Challenges and Solutions Encountered During the Deployment of the Turn-Key CRATER™ System at the River Corridor Closure Project at the U.S. Department of Energy's Hanford Site - 10384

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ABSTRACT

Washington Closure Hanford (WCH) is responsible for the performing safe decontamination/demolition of hundreds of excess facilities, placing deactivated plutonium production reactors in interim safe storage, cleaning up contaminated waste sites and burial grounds that exist throughout the 220 square mile area of the Hanford River Corridor, and operating the Environmental Remediation Disposal Facility for disposing of all CERCLA waste at Hanford.

Technology innovations that improve safety to workers, increases production efficiencies, and enhance operational quality are important aspects to a clean up closure project that is under strict regulatory requirements and deadlines for clean up and must ensure that the intended protection of human health and the environmental are achieved. Washington Closure Hanford LLC, working with Chesapeake Nuclear Services (ChesNuc) and Radiation Safety Associates (RSA) undertook the process of building a turn-key radiation detection system that could be used for identifying the presence of Spent Nuclear Fuel (SNF) fragments during the excavation of the reactor burial trenches at the Hanford Reservation. The result was a system called CRATER™ (Compton Ratio Analysis for Testing Environmental Radioactivity) and its proprietary software application CoRE (Compton-Ratio Evaluation). Application of the CRATER™ for burial trench remediation activities improved operations by providing a real-time screening of excavator buckets for SNF fragments and reduced personnel exposures by minimizing hands-on surveys of trench excavated materials. The previous method for searching for and identifying SNF was to scoop up a bucket of soil, spread this soil in a trench and then scan it with GM detectors.

The purpose of this paper is to present the challenges encountered during the deployment of the CRATER™ system at the burial trench. The harsh environment (vibration and mechanical shock) at the end of an evacuator boom challenged the reliability of the electronic components. Down time for parts replacement and repair became an issue. To address down time, each problem that occurred was aggressively dealt with. Some solutions were simple (such as utilizing cables with vibration-resistant connectors) while others were more fundamental (such as totally redesigned boards). Each modification reduced the down time and increased operator confidence in the system. The outcome of our modifications resulted in a smoothly running system with little or no down time and significant safety benefits to the workers. In addition to the safety benefits, a significant improvement in schedule performance was achieved. This allows reallocation of resources to other tasks and an overall improved efficiency. Cost saving realized by eliminating the double handling of waste will eventually result in a cost saving at one site of over $1,000,000. Further cost savings will occur when the system is used in subsequent excavations.

INTRODUCTION

The remediation of the reactor burial trenches at the Hanford Reservation is a significant element of the overall Hanford clean-up activities. Buried in the trenches that are located adjacent the reactor sites are various rubble, components and miscellaneous materials that resulted from the decommissioning of the reactors. The significant, gamma-emitting radionuclides present in the reactor burial trenches are Co-60, an activation product mainly associated with reactor components, and Cs-137, a fission product and main constituent for a spent fuel fragment.[1] The remediation activities require that spent fuel fragments be segregated and processed separately from other remediated materials. Therefore a method was needed for identifying these fuel fragments, which have been characterized as material containing greater than 1.1 Ci of Cs-137, from other Co-60 contaminated materials.

The result was the development of a specialized radiation detection system called ***CRATER*™** (Compton Ratio Analysis for Testing Environmental Radioactivity) and its proprietary software application ***CoRE*** (Compton-Ratio Evaluation) for screening excavator bucket soil content for presence of a spent fuel fragment. The screening methodology is based on conservatively established threshold conditions as a real-time means for clearing excavator bucket content. Application of the ***CRATER*™** for burial trench remediation activities has improved operations by providing a real-time screening of excavator buckets for SNF fragments and reduced personnel exposures by minimizing hands-on surveys of trench excavated materials.

SYSTEM DESCRIPTION

***CRATER*™** is enclosed in a welded aluminum housing, which is affixed to the arm of an excavator boom. The outside dimensions can be described as a solid right triangle "wedge" with 41 cm (16 inches) sides and 36 cm (14 inches) width. It is positioned such that the bottoms of the detectors are a nominal 61 cm (24 inches) from the top of the bucket/soil. The detector housing is constructed primarily of 0.64 cm (0.25inches) aluminum with a detector window of reinforced low-Z material (0.95 cm nylon) to provide an essentially open field of view for the detectors to the excavator bucket.

Within the housing are two NaI (Tl) detectors. One uses a 1-inch diameter by 1-inch long crystal intended for low-range operation of less than 0.2 mSv/h (<20 mR/h). The other uses a 0.25-inch diameter by 1-inch long crystal intended for high-range operation for greater than 0.2 mSv/h to 3.5 mSv/h (>0.2 mSv/h to <350 mR/h). Also housed within the wedge are two modified multi-channel analyzers (one for each NaI (Tl) detector); a motorized assembly for placing a gain-stabilization source in proximity to the detectors and retracting it back to a shield; and a master controller board responsible for direct management of all functions within the wedge and communication with the external controlling device.

***CRATER*™** is controlled through a master controller board communicating via Bluetooth with a Trimble Recon (a ruggedized PDA running the Windows Mobile 6 operating system). The software application residing on this Recon provides the user interface for controlling system operations, such as to begin measurements, evaluate spectrum for potential fuel fragment (utilizing the application methodology). Other functions, such as daily source checks, backgrounds and save/retrieve/view past spectra, are also controlled via the Recon.

Customized Multi-Channel Analyzer Description

The ***CRATER*™** contains two multichannel analyzers (MCA) for acquiring spectra from the two scintillation detectors. These MCAs are customized systems that have been specifically designed for the collection and analysis of the measurements as required for this project and are based off of the commercially-available URSA-II. They have been adapted to operate using raw excavator power (9 to 36 volts DC) and to minimize the heat generated by the electronics. Additionally, specialized firmware was developed to utilize an upgraded microcontroller with expanded memory and processing capability to

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[1] It has been approximately 30 years since the disposal of radioactively contaminated materials in the subject burial trenches. Therefore, through radioactive decay, most activation and fission products are no longer present. For gamma-emitting radionuclides, there is a relatively minor presence of Eu-152 with its 13.6 year half-life; but is insignificant compared with the presence of Cs-137 in a SNF fragment.

handle the real-time processing of spectral data on a continual basis. The microcontroller firmware was adapted to support a more efficient data packet to ensure integrity of transmitted spectra, improve autonomous operation, ensure high precision acquisition timing, and initialization without the intervention of an external controlling device. Hardware settings (high voltage, threshold, gain, and fine gain) are maintained in the non-volatile memory and the last-used settings are re-loaded on power-up. Regions of interest (ROIs) were established for analyzing the spectra. ROIs for the 0.667 MeV Cs-137 photopeak, the Cs-137 Compton continuum, and the 1.17 and 1.33 MeV Co-60 photopeaks, as described later.

Computer Application Description

The computer software program for the ***CRATER*™** running on the Recon was written specifically for this application using embedded Visual C++ version 4.0. The application provides control signals to the system, retrieves data from the MCAs and other sensors, and performs the Compton-Ratio Evaluation (***CoRE***) proprietary software application for screening excavator bucket soil content for presence of a SNF fragment. Additionally, the application controls the operation of the gain stabilization routine, background measurements, and continual QA/QC checks for ensuring proper system operation. The automated fine gain adjustment initiates measurements for both detectors (two NaI (Tl) scintillation detectors) after moving the check source out of its shielded position. Spectra are acquired and, if indicated, the fine gain is automatically adjusted to align the 662 keV peak with MCA channel 110, which has been established as a standard design feature to support multiple systems operations, exchange, maintenance, and comparison. This operation also provides a source check for the detectors. As a QA measure, both detectors are required to have background-corrected total counts within 20% of that determined during calibration.

Sodium Iodide Detector Temperature Induced Gain Shift

Thallium-activated sodium iodide (NaI(Tl)) scintillation detectors and the photomultiplier tubes to which they are coupled are subject to gain shift under changing temperatures and damage from mechanical shock.

The light output of NaI(Tl) in response to gamma energies varies with temperature. It is vital that the fine gain is adjusted, via the automated routine, to keep the 662 keV peak aligned with channel 110 of the MCA for both detectors. This alignment is maintained by the automated fine gain adjustment that is periodically performed by the Radiation Control Technician throughout the day. Upon measurement of a 7° C temperature change (inside the *CRATER*™ box), the CoRE software application requires the RCT to perform an auto fine gain adjust. The threshold for the fine gain adjustment was established based on an evaluation of gain shift as a function of temperature. The algorithms developed for SNF fragment screening maintained reliable performance within the gain shift (and resulting energy-channel alignment) for a 7° C temperature change.

Operability Determination

Due to the nature of the working environment (vibration and mechanical shock), it is important that the operability of the detectors be verified, essentially for each bucket measurement. This verification provides assurance that each bucket is appropriately screened. An operability evaluation is performed for each measurement by verifying that there is a minimum of 200 gross counts for the 1X1 inch NaI and 30 gross counts for the 0.25X1 inch NaI over the 15-second acquisition time. Additionally, the 1st two channels for each MCA unit, by design, should have zero (0) counts, which is also verified. If both conditions are not met, the system returns the message, “Detector Malfunction – Contact Supervision.” Additional software checks and controls are provided to ensure functionality, such as 2-way software communication (positive acknowledgement) for commands functions and error checking (checksum) for complete and accurate data transmissions.

CHALLENGES AND SOLUTIONS ENCOUNTERED DURING THE DEPLOYMENT

Challenges in system operation and operator use were encountered during the initial deployment of the CRATER™ system at the burial trench. The harsh mechanical vibration and shock environment at the end of an evacuator boom took a heavy toll on the reliability of electronic components. Use of a "new" system and approach to screening for SNF fragments provided adjustments in both design and personnel operations. The following information addresses all the changes made to reduce and eventually eliminated down time associated with equipment failure.

Excavator Mounting Bracket

The first issue we encountered was standardizing the mounting of the CRATER™ unit on the excavator boom. Initial mounting was by directly bolting the unit to brackets welded on the boom. This configuration required tight alignment, which was difficult to maintain in the field. To allow for greater tolerances and also facilitating quicker field change-out, onsite personnel engineered a mount basket arrangement. This new basket bracket setup consisted of two parts for easy removal and installation. Figures 1 and 2 presents the original and the redesigned brackets.

The second problem was protection of the CRATER™ unit from damage. There was little protection of the unit from debris (e.g., metal objects) and materials projecting above the bucket rim. To provide additional protection, a steel plate was added to the bracket to deflect objects or heaped material. This plate helped eliminate physical damage to the unit by deflecting materials and preventing direct hits on the unit. The nylon detector window fits over an opening in the plate.

Fig. 1. *CRATER*™ Original Bracket on Excavator Boom

Fig. 2. CRATER™ Redesigned Brackets on Excavator Boom

Training of Heavy Equipment Operators (HEO)

The CRATER system was injected into a site that was already in the act of remediating a reactor burial trench. This prompt field deployment of the initial CRATER design did not allow time for the HEOs to practice excavation techniques where more attention was needed to bucket movement, debris loading, and also required continual interaction with the radiation control technicians (RCTs) for the real-time measurements/screening. This situation contributed in part to the problems mentioned above. With start up of a new site in the fall of 2009, we had an opportunity to provide training to the HEOs using clean soil. During the dry runs we also trained the RCTs in the system use.

Figure # 3 Dry Run with HEOs

Bluetooth Communications

The original Bluetooth communications consisted of an internal low power Bluetooth device embedded in the Recon unit and a higher powered unit inside CRATER. Conventional wisdom was that the Bluetooth unit in the CRATER with longer range would make up for the short range of the embedded unit inside the Recon. Within 2 months it became apparent that dropped Bluetooth connections between the CRATER and the Recon unit was at the root of one of our productivity problems. Whenever communications are dropped, CRATER requires a complete start-up sequence that includes gain stabilization, background readings and a source check. This start-up sequence is by design as one of the measures to ensure an operational unit. The solution was to employ a high gain antenna on the excavator boom and the use of an external high powered Bluetooth dongle attached to the Recon. Once these fixes were implemented, our problems with dropped communications were resolved.. Figure #3 presents the inclusion of the new Bluetooth dongle.

Figure #4 External Bluetooth Dongle

Proximity Sensor

The initial design included a proximity sensor to determine when the bucket was in a place for counting. It would also detect if the bucket moved during counting and invalidate that measurement. The modeling developed for SNF fragment detection included a maximum distance between the top of the bucket soil and the CRATER unit. Early in field deployment, the proximity sensor did not provide reliable indication of the soil-CRATER distances. This caused the need for repeated unloading and reloading of buckets and multiple readings, which had a detrimental effect on productivity with no offsetting benefit. The uneven surface created by the debris in the bucket was the root cause. Several adjustments were attempted but were unreliable in resolving the issue. Rather than re-design with a more robust sensor system, we decided to rely on administrative controls and training. Operators were trained in ensuring a minimum bucket loading, which ensured the maximum distance was not exceeded. Field observations by management confirmed that the above measurements were effective in preventing out of placement counting.

Source Mover

Also housed within CRATER is a 10 µCi (nominal) ^{137}Cs check source to provide a known spectrum for gain stabilization. It is normally shielded from the detectors by a 10.16 cm (4 inch) lead block. The source is mounted on a chain and driven by a servo motor. A magnet is mounted on the chain to allow miniature reed switches to sense the source position. A servo motor was selected to drive the chain in order to ensure that no drift in the position of the source would occur, as designated position is positively maintained.

When extreme cold weather finally settled in, temperature sensitivity of the servo motor that controls the movement of the internal source manifested itself. The resistance of the components that set the "zero movement" position changed slightly with the temperature, ultimately resulting in source drift. Software flags that monitor source position would then prevent screening of buckets. The solution was to replace the (analog) servo with digital servo with an adjustable dead band (i.e., zero position) width and the introduction of a more suitable trim pot. Once implemented, the above problems disappeared. See figure # 5 below for picture of Source Mover.

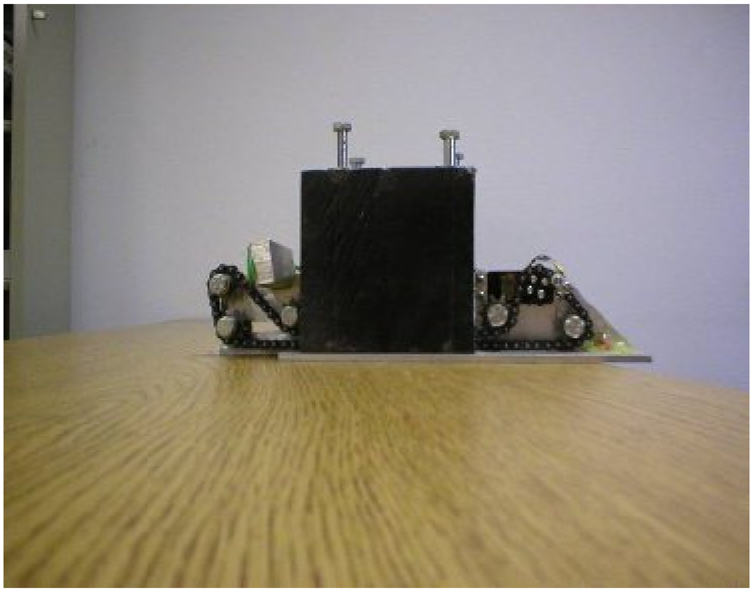

Figure # 5 Source Mover

Software Upgrade

After 5 months of continuous use, many lessons were learned regarding the overall operational activities. It was identified that a system software upgrade would make CRATER function more smoothly, less prone to glitches and able to handle data transfers more efficiently. A decision was made to change the operation such that the strobe light remains lit when an SNF fragment, high dose rate item, or other abnormal condition occurs. The initial functionality called for the HEO to await a signal for the RCT indicating a bucket acceptable for disposal or requiring isolation due to a potential SNF fragment or high dose rate item. The new change allows for the HEO to dump the bucket at the conclusion of the count as long as the flashing strobe stops. The strobe light will continue to flash if an alarm condition exists. This small change has made a positive impact on productivity. Small as the change may appear, the majority of the bucket screen out with no fuel fragment identified; without this change each bucket was held for RCT clearance. Coupled with both of the above improvements, we experienced another bump up in productivity.

Master Control Board (MCB) Redesign

Last of the major CRATER issues was the durability of the MCB. As time racked up on the CRATER units, MCB board failures and GM operability issue became a concern and a decision was made to redesign the MCB. The GM tube circuit was causing erratic operation; a redesign (or elimination in this case) was needed. Reducing size and enclosing in a hardened case provided a more robust operating design. The function of the onboard GM was to switch from low range monitor to high range monitor when encountering high dose rate fields. The solution was accomplished by exposure-rate calibrating the NaI (Tl) high range detector to provide the same functionality. These last two changes were responsible for the final transformation of CRATER. See Figure # 6 below for picture of the new harden MCB.

To accomplish a more reliable operation, it was determined that the integrated G-M detector must be eliminated to provide for a smaller foot print. Specifically, the low count rate from the peanut tube GM and poor statistics associated with such a low rate was causing an operability issue during start up checks.

Figure #6 Master Controller Board with Top Removed

Cables

Cables were an off and on again problem with CRATER. The tight quarters of the wedge interior caused problems for all the cables. One by one we replaced all cables that had tight bends to navigate with custom made cables with built in turns. Special latching connector ends that resist vibration were used to connect internal components. The redesign of the MCB also reduced the length of that component, serving to further reduce the stress on the cable ends. Please see figure #7 for details on those new cables.

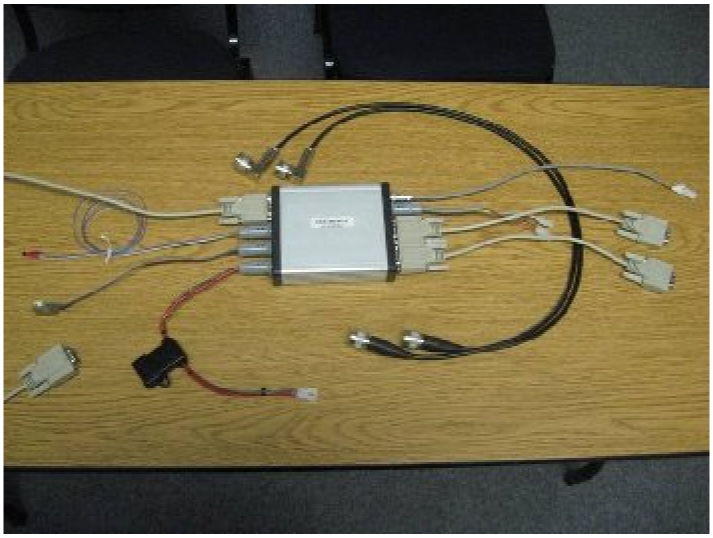

Figure # 7 Cables

Conclusion

The resolving the challenges encountered during the deployment of the CRATER™ system at the burial trench was a daunting task. The harsh environment at the end of an evacuator boom took a heavy toll on the electronic components and down time became an issue. Each problem was occurred was aggressively pursued. Each modification reduced the down time and increased operator confidence in the system. It is worth noting that many of these modifications also resulted in an overall simplification of the system. The outcome of our modifications resulted in a smooth running system with little or no down time and significant safety benefits to the workers. In addition to the safety benefits, a significant improvement in schedule performance was achieved.