CAEN SyS
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RESULTS OF NUCLEAR WASTE CHARACTERIZATION PERFORMED THROUG RADHAND INTEGRATED IN THE REACh™ DETECTOR SYSTEM

WHITE PAPER

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REACh™ Powered by RADMAN™

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Table of Contents

Executive Summary 1
Introduction 1
Issues Regarding Current Characterization Methods 2
The Solution 2
REACh™ System Description 3
Detector Technology 6
Laboratory testing 8
Field Testing Overview 9
Field Testing Experimental Setups 11
REACh™ Dose Rates 13
Geometry Correction Factors 13
Testing Results 13
Radionuclide Identification 13
REACh™ Characterization Results 16
Conclusion 19

LIST OF FIGURES

Figure 1 – The REACh™ Detector 2
Figure 2 – Remote Operation of the REACh™ Detector 5
Figure 3 – 55-Gallon Drum Measurement Setup 11
Figure 4 – B-25 Box Measurement Setup 12
Figure 5 – 20’ Intermodal Container Measurement Setup 12
Figure 6 – Fly Ash Drum Spectral Plot Section 14

LIST OF TABLES

Table 1 – Measured Co-60 Activity versus Co-60 Check Source Activity 8
Table 2 – Measured Cs-137 Activity versus Cs-137 Check Source Activity 8
Table 3 – Measured Eu-152 Activity versus Eu-152 Check Source Activity 8
Table 4 – Measured Co-60 & Cs-137 Activity versus Co-60 & Cs-137 Check Source Activity 9
Table 5 – Package Data Summary 11
Table 6 – Radionuclide Identification Comparisons 55-Gallon Drum 15
Table 7 – Drum Comparison Summary 17
Table 8 – B-25 Box Comparison 18

Executive Summary

Field testing for the REACh™ Detector System has been completed and shows that REACh™ is able to effectively detect the gamma emitting radionuclides present in the packaged radioactive waste. The results were in good agreement with those found with a High Purity Germanium Detector (HPGe) and the total gamma emitters found were within 10%. The REACh™ results for the 55-Gallon Drums on the aggregate were about six percent lower than the HPGe results. The REACh™ characterization results were over 20% lower on the average than the waste generator results.

REACh™ has the capability to detect gamma emitters very quickly with the Dynamic acquisition time that is completed in a matter of seconds. Dynamic acquisition times for the packages analyzed ranged from 1 to 19 seconds with all but 2 packages analyzed in less than 10 seconds. The Dynamic results observed during testing were in good agreement with acquisition times up to 5 minutes. One of the final tests done during testing was a “walk-around” spectra acquisition on a 20’ intermodal container where 6 readings were taken on the container. The walk-around acquisitions were completed in about 1 minute and the results were within 4% of those obtained using fixed detector locations with acquisition times totaling more than 20 minutes.

There were some discrepancies observed regarding radionuclide identification for isotopes with close peak energies. This was expected due to the relatively low resolution of NaI(Tl) detectors. Modifications were made to the software logic to better detect Ag-110m when present, but there were still a few discrepancies with Ag-110m, Mn-54 and Cs-134. A secondary gamma library will be incorporated to improve Ag-110m detection and additional modifications will be made to address the Mn-54/Cs-134 discrepancies. Additional source testing will be performed with these isotopes to ensure the revised logic is accurate.

Introduction

The REACh™ System represents a step change in the way Low-Level Radioactive Waste (LLRW) and Very-Low-Level Radioactive Waste (VLLRW) are characterized and classified. The detector directly measures gamma dose rates and gamma emitting activity by radionuclide from packaged radioactive material. This is accomplished by an automated pulse processing algorithm which completes the radionuclide identification process. The REACh™ Software uses the automated radionuclide information in conjunction with the measured gamma dose rates associated with the packaged material. The software communicates with the RADMAN™ Software Suite to scale in hard-to-detect radionuclides from the most appropriate waste stream to provide complete package characterization and classification in one easy step.

Figure 1: The REACh™ Detector

The REACh™ System has been designed to save the user time with instantaneous readings, minimize dose with an ALARA conscious solution, and minimize potential human errors with the integration of both software and hardware. It will also reduce costs associated with packaging, transportation, and disposition with highly accurate results.

Issues Regarding Current Characterization Methods

Current methods of characterizing low-level radioactive waste are gross approximations which tend to yield overly conservative results. More accurate methods are needed to reduce lifecycle costs because classification results drive disposition alternatives. Overly conservative results can significantly increase packaging transport and disposal costs. Current regulatory guidance for the characterization of Dry Active Waste (DAW) allows for periodic swipe sampling of areas where DAW is generated with independent laboratory analysis for 10 CFR Part 61 radionuclides, performed as infrequently as every two years. However, this is hardly representative. The inaccuracies of this sampling are compounded by the practice of compositing the swipes over time, prior to analysis which underestimates short-lived radionuclides which are typically found in LLRW. When dose-to-curie conversion techniques are used and hard-to-detect radionuclides are estimated using scaling factors relative to Co-60 or Cs-137, underestimating the short-lived gamma emitters results in overestimating the hard-to-detect radionuclides as well as Co-60 and Cs-137, since the majority of the dose rate is attributable to these two radionuclides. Providing efficient and reliable real-time radionuclide concentrations provides invaluable information while processing nuclear waste at commercial power plants.

The Solution

More accurate results can be achieved by directly measuring the gamma-emitting activity in the packaged LLRW. However, this is typically done using HPGe detectors, which are not easily portable, require significant data processing, and require Subject Matter Experts (SMEs) to interpret the detector results.

The REACh™ Detector utilizes a 2” x 2” Thallium doped Sodium Iodide crystal [NaI(Tl)]. This is a commonly used crystal type in the nuclear industry. It provides some of the best light output among other scintillators, which allows for easy scintillation (i.e., more flashes of light are produced from photons). NaI(Tl) crystals can be produced relatively inexpensively, provide good efficiency, and are able to measure the intensity and energies of incident radiation.

Typically, similar spectroscopy systems require significant post processing analysis performed by SMEs, in order to analyze spectrum results for determining which radionuclides are present. Additionally, typical systems require significant acquisition times to reach the Minimum Detectable Activity (MDA) confidence levels. The REACh™ System takes the leg work out of the typical post processing requirements by using software to conduct automated pulse processing for complete radionuclide identification. This process not only eliminates the need for SMEs, but it also reduces the potential human error by letting the software complete the identification process. The REACh™ System has extremely low MDA levels (on the order of a few thousand of Bq) for gamma-emitting radionuclides allowing for near instantaneous results. Should the need arise for SMEs, technical support is available in real time for analysis of results as requested by the user.

When performing spectroscopy on a given waste form, gamma interaction and attenuation must be considered. When photons pass through matter, the intensity of the photon can be attenuated (i.e., the photon’s intensity is weakened due to its interaction in matter) by the interactions with the matter itself as well as other photons. The REACh™ Software considers gamma interaction and attenuation by applying Geometry Correction Factors for container and waste form combinations encompassing most radwaste package types. The Geometry Correction Factors have been developed to account for the attenuation of low energy gamma emitting radionuclides

By directly measuring a package’s gamma-emitting activity, more accurate results can be achieved than those which are obtained through current characterization practices. The combination of both the REACh™ Detector and the REACh™ Software allows for increased accuracies and reductions in human error that can typically arise. In addition, this ALARA friendly solution allows technicians to minimize the time obtaining surveys on radioactive waste.

REACh™ System Description

The REACh™ System is a two-part system: part hardware and part software. The REACh™ Detector, as previously mentioned, utilizes a 2” x 2” NaI(Tl) crystal inside its detector housing. The detector itself is a handheld device which weighs less than 4.5 pounds. The NaI(Tl) crystal works in conjunction with the detector hardware to provide both measured dose rates and identified gamma-emitting radionuclides on the detector’s onboard display. The radionuclide identification process is completed by an automated pulse processing algorithm.

The REACh™ Software is a web interface which provides users a one-stop-shop to handle all their REACh™ Detector measurements. The software imports the automated

radionuclide information from the detector. All package measurements are synchronized to site-specific databases, where users can login and manage these measurements. The REACh™ Software uses package-specific radionuclide information with package-specific measured dose rates to perform waste characterization and classification. The REACh™ Software communicates with the RADMAN™ database to scale in hard-to-detect radionuclides (e.g., H-3, Tc-99, transuranics, etc.) from the most appropriate waste stream to provide complete package characterization and classification in one easy step. Note that the REACh™ Detector is a gamma radiation detector and is not able to measure pure beta or pure alpha emitters directly.

REACh™ utilizes the GAMON™ algorithm, which was developed by CAEN SyS Systems and Spectroscopy, GAMON™ was originally intended for use in environmental surveys, however, substantial modifications have been made for characterizing packaged radioactive waste. The REACh™ software is able to perform its automated peak processing thanks in part to GAMON™. REACh™ uses its automated radionuclide information to perform isotope-specific dose rate evaluations to calculate the identified radionuclides' concentrations.

The REACh™ System allows users the ability to obtain multiple measurements at multiple locations on a package to provide improved counting statistics. Packaged radioactive material often does not have its radioactive content uniformly distributed throughout the package. Having the ability to perform measurements at various locations on the package allows for low-energy gamma emitting radionuclides to be identified which may otherwise be self-shielded by packaged material. Self-shielding can still arise for packaged material, even for higher energy gamma-emitting radionuclides. The REACh™ Software incorporates self-shielding correction factors as a function of energy, geometry, material type, and reading distances.

Utilizing RFID technology, categorization, and storage management of radioactive waste has never been made easier thanks to the REACh ™ Detector. RFID tags can be attached to packages and have their package-specific information saved directly to the RFID tag for future retrieval and real time comparisons to current conditions of the package (e.g., differences in measured dose rates). This includes, but is not limited to, spectrum acquisition data (e.g., identified radionuclides, identification confidence levels, and measured dose rate), location where the reading measurement was taken, waste material composition (e.g., steel, cloth, trash, etc.), and container type. If clients have additional information they would like associated with a package (e.g., different package descriptors), these could be added and included as basic information which is stored onto the RFID tags. Additionally, user-specific actions can be implemented. When a user scans their ID badge, they will have their role-specific actions available (e.g., operators may perform measurements and administrators may access device-specific settings).

The REACh™ Detector is unique in that it is a handheld detector. This detector may be taken out into the field and used for measurements without any restrictions due to connectivity to either the internet or a database. All data which is obtained in the field, including package measurements, are stored locally on the device until a user has returned to an area where internet connectivity is accessible, or a wired USB connection

can be made. Once a connection is available, this stored data can be synchronized directly to the user's site-specific database.

Another unique feature of the REACh™ Detector is its ability to provide remote operation via USB connection. In this instance, a user would set up the detector and move the package of interest into position, perform measurements, and remove the package. Remote operation is performed via a user-friendly web interface. This ALARA-friendly solution reduces radiation workers' exposure times to radioactive material.

Additionally, the REACh™ Detector is unique in that the detector is capable of self-stabilization. That is, the device is able to, in real time, analyze the digitized pulses and process them via Digital Pulse Processing (DPP) algorithms which are embedded on the on-board computer within the detector which handles stabilizing the detector against temperature peak-drifts and natural detector aging. In this way, the REACh™ Detector is able to continuously measure the dose-rate and can identify the detected radionuclides among those existing in the internal library.

The REACh™ Detector is capable of having preset acquisition times utilized to obtain spectra, or the user may choose to perform an automated acquisition via the "Dynamic" option. By selecting the "Dynamic" option, the radionuclide identification measurement will last according to the radiological count rate measured by the device. That is, the "Dynamic" option on the device performs an automated spectra acquisition with the count time based on the count rate and the time required to achieve good counting statistics for nuclide identification. Due to the high efficiency of NaI(Tl) scintillators this automated count time is typically on the order of seconds for waste with any measurable dose rate.

In some instances, higher activity packages may require the use of additional shielding such as a collimator. The REACh™ Detector has the capability of having additional shielding rings added to reduce background radiation or external sources (e.g., additional nearby waste such as a room full of 55-gallon drums or B-25 boxes). Additionally, a collimator may be added when applicable.

Background radiation is continuously monitored by the REACh™ Detector. As described above, the detector will self-stabilize which is dependent on photon peak shifts because of background radiation changes or crystal degradation. The Spectra that the REACh™ Detector acquires, includes the count data and or contributions associated with background radiation. In other words, gross counts by channel or energy are obtained by the REACh™ Detector. As part of the automated pulse processing algorithm, GAMON™ utilizes various algorithms which automatically determine the Net Area Counts (NAC) for identified radionuclides. That is, these algorithms automatically determine background contribution for a given spectra in accordance with the ISO 11929 Standard.

Please see an example of the REACh™ Detector being used to measure a 55-gallon drum of Dry Active Waste (DAW) below. In this laboratory test, the detector has been setup for remote operations via USB and has been placed on its tripod. Additional shield plates have also been installed to the detector for this test to reduce background radiation in the laboratory.

Figure 2: Remote Operation of the REACh™ Detector

Detector Technology

One of the most accurate techniques used to characterize nuclear waste is via gamma spectroscopy as it is a relatively simple and inexpensive process which can be implemented into the waste management process with relative ease. Additionally, this characterization technique provides facilities the ability to identify and quantify gamma-emitting radionuclides, as well as provide waste-specific isotopic compositions via non-destructive measurements.

The basic principle of gamma spectroscopy involves measuring the photons produced by a radioactive source via sensor(s) which delivers a signal proportional to the photon energy. This signal is then analyzed and classified into a histogram typically referred to as a gamma spectrum. Two main physical phenomena related to the sensor material interaction are used to detect emitted photons:

1. Ionizing radiation generates charges which are transformed into electrical pulses or currents, by applying an electrical polarization. Such phenomenon occurs in either gas or semiconductor detectors such as HPGe, CZT, CdTe, etc.
2. Ionizing radiation is transformed into light photons which are collected and amplified by using a Photo-Multiplier Tube (PMT). Such a phenomenon occurs in scintillators such as NaI(Tl), $CaBr_3$, $LaBr_3$, etc.

Independent from the physical phenomena, the total photon energy transfer within the detector itself is represented by peaks in the gamma spectrum. The peak width, commonly referred to as the Full Width Half Maximum (FWHM), corresponds to the energy resolution of the detector which describes how well a detector can clearly discriminate adjacent energy peaks from one another for an unambiguous radionuclide identification. It is often provided as the percentage value of a reference energy peak (e.g., % of value at 662 keV, 122 keV, 1332 keV, etc.). Lower percentage values equate to better detector resolution and in turn result in better peak discrimination capabilities.

The fundamental parameter for quantitative measurements is the detector efficiency. Detector efficiency measures the percentage of radiation that a given detector detects from the overall yield that is emitted from a source into a solid angle (i.e., detector efficiency is the correlation between what the detector detects relative to the source

activity). This is dependent upon, but not limited to, detector volume, source dimensions, source-to-detector distance (i.e., reading distance), the incident photon energy, attenuation layers in the form of detectors, and absorption cross-sections within the detector. Detector efficiency is often expressed in terms of a percentage. Detector efficiency directly correlates to the MDA that a measurement system can reach for a fixed measurement time. Having higher detector efficiencies results in achieving lower MDAs for fixed measurement times.

HPGe provides the best energy resolutions on the order of 0.13-0.15% at around 1332 keV, CZT detectors have energy resolutions around five times larger than HPGe, and NaI(Tl) detectors have typical energy resolutions 30-50 times larger than HPGe.

Detector efficiencies for NaI(Tl) detectors are about a factor of 8 to 10 times better than that of HPGe, while CZT detectors have the lowest detector efficiencies due to the CZT limited detector size.

When determining which detector type is the most appropriate to use for gamma spectroscopy, one must not only consider things such as material dependent parameters like energy resolution and detector efficiencies, but practical considerations must be made which are application specific (e.g., what gamma emitting sources are you expected to measure, are these measurements being performed in a laboratory setting or are they in-field measurements, what are--should they exist--reference stands, etc.).

The REACh™ Detector has been developed with specific focus on nuclear waste generators such as commercial power plants, processing and sorting facilities, waste storage facilities, and decommissioning projects. With this in mind, it is obvious what the most appropriate detector technology is to implement in a handheld device such as the REACh™ Detector: NaI(Tl). HPGe detectors are not an ideal solution for these applications. Although it is dependent on the waste type being characterized, HPGe detectors are required to always be cooled to operate and often must be surrounded in thick lead shielding (upwards of 10cm thick) in order to achieve the required MDA values in reasonable times. HPGe detectors are not suitable for in-field operations, however, they are most appropriate for long measurements performed in a laboratory setting. Typical use cases for HPGe detectors are characterizing historic waste, waste whose origination process/location is not known thus resulting in little to no known information regarding the waste.

Typical nuclear waste which is generated is represented as low-level waste (LLW) or very-low-level waste (VLLW). These wastes often are comprised of well-defined, well-known, gamma emitting radionuclide such as Cs-137, Co-60, Eu-152, Mn-54, Nb-95, etc. Achieving the lowest MDA as possible is the primary goal while remaining within certain confidence levels. A scintillator such as an NaI(Tl) detector which has been integrated into a hand-held instrument, such as the REACh™ Detector, is the most appropriate tool for the application of in-field waste characterization primarily due to NaI(Tl) detectors having much higher detector efficiencies.

Experiments comparing MDA values between HPGe and NaI(Tl) were completed in May of 2021 following delays in in-field testing on radioactive waste due to the COVID-19 virus. The results of these comparisons are presented later in this report.

Laboratory testing

Testing for the REACh™ Detector System has been completed with laboratory testing completed in the Spring of 2021, and in-field testing on real radioactive waste completed in May of 2021. Many measurements of known quantities of radioactive material have been performed. These experiments were performed with disc sources, commonly referred to as check sources, in air. Measurements were taken with the REACh™ detector to identify each source and or source combinations and to determine their respective radionuclide concentrations. Comparisons were then completed by using the measured radionuclide concentrations obtained through the REACh™ System to the known radioactivity of the sources which were used to perform the measurements. In general, all measured radionuclide concentrations had a variance of less than 3.0 percent when compared to known source concentrations. These differences were found to also be within the statistical variances of the calculated concentrations. These results are shown in Tables 1-4 below.

Table 1: Measured Co-60 Activity versus Co-60 Check Source Activity

Nuclide	Check Source Activity (µCi)	Measured Source Activity (µCi)	Measured Source Error (µCi)	Percent Difference
Co-60	8.98E-01	8.77E-01	3.89E-02	2.36%

Check source reference date is as of 12/1/2019; Survey date 9/23/2020. All activities as of the survey date.

Table 2: Measured Cs-137 Activity versus Cs-137 Check Source Activity

Nuclide	Check Source Activity (µCi)	Measured Source Activity (µCi)	Measured Source Error (µCi)	Percent Difference
Cs-137	9.80E+00	9.94E+00	5.49E-01	1.45%

Check source reference date is as of 11/1/2019; Survey date 9/24/2020. All activities as of the survey date.

Table 3: Measured Eu-152 Activity versus Eu-152 Check Source Activity

Nuclide	Check Source Activity (µCi)	Measured Source Activity (µCi)	Measured Source Error (µCi)	Percent Difference
Eu-152	9.59E-01	9.61E-01	7.16E-02	0.17%

Check source reference date is as of 12/1/2019; Survey date 9/24/2020. All activities as of the survey date.

Table 4: Measured Co-60 & Cs-137 Activity versus Co-60 & Cs-137 Check Source Activity

Nuclide	Check Source Activity (µCi)	Measured Source Activity (µCi)	Measured Source Error (µCi)	Percent Difference
Co-60	8.98E-01	8.85E-01	3.88E-02	1.42%
Cs-137	9.80E-01	9.87E-01	6.41E-02	0.76%

Check source reference date is as of 12/1/2019; Survey date 9/24/2020. All activities as of the survey date.

Additionally, testing has been performed to ensure the automated pulse processing performed via the GAMON™ algorithm is correct. This was done by having the detector's raw gamma spectra analyzed by SMEs to identify the radionuclides of interest and determine their respective activities. These analyzed results were then compared to the automated results performed by the GAMON™ algorithm and were found to be within a few percentage points of one another.

Due to travel restrictions and limited personnel at many facilities as a result of COVID-19, field testing at a commercial facility was delayed until May 2021. The field testing results are summarized below.

Field Testing Overview

Twenty-nine waste packages had spectral acquisitions during the field testing. This included 21 55-gallon drums, 6 B-25 boxes and 2 20' long intermodal containers. The information for these packages is summarized in Table 5.

Detailed radiation surveys were performed on the packages prior to each spectral acquisition. Historical characterization information was available for each package for validation purposes.

WMG acquired multiple gamma spectra for each waste package. They are as follows:

- Drums: 21 55-gallon drums were analyzed. Gamma spectra were obtained with the Dynamic acquisition time,1 minute, and 5 minutes acquisition times for all 55-gallon drums. The first 3 55-gallon drums had spectra acquired at a reading distance of 1 m. The third 55-gallon drum had its spectra re-acquired at a reading distance of 1 foot. The remaining gamma spectra were acquired at a reading distance of 1 foot. CZT spectra acquisitions were also taken with 10-minute acquisition times which corresponded with each REACh™ spectra acquisition that was taken. HPGe measurements were performed for 5 minutes on each 55-gallon drum.
- B-25 boxes: 6 B-25 boxes were analyzed: 1 which contained DAW, 1 which contained bead resin, and 4 which contained contaminated metals. REACh™ gamma spectra were obtained on each of the two long sides using the Dynamic acquisition time, 1 minute, and 5-minute acquisition times at 1 foot.

- 20’ intermodals: 2 20’ intermodal containers were analyzed: One which contained DAW bags and one which contained metals and scaffolding. Two sets of REACh™ gamma spectra were obtained on each of the two long sides using the Dynamic acquisition time, 1 minute, and 5-minute acquisition times at 2 meters.

The following waste forms were analyzed in the previously described container types:

- Ion Exchange Resins
- DAW
- Contaminated Metals
- Activated Metals
- Incinerator Ash

Table 5: Package Data Summary

Container Type	Waste Weight (lbs)	Contact Dose Rate (mR/hr)	Activity (mCi)
55 GALLON DRUM	100	20	4.47
55 GALLON DRUM	82	20	1.55
55 GALLON DRUM	76	15	1.85
55 GALLON DRUM	80	15	1.11
55 GALLON DRUM	78	10	2.58
55 GALLON DRUM	70	10	2.45
55 GALLON DRUM	120	7	1.69
55 GALLON DRUM	180	7	0.65
55 GALLON DRUM	88	5	1.26
55 GALLON DRUM	185	5	0.85
55 GALLON DRUM	72	4	1.48
55 GALLON DRUM	132	4	0.56
55 GALLON DRUM	80	4	0.10
55 GALLON DRUM	60	4	0.07
55 GALLON DRUM	86	3	0.66
55 GALLON DRUM	85	3	0.49
55 GALLON DRUM	82	2	0.65
55 GALLON DRUM	76	2	0.63
55 GALLON DRUM	42	2	0.35
55 GALLON DRUM	46	2	0.26
55 GALLON DRUM	52	0.8	0.10
B-25 BOX	2,778	20	5.22
B-25 BOX	2,286	20	4.30
B-25 BOX	2,131	20	4.01
B-25 BOX	1,764	20	3.32
B-25 BOX	2,225	2	0.30
20' SEAVAN	11,520	10	16.25
20' SEAVAN	5,420	5	4.69

Field Testing Experimental Setups

The testing area was set up in a low background area at the testing facility. For the acquired 55-gallon drum gamma spectra, the HPGe detector was set up on a small cement porch whereas the REACh™ Detector was setup on a cart stand at the 55-gallon drum mid-height. The cart and 55-gallon drum locations were marked on the ground and subsequent 55-gallon drums were placed in the marked locale. REACh™ 55-gallon drum readings were initially taken at 1 meter but due to the extremely low dose rates on some of the 55-gallon drums the detector was moved closer to a reading distance of 1 foot after the third 55-gallon drum. The 55-gallon drum measurement setup is shown in Figure 1 below. Twenty-one 55-gallon drums were analyzed. The acquired REACh™ gamma spectra were performed using the Dynamic acquisition time setting, which finished acquiring data in a matter of seconds, and at fixed time intervals of 1 minute and 5 minutes. All HPGe gamma spectra were acquired using a 5-minute acquisition time.

Figure 3: 55-Gallon Drum Measurement Setup

The B-25 box gamma spectra were acquired such that the HPGe Detector and REACh™ Detector were on opposite sides of the B-25 box which allowed both detectors to obtain gamma spectra in parallel thus saving time. The B-25 box was then rotated 180 degrees such that additional spectra could be acquired. The setup was similar to how the 55-Gallon Drums were acquired with the REACh™ Detector. That is, the REACh™ Detector was set up on a cart at 1 foot as shown in Figure 4 below. The REACh™ gamma spectra were obtained using the Dynamic acquisition time and at fixed time intervals of 1 minute and 5 minutes. Additionally, 10-minute spectra acquisitions were obtained for all B-25 boxes with a CZT detector for comparative purposes

Figure 4: B-25 Box Measurement Setup

Two 20’ intermodal containers were analyzed at a concrete storage pad at the testing facility. Gamma spectra were acquired at two locations on each long side of the package with each detector. The REACh™ Detector was set up at 2 meters for the intermodals. The 20’ intermodal container measurement setup is shown in Figure 5 below. The REACh™ gamma spectra were obtained using the Dynamic acquisition time and at fixed time intervals of 1 minute and 5 minutes. Additionally, 10-minute spectra acquisitions were obtained for all intermodal containers with a CZT detector for comparative purposes.

Figure 5: 20’ Intermodal Container Measurement Setup

One of the final tests which was performed on an intermodal container was a “walk-around” spectra acquisition. That is, six (6) spectra acquisitions were obtained on the intermodal container. The walk around spectra acquisition of the intermodal container was completed in about 1 minute of real time.

REACh™ Dose Rates

The REACh™ Detector continuously monitors the gamma dose rates and the data is integrated over the spectra acquisition time and is stored alongside the gamma spectra which was acquired. The background can be subtracted from this dose rate, which represents the best available information for characterization. For packages where multiple readings are obtained, the average dose rate is used.

Geometry Correction Factors

REACh™ uses geometry correction factors to account for differences in absorption as a function of energy. REACh™ measures the gamma flux at the surface of the package and the results need to be corrected for self-absorption within the source to properly account for the gamma distribution which is distributed throughout the source. REACh™ does this with correction factors calculated with point kernel shielding for each geometry and material combination as a function of density and energy.

Testing Results

The testing results are summarized below. The results are broken down into radionuclide identification, spectra acquisition comparisons, and final characterization results. Detailed comparisons for the results are provided for representative packages from each package type analyzed. The final characterization for the 55-gallon drums is provided for the aggregate of all the 55-gallon drums with the results compared to the HPGe acquired gamma spectra.

Radionuclide Identification

One of the main functions of REACh™ is to identify the predominant gamma emitting radionuclides present in the waste packages. One advantage of REACh™ is that it performs this task without the need for an SME to review spectra, therefore allowing technicians to easily use the device in the field to characterize packaged waste in real time. REACh™ was easily able to identify Co-60 and Cs-137 in the waste packages. REACh™ was also able to identify other gamma emitting radionuclides in the waste packages including Ag-110m, Co-57, Co-58, Cs-134, Mn-54, Zn-65, Nb-95, Zr-95, and Sb-125.

The REACh™ Detector acquired gamma spectra for all waste packages with a Dynamic acquisition, a 1-minute, and a 5-minute spectral acquisition time. One primary benefit to increased acquisition times is reduction in uncertainties associated with identified gamma emitters. On average, the uncertainty was reduced by a factor of 4 when performing a 1-minute measurement relative to a Dynamic acquisition (e.g., 8% uncertainty to 2% uncertainty). On average, the uncertainty was reduced by a factor of 2 when performing a 5-minute measurement relative to a one minute (e.g., 2% uncertainty to 1% uncertainty).

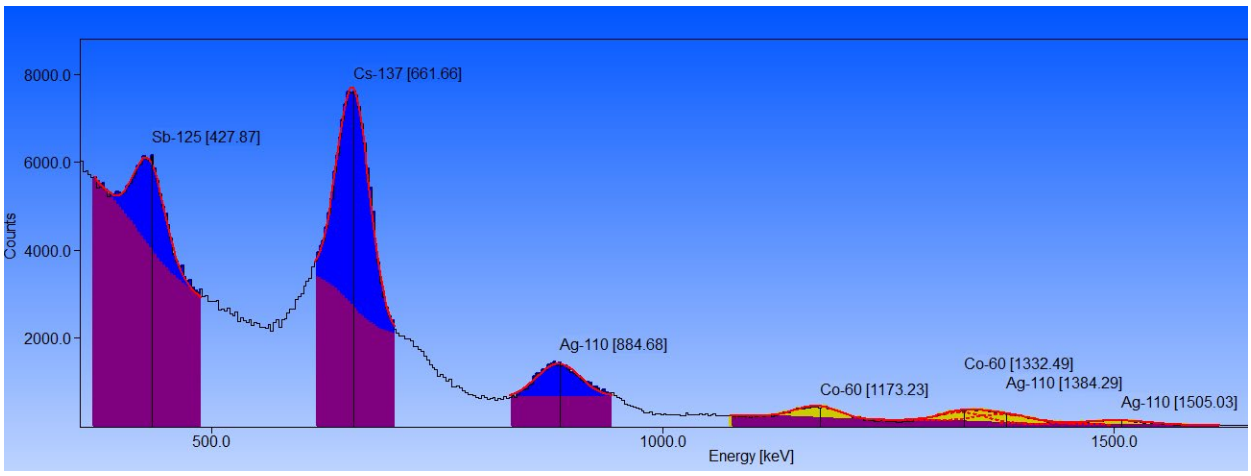
The REACh™ Detector-identified radionuclides were in good agreement with those found by the HPGe detector. There were some issues encountered with coincident energy peaks for some radionuclides. REACh™ uses automated peak processing software based on radionuclide main peak energy matching. Based on the expected distribution of

gamma-emitting radionuclides in typical low level waste streams, some overlaps in energy peaks are expected.

Initially there were some identification issues with Zn-65 (1116 keV), Na-22 (1275 keV), and Fe-59 (1292 keV) relative to Co-60. Zn-65 was sometimes mis-identified and or lost within the 1173 keV Co-60 photon peak whereas the Na-22 and Fe-59 photon peaks were getting lost in the Compton Scatter that occurred between the two Co-60 photon peaks. There were also identification issues with Nb-95 (766 keV) relative to Cs-134 (795 keV).

The program's search logic was adjusted to search for radionuclides with close energies concurrently, and this eliminated most of the issues except for Ag-110m, which is a special case. Ag-110m gives off numerous gamma photons, but most of the higher energy, higher yield photons are right on top of other photon peak energies that are expected to be seen in commercially generated nuclear waste. It is expected that interference with the Ag-110m photon peak at 658 keV, 94.4% Probability of Emission, could occur when Cs-137 (662 keV) is present and the Ag-110m photon peak at 884 keV, 74% Probability of Emission, could be interfered with by the Nb-94 photon peak at 871 keV and or with the Mn-54 photon peak that occurs at 835 keV. Therefore, REACh™ searches for Ag-110m using the 937 keV photon peak, 35% Probability of Emission, which is only interfered with by Th-232 (911 keV). It is not expected to see Th-232 in typical LLRW or typical VLLRW, However, REACh™ misidentified Ag-110m as Th-232 in a few cases. Therefore, we are incorporating a secondary library into the identification routine to search for radionuclides which produce multiple prominent photon peaks for purposes of verifying their identification (e.g., Ag-110m, Sb-124, Eu-152, etc.). See Figure 6 below, which provides a portion of the spectral plot for a 55-gallon drum filled with fly ash. The plot showcases that multiple photo peaks are present for Ag-110m, therefore, a secondary library within REACh™ could be utilized for purposes of improved identification and verification.

Figure 6
Fly Ash Drum Spectral Plot Section



The radionuclides identified by REACh™ as a function of acquisition time are shown in Table 6 below and are compared to the HPGe detector results which were acquired via 5-minute acquisition times.

Table 6
Radionuclide Identification Comparisons
55 Gallon Drum

Radionuclides of Interest	Peak Energy Peak Data (keV)	Activity (µCi) REACh Dynamic	REACh 1-Minute	REACh 5-Minute	HPGe 5-Minute
Ag-108m	433.96				2.69E+00
Ag-110m	885.00		4.94E+00	4.62E+00	5.24E+00
Co-57	122.06				2.82E+01
Co-60	1,252.86	9.96E+00	9.54E+00	8.01E+00	1.21E+01
Cs-137	661.60	5.24E+01	3.99E+01	3.13E+01	2.59E+01
Ge-68	1,077.35	1.72E+02	1.67E+02	1.76E+02	2.02E+02
Totals		2.34E+02	2.22E+02	2.20E+02	2.73E+02

Radionuclides of Interest	Peak Energy Peak Data (keV)	Gamma Percent Abundance REACh Dynamic	REACh 1-Minute	REACh 5-Minute	HPGe 5-Minute
Ag-108m	433.96				1.0%
Ag-110m	885.00		2.2%	2.1%	1.9%
Co-57	122.06				10.3%
Co-60	1,252.86	4.3%	4.3%	3.6%	4.4%
Cs-137	661.60	22.4%	18.0%	14.2%	9.5%
Ge-68	1,077.35	73.4%	75.4%	80.0%	73.8%

As shown in Table 6, the REACh™ Detector was easily able to detect Co-60, Cs-137 and Ge-68 and the results agree with the HPGe results. REACh™ was unable to detect the Ag-108m at 434 keV which was less than 1% abundance of the gamma-emitting activity. This was not surprising considering there were less than 3 microcuries of Ag-108m in the waste package. REACh™ was however able to detect the Ag-110m at 1 minute and 5-minute acquisition times and the results compare very well. Performance for the Dynamic acquisition times should improve once the secondary library is implemented for Ag-110m. REACh™ had difficulty detecting Co-57 in this package. Analyzing the raw spectral data shows REACh™ was able to detect Co-57 for all three acquisition times, however, due to its uncertainty, the associated net counts were screened out.

REACh™ was able to easily detect Co-60 and Cs-137 in all the 55-Gallon Drums despite the relatively low activities. For some of the trace gamma emitters including Ag-110m, Co-57, Mn-54, Sb-125 and Zn-65, REACh™ was able to detect them in some but not all the 55-Gallon Drums. The only discrepancies in radionuclide identification occurred with Mn-54 (835 keV) and Cs-134 (795 keV). In one instance, Cs-134 was identified when Mn-54 was present and in a second case the reverse was true. More work needs to be done

to resolve this issue, but in the future, WMG intends to use the waste stream data to properly select which radionuclide has been detected. WMG has reviewed over 3855 DAW samples going back five years and Cs-134 was present in less than 1% of the samples with an average abundance of only 0.7%. whereas Mn-54 was present in significant quantities as expected.

In addition to the REACh™ Detector and the HPGe detector which were used to obtain spectral measurements, CZT measurements were also obtained. CZT measurements were obtained to evaluate and compare the three detector technologies to determine which of the three was most applicable to measuring commercially-generated Low-Level-Radioactive-Waste. CZT was selected due to its significantly better Energy Resolution when compared to NaI(Tl). However, a large drawback to CZT was its very low detector efficiency thanks in part to the limited detector sizes available for CZT.

Because of CZT detectors' intrinsically low detector efficiencies, 10-minute measurements were performed on each package with the CZT detector. This was significantly longer than the typical Dynamic acquisition times of the REACh™ Detector which were, on average, a few seconds long. After analyzing the results, in comparison to the REACh™ results, the CZT detector would require longer than 10 minutes of acquisition time to obtain similar results. Furthermore, the radionuclide identification of the CZT was poor as a result of the low detector efficiency. That is, the CZT results, in general, were unable to obtain enough statistically valid acquisition data to have comparatively accurate identification results. Significantly more time would be required to obtain comparative results to REACh™.

REACh™ Characterization Results

The characterization results from REACh™ were compared with the activities of the gamma emitters found with the HPGe detector for all 21 55-gallon drums. The 55-gallon drums were compared on the aggregate relative to the HPGe results. The total calculated activity for the 21 55-gallon drums is summarized in Table 7 below. As shown in the Table, the gamma emitters were within 6% of the results obtained with HPGe and the total activities are about 22% lower than the generator results for the 55-gallon drums. Co-60 and Cs-137 were in good agreement. with both HPGe and the waste generator results. The Ag-110m, which was detected by REACh™ is relatively low and we will re-run the spectra after the Ag-110m refinements discussed above are implemented.

The REACh™ detector did not see any Ag-108m, Ce-141 or Co-58 in the 55-gallon drums due to the extremely low percent abundance of these isotopes that were much less than 1% of the activity.

Table 7
Drum Comparison Summary

Radionuclides of Interest	REACh µCi	HPGe µCi	Percent Abundance	REACh/HPGe
Ag-108m		7.25E+01	0.61%	0.00
Ag-110m	7.06E+01	1.31E+02	1.10%	0.54
Ce-141		8.33E+00	0.07%	0.00
Cm-243	2.30E+01	1.08E+02	0.91%	0.21
Co-57	5.40E+01	1.16E+02	0.98%	0.47
Co-58		9.38E-01	0.01%	0.00
Co-60	1.82E+03	1.92E+03	16.22%	0.94
Cs-134	7.04E+00	4.25E+00	0.04%	1.66
Cs-137	4.69E+03	4.01E+03	33.81%	1.17
Ge-68	3.83E+03	5.31E+03	44.81%	0.72
Lu-177m		2.99E+01	0.25%	0.00
Mn-54	3.69E+01	3.82E+00	0.03%	9.66
Nb-95	1.69E+02	6.70E-01	0.01%	**
Sb-125	4.60E+02	7.51E+01	0.63%	**
Zn-65	6.22E+00	6.24E+01	0.53%	**
Totals	1.12E+04	1.19E+04		0.942

There were six B-25 boxes analyzed. The results for a typical B-25 box containing DAW from a commercial power plant are summarized below in Table 8. The total gamma-emitting activity is within 2% of the HPGe results, but the REACh™ results contain slightly higher Cs-137 than the HPGe results.

Table 8
B-25 Box Comparison

Radionuclides of Interest	REACh µCi	Percent Abundance	HPGe µCi	REACH/ HPGe
Am-241	8.29E-02	0.02%		
Ce-144	4.41E+01	11.35%		
Co-58	9.90E-01	0.26%		
Co-60	1.78E+02	45.89%	2.26E+02	0.79
Cs-134	4.20E+01	10.83%		
Cs-137	8.57E+01	22.09%	5.86E+01	1.46
Fe-55	1.17E+01	3.03%		
Mn-54	1.97E+01	5.08%	2.55E+00	7.75
Ni-63	1.17E+00	0.30%		
Pu-238	8.53E-02	0.02%		
Zn-65	4.38E+00	1.13%		
Totals	3.88E+02			9.87E-01
Total Gammas	2.84E+02		2.87E+02	

The underlying objective of the REACh™ Detector System is to enable users to characterize packaged radioactive materials quickly and accurately. To do this in an ALARA fashion, the Dynamic acquisition time must be used to acquire the data in a matter of seconds from each reading. The last phase of the testing was to perform a “walk around” gamma spectra acquisition on a 20’ intermodal container. Three measurements were taken on each long side of the package using the Dynamic acquisition time setting. The average measurement time per acquisition was 5 seconds and the intermodal’s six gamma spectra were acquired in 22 seconds. The results were within 4% of the results obtained using the fixed detector positions with substantially longer acquisition times. This showcases that the REACh™ Detector can perform its intended function quickly and easily. We anticipate final release of the REACh™ Detector System within 90 days after the issues observed during field testing are resolved.

Conclusion

The REACh™ Detector System has been shown to be an effective tool to characterize LLRW waste packages. This revolutionary lightweight handheld device allows for a very portable detector system. As previously discussed, Dynamic acquisitions which are obtained via the REACh™ Detector have been shown to be reliable and compare well to longer acquisition times. Allowing technicians to utilize the Dynamic acquisition time provides an ALARA-friendly detector which can quickly perform in-field gamma spectroscopy on waste containers.

The REACh™ Detector System utilizes package-specific gamma spectroscopy results in conjunction with package-specific dose rates to provide more accurate characterization results than current methods can provide. Accounting for short-lived radionuclides more effectively, such as what the REACh™ Detector has been shown to be capable of accomplishing, conservatism is removed from characterization results by not overestimating hard-to-detect radionuclides and transuranics thus saving customers money in regards to their transportation, packaging, and disposition costs.

As previously discussed, the REACh™ detector utilizes a 2” x 2” NaI(Tl) crystal. The REACh™ Detector has a lower detector resolution when compared to that of a CZT or HPGe detector. This in turn can result in radionuclide identification challenges for coincident photon peaks. The REACh™ Detector system will be incorporating a secondary photon peak library to more accurately identify radionuclides that may have coincident photon peaks. The REACh™ Detector System is fully integrated into the RADMAN Suite. Having prior knowledge of expected gamma emitting radionuclides present in waste stream distributions allows the REACh™ System’s search algorithms to more accurately search for expected gamma emitters.

The REACh™ Detector has a very high detector efficiency which allows it to detect at very low radiation levels very quickly. This makes the system suitable for evaluating disposition options for a given package such as being disposed of in an exempt cell or satisfying free release requirements. Due to the limitations with radionuclide identification, additional analysis may be required on some packages containing unknown isotopes. Additionally, the REACh™ detector is great for quickly assaying areas or objects to determine if gamma emitting radionuclides are present. Save time, dose, and money with quick, accurate acquisition times thanks to REACh™.

Once the aforementioned secondary photon library is implemented, the 160 gamma spectra collected during field testing will be reanalyzed using the new software and additional laboratory and field testing will be performed.

The REACh™ Detector is scheduled for commercial release during the fourth quarter of 2021.

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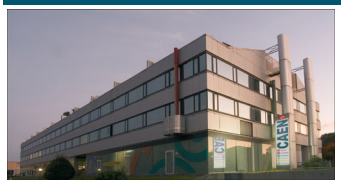

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