Design Process for the Development of a New Truck Monitoring System – 13306

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ABSTRACT

Canberra Industries, Inc. has designed a new truck monitoring system for a facility in Japan. The customer desires to separately quantify the Cs-137 and Cs-134 content of truck cargo entering and leaving a Waste Consolidation Area. The content of the trucks will be some combination of sand, soil, and vegetation with densities ranging from 0.3 g/cc - 1.6 g/cc. The typical weight of the trucks will be approximately 10 tons, but can vary between 4 and 20 tons. The system must be sensitive enough to detect 100 Bq/kg in 10 seconds (with less than 10% relative standard deviation) but still have enough dynamic range to measure 1,000,000 Bq/kg material. The system will be operated in an outdoor environment.

Starting from these requirements, Canberra explored all aspects of the counting system in order to provide the customer with the optimized solution. The desire to separately quantify Cs-137 and Cs-134 favors the use of a spectroscopic system as a solution. Using the In Situ Object Counting System (ISOCS) mathematical efficiency calculation tool, we explored various detector types, number, and physical arrangement for maximum performance. Given the choice of detector, the ISOCS software was used to investigate which geometric parameters (fill height, material density, etc.) caused the most fluctuations in the efficiency results. Furthermore, these variations were used to obtain quantitative estimates of the uncertainties associated with the possible physical variations in the truck size, detector positioning, and material composition, density, and fill height. Various shielding options were also explored to ensure that any measured Cs content would be from the truck and not from the surrounding area. The details of the various calculations along with the final design are given.

INTRODUCTION

Truck cargo with potentially radioactive contents enters and leaves a Waste Consolidation Area daily. The facility would like to separately quantify the amount of Cs-137 and Cs-134 contained within each truck. The estimated vehicle capacity of the facility is 800/day incoming and 400/day exiting. The facility will operate during an 8-hour working day. That corresponds to roughly 30 seconds per truck. Assuming it takes 15 seconds for one truck to move out and a new one to move in, and 5 seconds for results to appear, that means the measurement itself needs to be around 10 seconds. The content of the trucks will be some combination of sand, soil, and vegetation with densities ranging from 0.3 g/cc - 1.6 g/cc. The typical weight of the trucks will be approximately 10 tons, but can vary between 4 and 20 tons. The dimensions for this base vehicle are 3.76 m total height, 1.33 m elevation to the base of the cargo, and 6.18 m length of the cargo portion of the vehicle. The 4 ton and 20 ton vehicles were assumed to be longer or

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shorter in proportion to their capacity. Figure 1 below shows an image of the basic 10 ton truck.

Figure 1. Photo of the 10t vehicle which this study was based on.

There should be five user-adjustable decision levels which combine nuclide and concentration levels of the two nuclides of interest. The current design of the system is based on decision levels for the total activity of the ash A_{Cs-137} to be:

- $A_{Cs-137} < 100$ Bq/kg

- $100 < A_{Cs-137} < 3,000$ Bq/kg

- $3,000 < A_{Cs-137} < 8,000$ Bq/kg

- $8,000 < A_{Cs-137} < 100,000$ Bq/kg

- $A_{Cs-137} > 100,000$ Bq/kg

The uncertainty of the measurement should be below 10% at the decision levels for a 10 second count time (for the 10t truck).

In addition to the performance requirements, the system has many operational requirements that had to be satisfied. It will be operated in an outdoor environment and therefore must be protected from the elements. It must be easily integrated with the facilities existing vehicle operation flow. The system must minimize the influence from radioactive sources not contained in the cargo truck.

PERFORMANCE ESTIMATION

Detector

One of the requirements of this project is separate reporting of Cs-134 and Cs-137 radioactivity. This is important for waste disposal evaluations. Today, the Cs-134 dominates the radiation signal, and the exposure rate from the sample, so is important for operation radiation protection purposes today. But with its short half-life, Cs-134 will become not very important in a few years. Cs-137, however, with its approximately 30y half-life will control the waste disposal options.

This requirement to report Cs-134 and Cs-137 separately means that non-spectroscopic detectors like plastic scintillators cannot be used.

We have many different detector possibilities for quantitative gamma spectroscopy. The High Purity Germanium detector (HPGe) is the defacto "gold standard" for measurements, especially those where clear separation is important, and where widely varying levels of Cs-134 and Cs-137 exist. It is the best choice where there is a wide dynamic range between the lowest and the highest signal rate levels. And HPGe is the best choice where results must be "approved" or "believed" by non-technical inspectors and auditors and other outside observers.

 Scintillation detectors are lower cost options, and seem to be suitable for this application. Canberra offers both LaBr medium resolution scintillation detectors and the more conventional NaI scintillation detectors. And these detectors are available in different sizes.

LaBr has the advantage of clear visual separation between Cs-134 and Cs-137 and therefore better ability for the software to separate those two nuclides. LaBr detectors are approximately the same cost as an equal detection efficiency HPGe detector. However, they have a lower system cost, as they do not have the cost of a cooling system and the other associated hardware that is necessary to support HPGe detectors.

NaI detectors must rely on the ability of the Gamma Spectroscopy software to separate Cs-134 from Cs-137. The Genie scintillation algorithms have proven satisfactory to do this in Japan as they are widely used in our FastScan Whole Body Counting systems and our FoodScreen food assay systems.

Possible scintillation detector choices are:
- 38mm [diameter] x 38mm LaBr
- 50mm x 50mm NaI
- 76mm x 76mm NaI

The 3"x3" [76mm x 76mm] NaI detector has been used for the calculations in this proposal, as it seemed to best meet all the criteria. In particular, as several detectors will be used to gauge the uniformity of the radioactive contents, the lower cost of the NaI made it the better choice. Also, the nuclide mixture will not be very complicated, and therefore the resolving power of HPGe is not necessary.

In addition, NaI detectors can also be made available with LED gain stabilization. This is very important for this project. The detector will be in an outdoor environment. Therefore it must operate in the wide range of environmental temperatures common to Japan. But the photomultiplier tube, and the scintillator are also sensitive to temperature – they change gain as the temperature changes. Canberra has a unique patented method to keep the detectors at constant gain [± 2%] over a wide range of temperatures [-20°C to +50°C]. This is completely automatic – no need for the operator to do anything or use any radioactive sources.

If the cargo content is 10x the highest decision level, the detector is still approximately within its dynamic operating range.

Hardware and Electronics

The detector and photomultiplier tube [PMT] will be connected to our Osprey digital MCA. This unit provides High Voltage power to the PMT and digitizes the signal from the PMT. The Osprey MCA is connected to the PC via and Ethernet connection and powered via a POE [Power over Ethernet] signal. Each MCA is fully accessible from any PC on the Ethernet connection, or Internet connection if so enabled. This is important as it allows the technical supervisor to check on the performance of the system, or to review the results, or to review the QC data from a remote location. If an internet connection is enabled, it also allows Canberra Technical Support personnel to evaluate the system. A PC to control these items and a printer will be supplied. A Control Box containing the PLC will be supplied. This will be the interface to receive the Operator input signal, and to provide the Decision Level outputs to the Operator or the Vehicle Driver. The detector and shield will be contained within the supplied weatherproof housing. The PC and printer and Control Box must be placed in a suitable weatherproof environment. All items must be connected via Ethernet, with POE supplied to the detectors.

Detector Shielding

The detector will be surrounded by 15 cm of lead on the sides and at least 10 cm behind the detector.   Since this unit is operating in a radioactive waste facility it is highly likely that there will be elevated and variable amounts of radio-Cesium in the area around the detector.   This

shielding should allow the counting system to be placed in most any area where plant workers would normally be allowed to work for extended periods of time.
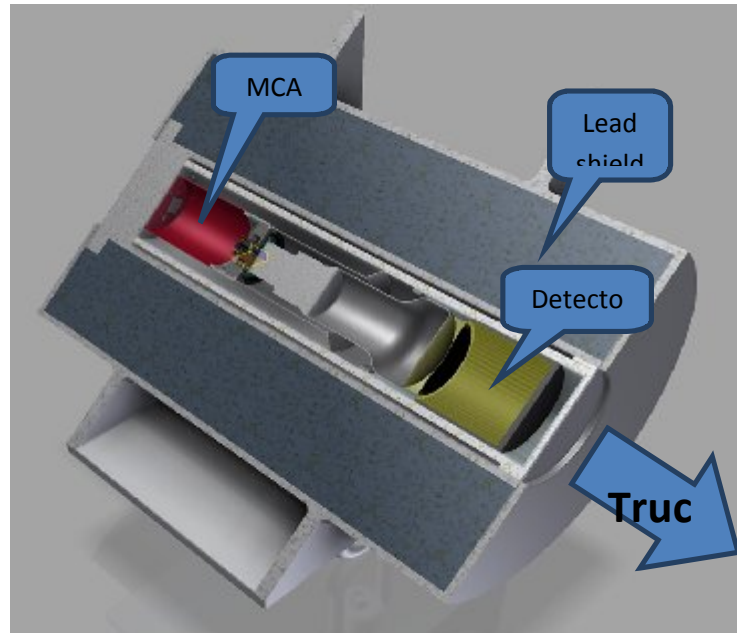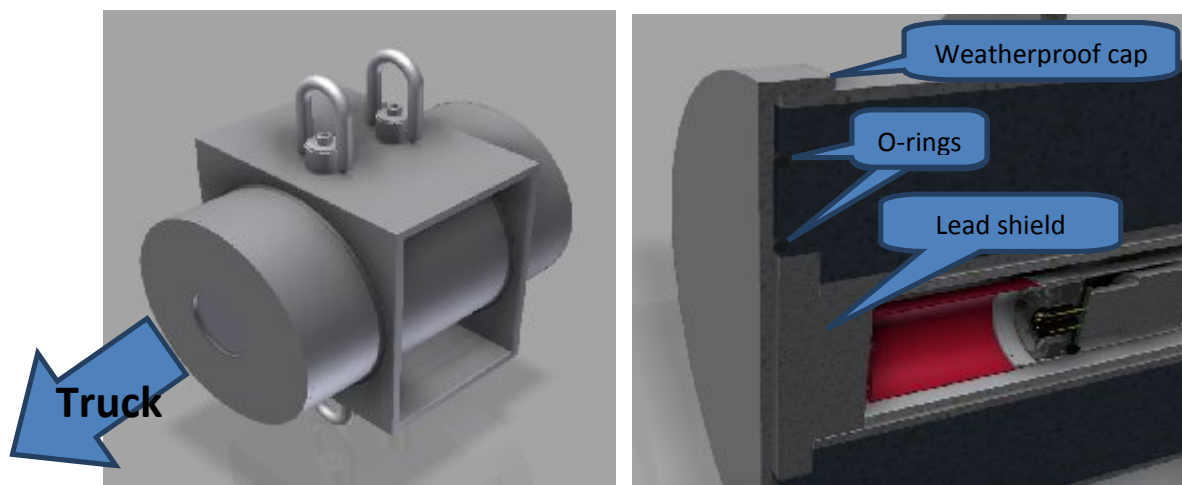

Figure 2. Cross sectional view of the proposed detector shielding configuration.

The shield is a simple cylinder. In Figure 2, above, a cross-sectional view of the detector and shield is on the top is shown. The detector is the yellow object pointing in the direction of the truck. The Osprey Digital MCA is the red object. The lower right hand end of the shield/collimator is open to view the truck. The detector is behind a thin weatherproof window.

The shield module will be designed for external deployment. The shield module can be placed horizontal as shown in Figure 3 [for viewing the sides of the vehicle] or vertical [for viewing the top of the vehicle. There are lifting eyes on the side for both orientations.
The shield will have a removable shield plug and removable waterproof cap on the end to allow the detector to be inserted and removed. One possible method of accomplishing this is shown in the next graphic using two O-rings. Other methods will be explored during the final design phase.

Figure 3. Illustration of the proposed shielding configuration and cross sectional view showing the lead shield and weatherproofing options.

Efficiency Calculations

In preparation for this proposal a set of efficiency calculations were done. The results of these calculations helped us choose the proper detector to meet the estimated range of sample conditions. The results presented below are not intended to represent the final instrument performance, only to aid in the creation and selection of the proper design.   However, they should be quite close to the final performance. In addition, all efficiency calculations assume that the parts of the item that are viewed by the detectors are representative of the entire item. That means that the concentration of radioactivity in the top layer of cargo should be the same as in the bottom layer. The vehicle loading process should control this. The process should not allow a bottom layer of quite radioactive material to be covered with a top layer of lower radioactivity material.

The goal is to minimize the work for the operator and therefore maximize throughput – vehicles per hour. This is best accomplished with a single design that works for all vehicle sizes, and works for all vehicle contents.

The most common vehicle to be used is a 10 ton vehicle.   Two other vehicles were considered – a 20 ton and a 4 ton. We received dimensions for the 10t vehicle, and we scaled those dimensions proportionally for the 20t and the 4t vehicles. The sample matrices evaluated were sand at a density of 1.6 g/cc, soil at a density of 1.2 g/cc and vegetation at a density of 0.3 g/cc. Each vehicle was assumed to be filled to maximum capacity. For sand and soil contents, the maximum capacity was determined by weight, while for vegetation it was determined by height.

Two different detector strategies were evaluated – side detectors and top detectors. In the side configuration, 3 detectors were at each side. For the top configuration, all 6 detectors were on the top, 3 toward one side, and 3 toward the other side. Figure 4 show the detector positioning for the 10t vehicle. The dimensions are with reference to the cargo portion of the vehicle. In both cases, the detector was 50cm from the side [or top] of the vehicle.
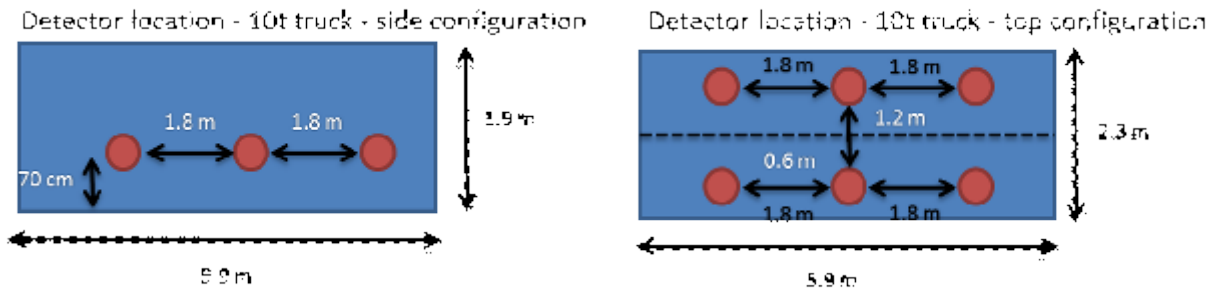
Figure 4. Schematic of side (left) and top (right) detector configurations for the 10 ton truck (not to scale). The detector positions were chosen to maximize efficiency and minimize variations due to truck size and content.

The same detector placement was assumed for the 20t and the 4t vehicles. Figure 5 shows those 4t and 10t geometries for the configuration where the detectors are mounted on the top. We recognize that these are not optimum geometries for these two vehicles, but since they are used less frequently, perhaps a non-optimum solution is still adequate.
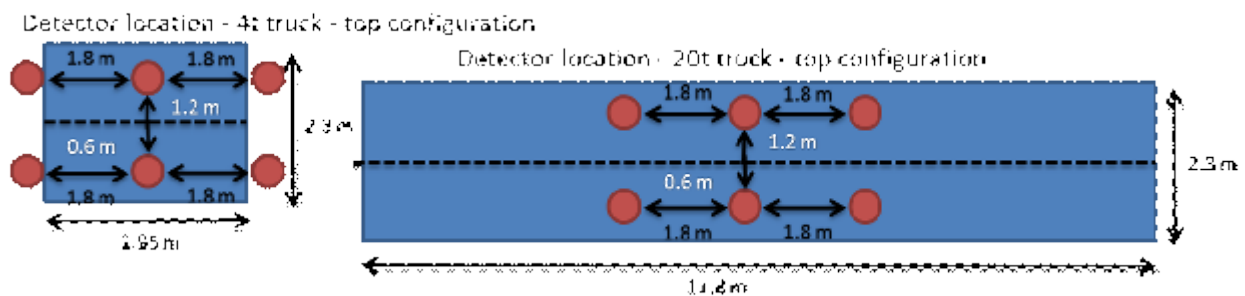
Figure 5. Schematic of the top detector configuration for the 4 ton truck (left) and the 20 ton truck (right).

Canberra's In Situ Object Counting System (ISOCS) software [1,2,3] was used to evaluate the efficiency for each combination of these multiple conditions

- Truck size: 4t, 10t, 20t
- Detector location: side, top
- Sample matrix: sand at 1.6g/cc, soil at 1.2g/cc, vegetation at 0.3 g/cc

- Calibration method: Normal efficiency requiring cargo weight; massimetric efficiency or infinite sample thickness method

For each of the 36 different geometries, the efficiency was evaluated at 15 different energies from 60 to 1800 keV.   The quality of each of the geometries was determined by calculating the relative standard deviation of the 662 keV efficiencies [Cs-137] for each of the comparison methods. The method with the lowest relative standard deviation best meets the goal of a geometry that is invariant to sample size and sample type.

In all cases the geometry where the detectors are on the top was superior – the relative standard deviation with the detectors on the top was 15 to 50% of the value of the relative standard deviation with the detectors on the side. The advantage of the top detector configuration is due to the constant distance between the opposite side of the sample and the front of the detector. In Figure 6 the same effect can be seen in a simple example where the thickness of the sample is increased for the top and side configurations.
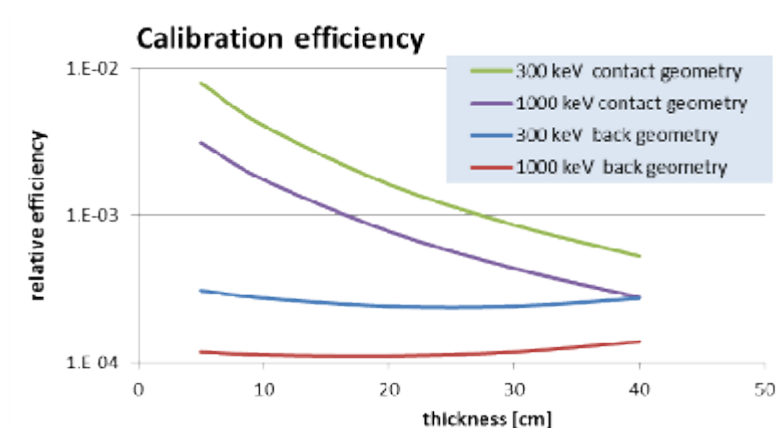

Figure 6. Efficiency calculations for samples of various thickness for a top and side configuration.

In all cases the method of calibration using massimetric efficiency [or infinite sample thickness] had a lower relative standard deviation than the traditional efficiency calibration method [60% to 95%]. In addition, the use of massimetric efficiency calibrations means that the results are automatically in Bq/kg without the requirement to weigh the vehicle.

If one single massimetric efficiency calibration is used for the top detectors on all 3 sizes of trucks, containing all 3 possible matrices, then the relative standard deviation of the measurement will be approximately 25%. The major contributor to this "high" relative standard deviation is the 4t truck. If only the 10t and 20t vehicles are considered, and with all 3 matrices

used, then the relative standard deviation due to variations in efficiency calibration is only 6%, which is quite acceptable for this type of operation.

For the 20t vehicles, if the 6 individual detector results show that the 10t central portion viewed meets a certain Decision Level, then it is statistically reasonable to expect that the front and back of the vehicle that is not measured also meets the same Decision Level. Alternately, the operator could simply do two counts on that vehicle, one on the front half, one on the back half, and use the most restrictive Decision Level.

If 4t vehicles are going to be used, then it is recommended that a separate counting geometry and efficiency calibration be defined for this vehicle size. It might even be create a counting geometry with only 4 detectors, and to position the truck so that it is centered under these 4 detectors. The operator would tell the computer that this is a 4t truck by either a software command or a hardware switch. This would reduce the 4t relative standard deviation to the 10% range.

CONCLUSION

A truck monitoring system has been proposed to meet the needs of a waste consolidation area. The proposed solution involves 6 shielded NaI detectors configured in a top orientation in order to minimize the variances in result due to truck size, cargo fill height, material and density.
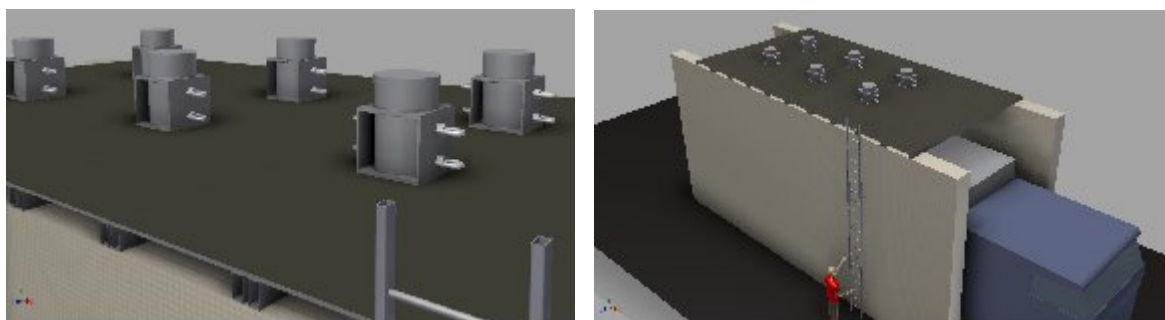
Canberra's ISOCS software was used to evaluate the performance of the proposed system. Efficiency calculations were performed for 36 different configurations in order to determine what the optimal solution would be which met all of the user-specified requirements.

Massemetric efficiency calculations were found to have smaller uncertainties due to variations in geometric parameters. In addition, using massemetric efficiencies gives assay results directly in Bq/kg, which makes evaluating the cargo against the different decision criteria easier.

REFERENCES

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