenario	Distance (ft.)	Node Id	dlRssi	Standard Dev.(±)	ulRssi	Standard Dev.(±)	dlSf	ulSf
Lead Shielding Lid off	25	0x00010402	-41.866	3.190	-118.459	3.313	4	9
Lead Shielding Lid on and Torqued	25	0x00010402	-66.050	3.903	-128.206	2.544	4	9
Insulation top sub assembly installed	25	0x00010402	-74.892	2.786	-128.465	2.133	4	9
Drum Lid, torque 30 ft-lb	25	0x00010402	-119.657	1.646	-134.277	1.924	8	11
Drum Lid, torque 30 ft-lb	75	0x00010402	Link Lost					
Insulation top sub assembly off	25	0x00010402	-46.394	1.028	-122.398	0.663	4	9
Drum Lid torqued, Lead shield lid off	25	0x00010402	-109.012	3.754	-127.988	2.546	4	9
Drum Lid torqued, Lead shield lid off	50	0x00010402	-126.464	2.332	-139.256	1.787	9	13
Drum Lid torqued, Lead shield lid off	75	0x00010402	Link Lost					

6.2 On-Ramp Wireless Radio Test Results with grounded 9975 and 9978 Packagings

A series of tests were performed to determine if grounding the packagings had any effect on their communication links. An On-Ramp Wireless radio node was placed inside each packaging. The packagings were then re-assembled and positioned 17 feet away from the base station at a location just outside the building where the closest available earth ground was located. Figure 6-7 shows the 9975 and its connection to earth ground. Data for both packagings was collected at this location for 15 minutes. The 9975 was only tested at this location because of its limited range of less than 50 feet.

Figure 6-7. Grounding wire connection (Left) and connection to Model 9975 package (Right).

The 9978 was re-located to the 75 and 175 foot locations inside the building and connected to earth ground at those locations. Data from the packaging was collected for 15 minutes at each location as shown in Table 6-7. The results from the 9975 are shown in Table 6-8. As is evident from the tables, grounding the 9975 and 9978 had no effect on the communication link at any location.

Table 6-7. Grounding Test on Model 9978 packaging.

Grounding Test Radio Node 10402 Performance with 9978 Type B package, SN 100005								
Test Scenario	Distance (ft.)	Node Id	dlRssi	Standard Dev.(±)	ulRssi	Standard Dev.(±)	dlSf	ulSf
Ungrounded and Torqued	17	0x00010402	-80.810	5.933	-126.940	3.270	4	9
Grounded and Torqued	17	0x00010402	-78.372	1.399	-128.819	1.263	4	9
Ungrounded and Torqued	75	0x00010402	-82.492	1.609	-128.924	1.348	4	9
Grounded and Torqued	75	0x00010402	-82.950	1.750	-128.922	1.470	4	9
Ungrounded and Torqued	175	0x00010402	-99.271	2.885	-128.844	2.235	4	9
Grounded and Torqued	175	0x00010402	-98.5592	3.680914	-128.28	2.77531	4	9

Table 6-8. Grounding Test on Model 9975 Type B package.

Grounding Test Radio Node 10402 Performance with 9975 Type B package								
Test Scenario	Distance (ft.)	Node Id	dlRssi	Standard Dev.(±)	ulRssi	Standard Dev.(±)	dlSf	ulSf
Ungrounded and Torqued	17	0x00010402	-120.960	4.118	-134.485	2.620	9	12
Grounded and Torqued	17	0x00010402	-123.457	3.922	-136.235	2.885	9	12

7.0 Conclusion and Recommendations:

Proof-of-concept wireless testing was performed with radio frequency devices installed within both 9975 and 9978 packagings. The results were very encouraging in that viable communication links were established with an off-the-shelf Librestream Onsight™ Wi-Fi camera and Fortress ES820 AP radio system as well as the On-Ramp Wireless ULP radio system. As stated previously, the Onsight™ Wi-Fi camera system was not a genuine candidate for use in a Type B packaging. The purpose of testing it was to see if a typical Wi-Fi system could be successfully operated inside an assembled stainless steel packaging. It had less range and lower receiver sensitivity than the On-Ramp Wireless ULP radio system. The On-Ramp Wireless system had a much smaller physical footprint and greater receiver sensitivity. It exhibited great range within the 9978 and good range within the 9975. It performed well above expectations. Testing showed that grounding the packagings had no effect on the On-Ramp Wireless radio's communication link.

Due to the positive proof-of-concept test results, SRNL R&D Engineering requests additional funding authorization to design a sensor interface for testing within the Type B packagings and developing a means of integrating the On-Ramp Wireless radio sensor data to the ARG-US RFID system. In this phase of development, several technical issues will have to be addressed as listed below:

- Develop a solution to the problem that prevented the On-Ramp Wireless radio system from re-establishing communication after the link was lost.
- Determine if a viable communication link can be established within a 9977 packaging.
- Determine how real world conditions affect the robustness of the communication link.

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