Second Validation Testing of Canberra-Obayashi Mobile type TruckScan Pre-production Unit – 17214

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ABSTRACT

Canberra Industries, Inc., (Now, Mirion Technologies (Canberra), Inc.), has developed and validated a new truck monitoring system “Mobile TruckScan (MTSCAN)” for use with the Interim Storage Facilities (ISF) in Japan. MTSCAN consists of eight shielded LED-stabilized 3x3” NaI detectors. Each detector has a lead shield with a collimated view of the truck. Four detectors are placed on each side of the truck, thus 8 in total, each at about 1.1 meter from the side of the truck. These NaI detectors and collimators were calibrated by the CANBERRA In-Situ Object Counting System (ISOCS) mathematical efficiency calculation tool.

Around the Fukushima Daiichi NPS area, the decontaminated waste was put into flexible containers called Super Sacks (SS), for transportation to the ISF, typically in 10 metric ton dump trucks.

The MTSCAN pre-production unit was used to measure multiple SSs loaded into 10 ton trucks, and was able to accurately report the activity of each individual SS, with around 10-20 second acquisition time. The system can also accommodate smaller 2 ton and larger 20 ton trucks. The system is relatively compact, and therefore easy to move and setup at a different location. MTSCAN is expected to measure the SSs after loading onto trucks at the Temporary Storage Area (TSA), and at the entrance of the ISF. The MTSCAN assay results showed good accuracy in this demonstration which simulated the actual operation. From these tests, the combined standard deviation for each SS is about 20%, when compared to the reference activity from multiple Ge measurements of each sack.

INTRODUCTION

Six years after Fukushima NPS accident, the decontamination of the land has made considerable progress. The total volume of decontaminated wastes from Fukushima Prefecture was estimated to be more than 22 million cubic meters. Most of this is soil and vegetation, and has been put into large flexible containers called SuperSacks [SSs]. The primary radionuclides remaining today are Cs-137 and Cs-134. These SSs are nominally 1.1m in diameter and 1m in height, and typically weigh between 0.5 and 1.5 metric tons per sack. Occasionally some broken SSs are repacked into 1.3m diameter SSs, with weight between 1.5 and 2.0 metric tons. These SSs are collected in the Temporary Storage Area [TSA], and transported to the Interim Storage Facility [ISF] mainly by 10 ton dump trucks.

At the ISF, these SSs are required to be measured and are divided into three categories according to total Cs concentration. Those SSs with radioactive level (RL) higher than 100,000Bq/kg will be sent to the TYPE IIb storage area; those meeting 100,000Bq/kg>RL>8000Bq/kg will be sent to the TYPE IIa storage area, and those meeting 8000Bq/kg>RL>3000Bq/kg will be put in TYPE I storage.

However, it is very difficult to measure all the SSs at the ISF because of the large quantity of wastes arriving and the small site area. CANBERRA proposed TruckScan [1] which allows measurement of the decontamination waste at the ISF, which then evolved to MTSCAN which can be used at both the ISF and also at the waste accumulation TSA, just before the loaded trucks leave for the ISF. The initial design was estimated to have a Total Measurement Uncertainty [TMU] of 17%. In this paper, MCI, MCKK and Obayashi Corporation (OC) report the performance of the second validation testing of the improved Pre-production unit of the MTSCAN at a temporary storage site next to Fukushima Daiichi Site.

The first validation test for SS was done at Tomioka city from August to October 2015 [2,3]. These tests showed that under good conditions of low background, well-known truck construction, careful loading of the SSs in the truck, and careful stopping position of the truck that a combined standard deviation about 16% is possible. But those very careful conditions were not practical for normal operations. And, if these careful conditions are not met, then the combined TMU standard deviation is approximately 34%. Areas of improvement were defined that would allow a reduction of the TMU to approximately 20%.

These new improvements in equipment and procedures have since been developed to allow these careful conditions to be more easily achieved. These include better measurements of critical areas of the truck, better control of the truck stopping position, and better measurements of the actual sack locations on the truck. This second validation test was done from August to September 2016, and was designed to demonstrate the assay uncertainty under typical operating conditions, after these improvements have been implemented.

PREPARATION

Previously, it was assumed that all trucks had the same sidewall construction. However subsequent tests showed that there was a significant variation in the amount of steel from different vendors of the truck bodies. This steel is a good attenuator of the Cs gammas, and therefore must be properly accounted for in the efficiency model. To accurately determine the sidewall thickness a sidewall thickness gage was created, as shown in Figure 1. This gage consists of stainless steel collimator and Na-22 source on one side, and a NaI detector on the other side. Side wall effective thickness is calculated by the Na-22

Fig.1 Measurement of the truck sidewall thickness

attenuation rate. The intensity of Na-22 is ~1 MBq which is less than the BSS level, and therefore easy to handle and transport.

A Laser Scan System (LSS) was developed by OC to determine the stopping position of the truck, and to automatically determine the exact position of each sack on the truck. During operations, the data from the LSS would be sent to the Super ISOCS calibration software via MCKK interface software.

Other information such as truck type, truck loading pattern, sack diameter and fill height and weight, would be entered into the tablet PC using a program developed by OC. This information is sent to the MTSCAN operations PC via MCKK interface software, too.

After the truck is stopped, the acquisition can begin. The acquisition time is typically 15 seconds. The custom software performs gamma spectroscopy on each of the 8 spectra, and then decodes the results to determine the activity in each of the 6 [typically] SSs using a Maximum Entropy Analysis Method. This analysis method was patented in Japan.

MOBILE TRUCKSCAN COMPONENTS

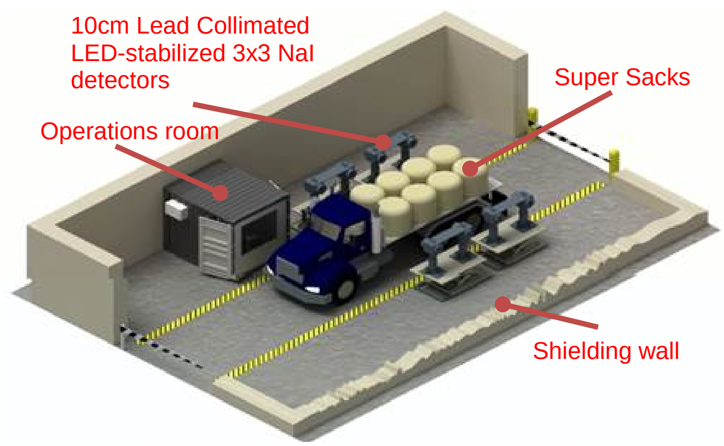

Fig.2 MTSCAN image

Figure 2 is an illustration of MTSCAN. It consists of eight LED-stabilized 3x3" NaI detectors; each detector has a lead shield with a collimated view of the truck. Two detectors are on each lift unit, which can adjust the detector height for various sizes of trucks, or lower them for easy transport. Four detectors are on each side of the truck, at about 1.1m from the truck side wall, equally spaced at approximately 1.3m. The efficiency of each detector for the exact conditions of each truck loading is dynamically calculated very quickly by an advanced version of the ISOCS [4, 5, 6] efficiency calibration software, called SuperISOCS. The truck stops in-between the two sets of detectors for the short measurement period – typically 10-20s for 8000Bq/kg SSs and higher, 30 seconds for 3000Bq/kg SSs. The custom-made software performs gamma spectroscopy on each of the 8 spectra, and then decodes the results to determine the activity in each of the [typically 6] SSs using a Maximum Entropy Analysis Method. [7, 8, 9]

Figure 3 shows the LSS system developed by OC. This device determines the position of the stopped truck, and then the location of each sack on the truck bed. The LSS Scan System consists of a digital camera and two Laser Scanners installed on the truck. When the truck has entered counting area and stopped, the two laser scanners move from the front of the truck bed behind the cabin to the end of truck bed. The truck stopping position sensor will detect the location of a large '+' symbol placed on the top of the cabin. The obtained data from these sensors is analyzed and the actual sack locations are sent to the SuperISOCS calibration software. These new peripherals greatly improve combined standard deviation.

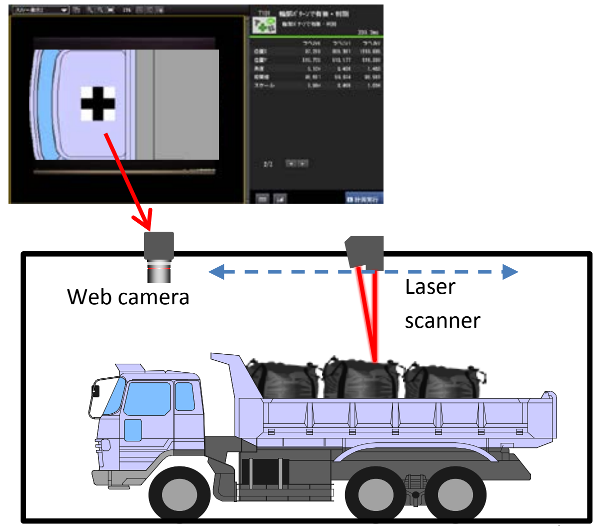

Fig.3 Image of LSS Scan System

The MTSCAN is designed to be installed outdoors and in an elevated Cs background area, as is typical in the Fukushima TSAs. To obtain best performance under these elevated background conditions, the MTSCAN site area needs some preparation to lower the background seen by the detectors. This can be easily done by removing contaminated soil in the parking area between the detectors and/or adding steel plates over the soil. In addition, shielding walls must be added behind each row of detectors to prevent the detectors from seeing the other sacks in the TSA. Those preparations were made in the previous demonstrations, however, in this test, the shielding walls were not able to be created because of the narrow space.

For best performance, the background (BG) of the Cs-134+137 peak area in each detector needs to be reduced to approximately 1-2 cps or lower. In this validation test location, the BG level was 1 μSv/h, which made the Cs-134+137 peak area about 30 cps without shielding. When an empty truck entered at the counting area, the BG level of each detector decreased to about 4 or 5 cps. But each different truck type and each different truck loading changes the background differently; therefore the true background cannot be accurately determined. For this geometry, 1 cps represents approximately 300 Bq/kg for a typical soil SS. Therefore, under these test conditions, we expect deteriorated performance [higher bias and standard deviation] for SSs with a few thousand Bq/kg Cs activity.

VALIDATION TEST PROCEDURE

The Validation test procedure is shown in Table 1. Prior to the tests, the sidewall thicknesses of the dump trucks (25 trucks) used for transport were measured with sidewall thickness gage. An average sidewall thickness was determined from 10 measurements in different locations of the sidewall of each truck.

MTSCAN was set up in an empty factory building at the test site, as shown in Figure 4. For the test, SSs were transported from TSA1 and TSA2. The SS contamination level from TSA1 was relatively low; the total Cs activity measured by Survey meter method was "3,780, 727, 30,700, 3,300Bq/kg" for "Average, Min., Max., 1SD", respectively. Those from TSA2 was very high, the total Cs activity was "93,100, 2,370, 3,060,000, 283,000Bq/kg", respectively.

There were 246 SSs from TSA1 and 353 SSs from TSA2. From this population 90 sacks from TSA2 were measured with Ge in-situ system (Fig.5) to determine the reference SS activity. Because of the high BG level around the counting area, the low level of activity in the SSs from TSA1 would be biased high, and therefore not representative of the accuracy of MTSCAN. The measurement results of 90 sacks from MTSCAN were compared with those from the Ge in-situ system measurements.

Table 1 Validation test procedure

Responsibility	No	Contents
OC and MCKK	0	Count the Truck sidewall thickness and put '+' sticker on truck cabin
OT JV[#1]	1	Weighing dump truck
	2	Remove a sheet on truck bed
OC	3	Read truck driver IC card
	4	Select loading pattern
	5	Select SSs position
	6	Read a bar code in each SS
	7	Measure a SS height and select Diameter
	8	Input SS height to Tablet
	9	These data send to Obayashi cloud server
OT JV	10	Move to counting area
MCKK	11	Detect truck stopped position
	12	Measure a SSs position
	13	Send these data to TruckScan PC
	14	Counting
	15	Print out a result and send it to Obayashi PC
OT JV	16	Move to unloading area
	17	Storage SSs in temporary storage area
	18	Screening of truck
	19	Exit

#1 OT JV : Joint Venture of Obayashi and Toa

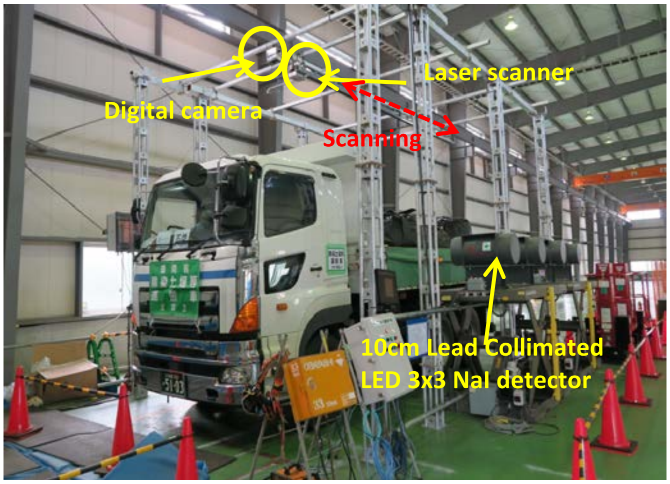

Fig.4 The MTSCAN installation

Fig.5 The Ge in-situ measurement station; the average of 4 measurements at 90 degrees was used.

VALIDATION TEST RESULTS

Table 2 Results of truck sidewall thickness distribution
Unit : Equivalent iron (mm)

Thickness	Number of trucks
4 - 6	5
6 - 8	2
8 - 10	8
10 - 12	4
12 - 14	3
14 – 20	5
	27

For each type of truck, the dimensions needed for the calculations were measured manually [e.g. bed width and length and height, sidewall height, ...]. The sidewall effective thickness was measured with the sidewall transmission gage. The counting time was 30 seconds which gave an uncertainty of less than 2% for the 511keV peak of Na22. Typically about 10 different counting points were measured to determine the average thickness. Table 2 lists the distribution of the truck sidewall thickness values. The trucks had wide range of sidewall thickness, because they were built by the different truck body vendors. The attenuation factor of the minimum sidewall thickness was 17% for fully filled SSs; for the maximum sidewall thickness, the attenuation factor was 40%. This confirmed that the sidewall thickness must be considered to allow us to achieve the target total uncertainty.

The calibration accuracy also depends upon knowing the position of each sack, and therefore the position of the truck when stopped in the counting area. The stopping position was detected with digital camera in the OC SS Scan System. The uncertainty of detection was less than+/- 10mm 1SD against to correct position for all directions.

The positions of SSs loaded on truck bed were detected with two Laser scanners. Table 3 lists the statistical difference value between scanned data and the reference values as measured manually. In addition, the LSS system determines if the truck was parked in a line parallel with the detectors, or is at an angle. The 1sd uncertainty of SS position is 43mm in the fore-aft direction and 32mm in the left-right direction.

Table 3 The statistical results of SS position compared to the reference location value for 105 trucks; units = mm

Direction		Average	1SD	Uncertainty#1
X axis#2	front right side	-4.45	71.6	42.8
	rear right side	19.4	106	
	front left side	6.34	92.1	42.8
	rear left side	31.4	89.1	
Y axis#3		0.00	20.0	31.6

#1 Uncertainty for each SS
#2 X axis is fore and aft direction
#3 Y axis is right and left direction

A total of 599 SSs were measured with MTSCAN, using 105 different truck loadings. Tables 4-6 show the range of results obtained.

Table 4 shows that the total Cs concentration for all SSs had a very wide range, from several hundred Bq/kg to more than 1MBq/kg. MTSCAN is optimized for accurate assay of SSs with at the sorting level of 8,000 Bq/kg SSs, which requires an appropriately low background. But the presence of the elevated background and the presence of these very high level SSs in the nearby vicinity and the absence of the shield walls makes this a very severe test condition for MTSCAN.

Table 4 The statistical results of all 599 sacks Unit : Bq/kg

Method	Average	Min.	Max.	1SD
MTSCAN	37,100	ND	1,150,000	76,100
Survey meter	56,100	727	3,060,000	221,000

Table 5 The statistical results of all 246 sacks from TSA1 Unit : Bq/kg

Method	Average	Min.	Max.	1SD
MTSCAN	5,700	ND	23,100	4,320
Survey meter	2,370	727	30,700	3,200

Table 6 The statistical results of all 353 sacks from TSA2 Unit : Bq/kg

Method	Average	Min.	Max.	1SD
MTSCAN	55,400	1,640	1,150,000	90900
Survey meter	92,600	2,370	3,060,000	282000

Table 7 The results of 90 TSA2 and Ge reference values Unit : Bq/kg

Method	Average	Min.	Max.	1SD
MTSCAN	86,800	3,150	445,000	94,600
Survey meter	151,000	2,370	1,930,000	289,000
Ge in-situ	83,300	2,130	477,000	101,000

In this validation test, SSs from TSA1 and TSA2 were used. Table 5 lists the results of statistical TSA1 data (246 sacks and 47 trucks). The average total Cs concentration was 5,700Bq/kg with MTSCAN, with a range between non-detectable and 23,100 Bq/kg. At these low levels, the MTSCAN data were influenced by the elevated background, causing a bias of 0 to 1500Bq/kg for each SS. This value isn’t negligible and worsens MTSCAN accuracy.

Table 6 lists the results of statistical TSA2 data (353 sacks and 59 trucks). The average total Cs concentration was 55,400Bq/kg with MTSCAN, with a range between 1,640 and 1,150,000 Bq/kg. Such a high concentration is hardly influenced by the elevated BG level.

Ninety SSs from TSA2 were selected for comparing MTSCAN data with reference Ge in-situ data. Table 7 lists the results of the TSA2 SS as compared to Ge in-situ reference measurements (90 sacks and 15 trucks). The average total Cs concentration of MTSCAN was 86,800 Bq/kg as compared to 83,300 Bq/kg from the Ge reference measurements. The high and low values were also comparable.

The Survey meter method (Figure 9) is the current standard method of assaying the activity in these bags. As shown in Tables 4-7, when SS concentration was high [TSA2 sacks], the survey meter value average results were biased 70% high. And when the SS concentration was low [TSA1 sacks], the average survey meter value was biased 60% low.

Measurement time from entrance of truck to exit was about 90 seconds, using an MTSCAN counting time of 30 seconds. When loading the trucks, the average time to create and enter the information into the Tablet was about 3 or 4 minutes per truck.

DISCUSSION

Table 8 shows the results of various analysis conditions using the selected 90 reference SSs. The table shows the comparisons between the MTSCAN results for each SS and the reference Ge in-situ value. The Mean Value Ratio is the ratio of the mean MTSCAN value of that group to the mean Ge value for that group. The Mean Ratio is the mean of the ratios of each individual MTSCAN SS value its Ge reference value. The 1 Standard Deviation [SD] Total Measurement Uncertainty [TMU] is also shown.

Table 8 The statistical results of various analysis condition of the reference 90SSs

	Analysis condition#1	Num. of sacks	Mean Value Ratio#2	Mean Ratio#3	1SD TMU
1	All sacks	90	1.06	1.66	1.77
2	Min. to max. < 5 times	24	0.97	1.02	0.20
3	Min. to max. > 5 times	66	1.06	1.89	2.01
4	> 100,000Bq/kg and > 5 times	24	0.95	0.95	0.24
5	< 100,000Bq/kg of > 5 times	42	1.55	2.43	2.36

#1 Activity range of SSs loaded on truck bed simultaneously
#2 Mean Value Ratio is MTSCAN mean value/Ge in-situ mean value
#3 Mean Ratio is mean value of each SS activity ratio (MTSCAN value/Ge in-situ)

Analysis condition 1 uses all the data. There the Mean Value Ratio of 1.06 shows good agreement, however the some of the individual values from low activity SSs are high leading to the high Mean Ratio and TMU. The reasons for this were shown in the previous Validation tests and are due to loading on the same truck very high activity SSs adjacent to low activity SSs.

In Condition 2, only those trucks where the maximum sack activity was no greater than 5x the minimum sack activity were considered; the group bias and the average individual bias were both less than 3%, and the TMU was 20%. These measurement conditions meet our stated goal of 20% TMU for low activity SSs. Condition 4 shows similar results for the very high activity SSs, with acceptable biases, and a slightly higher TMU of 24%.

Whereas in Condition 3 and 5, with those trucks loaded with SSs of a wide range of activity, the average individual bias increased to 89% and 143% respectively, and the TMU increased to 101% and 136% respectively. When a high activity SS is positioned near to a low activity SS, it greatly influences the activity of the low activity SS, usually by increasing the activity of the low level SS, with a corresponding (but proportionally smaller) reduction in the reported activity of the high activity SS.

Figures 6, 7 and 8 show graphically the data from Analysis conditions 1, 2 and 4. Superimposed on each graph is the best linear correlation line along with the slope and R^2 value. Also, shown in red is the line for perfect 1:1 correlation between the MTSCAN and Ge values.

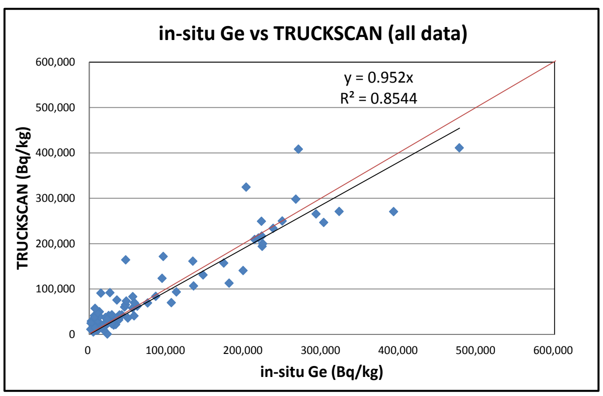

Fig.6 The correlation between MTSCAN and Ge in-situ for all sacks

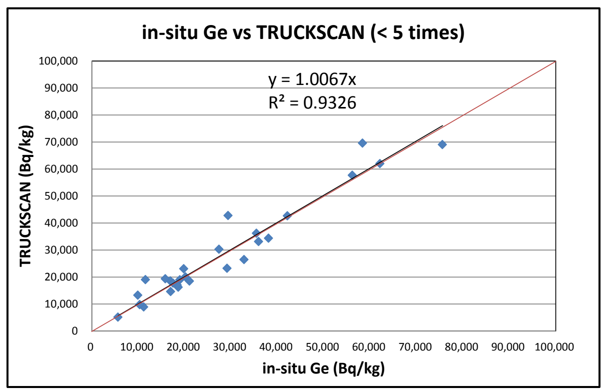

Fig.7 The correlation between MTSCAN and Ge in-situ for <5times loading pattern

Figure 6 shows the correlation between Ge in-situ and MTSCAN measurement for all sacks – condition 1. From table 8, the Mean Ratio was 1.66, and the TMU was 1.77.

Figure 7 (condition 3) shows the data measured under the recommended conditions where the Max-Min range is controlled. Here the Mean Ratio was 1.02 and the TMU was 0.20 (20%).

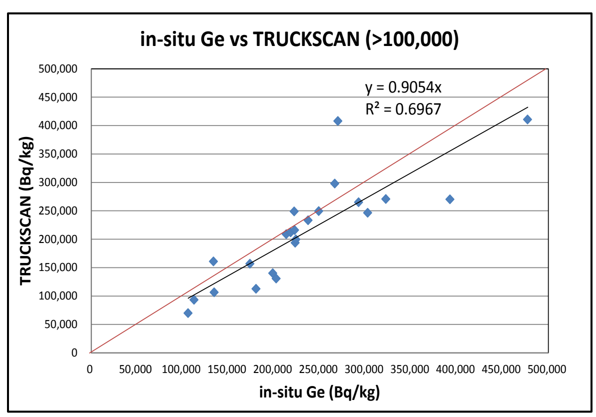

Fig.8 The correlation between MTSCAN and Ge in-situ for >100000 SSs loading pattern

The results from this validation test are similar to the results from the first validation test. MTSCAN has very good accuracy and no bias from low level to high level. However, when more than 5 to

10 times higher SSs are positioned next to low level SSs, the low level SSs accuracy becomes worse, and the low level SS activity is a higher value than it should be. In an operational scenario, when very high level SS is found along with other low level SSs, the high level ones should be removed and the other low level ones re-measured. The high level SS value can be considered accurate, and do not need to be measured again.

The target performance of MTSCAN TMU is less than 20% for 8000 Bq/kg SSs. Table 9 shows estimated uncertainty for different elements of MTSCAN. These uncertainty contributions are listed at the 1-sigma level, both as a percentage and as an uncertainty on the activity concentration for an 8000 Bq/kg assay result. All of the listed uncertainty contributors are added in quadrature to estimate the TMU. According to last validation test, main contributors for TMU were Sidewall thickness, Sack fill height, and Sack diameter/positioning. Values listed are from the original calculations and estimates for the improvements we then planned to make. We previously predicted that with the planned improvements, the TMU would be 19% for SSs in the 3,000 to 13,000Bq/kg range. Those improvements have been made and tested here. The TMU from the actual measurements was about 20%. This result indicates truck stopping position sensor, the sack position sensor, and the truck sidewall thickness gage all worked suitably and all uncertainty contributors were controlled suitably.

Table 9 Total Measurement Uncertainty contribution by component (750mm fill height condition)

Contributing Factor to the Total Measurement Uncertainty	1SD condition	1sd TMU contribution, original estimate	Validation testing result
Matrix layering	Validation testing data	4%	4%
Different matrix material	Idem	2%	2%
Matrix density inhomogeneity	Idem	2%	2%
Different material per sack	Idem	3%	3%
Heterogeneous source distribution	Idem	5%	5%
Bed height	±100mm	6.5%	Controlled suitably
Sidewall height	±25mm	1.5%	Idem
Sidewall thickness (with planned improvement)	13 – 23mm (New modeling)	18% (2.4%)	Idem
Sack fill height (with planned improvement)	±125mm (±25mm)	17% (4%)	Idem
Sack diameter and positioning (with planned improvement)	Validation testing data (New Modeling)	5-25% (6.5%)	Idem
Sack weight	±5% difference	0.25%	Idem
Vehicle location – fwd / bkwd	±100mm	4.3%	Idem
Vehicle location – left / right	±100mm	8.2%	Idem
Different concentrations per sack	8,000±5,000 Bq/kg	10%	Idem
Counting statistics	8,000 Bq/kg condition	4.8%	Idem
Combined TMU at 8000 Bq/kg (With planned improvements)		**34% (2,700 Bq/kg) (19%) (1,550 Bq/kg)**	**20% (1,600 Bq/kg)**

The throughput of MTSCAN Production version is estimated to be about 560 tons per hour. This assumes 45 seconds to measure the truck and get a new truck in position, and assumes each truck has 7 SSs of 1 ton each. In the last validation test, the measurement and truck exchange process took about 90–120 seconds. In the validation test reported here with the pre-production unit, the measurement and truck exchange process took about 90 seconds, in spite of introducing the additional operation of the LSS.

Now the concentration of SS is measured by a 'Survey meter' in Japan - a Survey meter with a collimator placed in close contact with the SS, and generally with multiple other SSs nearby (Fig.9). Table 10 shows the results of the analysis of the same selected 90 SSs, but using the Survey Meter results. This is the same Analysis Conditions and data analysis as previously shown in Table 8 for MTSCAN measurements. Under Conditions 2 and 5 where the MTSCAN has shown a TMU of 20-24%, the Survey meter method has a TMU of 37-60%. High activity SSs have progressively higher TMUs.

Fig.9 The situation of Survey meter measurement

Table 10 The statistical results of various analysis condition selected 90SSs (comparable between Survey meter and Ge in-situ)

Analysis condition[#1]	Num. of sacks	Mean Value Ratio[#2]	Mean Ratio[#3]	1SD TMU
1 All sacks	90	1.81	1.40	0.88
2 Min. to max. < 5 times	24	1.23	1.17	0.37
3 Min. to max. > 5 times	66	1.88	1.50	0.98
4 > 100000Bq/kg of < 5 times	24	2.00	1.87	1.35
5 < 100000Bq/kg of > 5 times	42	1.36	1.28	0.60

#1 Activity range of SSs loaded on truck bed simultaneously
#2 Mean Value Ratio is Survey meter mean value/Ge in-situ mean value
#3 Mean Ratio is mean value of each SS activity ratio (Survey meter value/Ge in-situ)

Figure 10 shows the correlation between Survey meter method and Ge in-situ for all SSs. This is similar to Figure 6 for MTSCAN results vs. Ge results. The bias between the correct result (the red line) and the linear fit result (the black line) is clearly shown. The R^2 value is also much worse here than for the MTSCAN data, again showing a higher TMU.

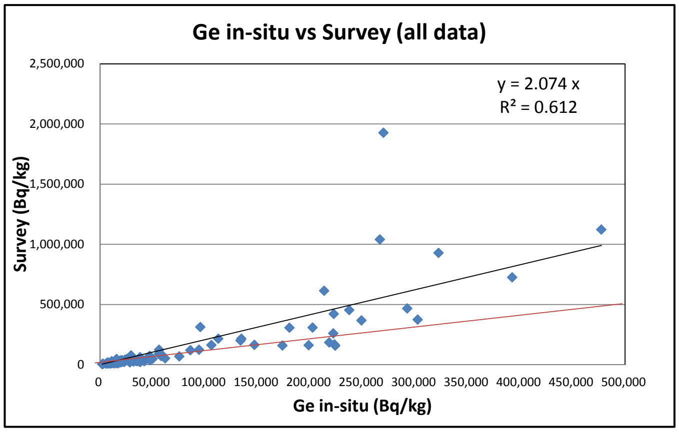

Fig.10 The correlation between Survey results and Ge in-situ results for all sacks

A further problem with the Survey meter method is that it requires two workers near to each SS, increasing the workers radiation exposure. On the other hand, MTSCAN needs only one operator, and the operator does not need to be close to the SS. MTSCAN can reduce workers labor cost and exposure dose. According to the estimation from the previous Validation test, the total cost of MTSCAN per SS is about 140 JPY and that of Survey meter is about 2,100 JPY, 93 times higher. In addition to this, radiation dose to the Survey meter method workers is 7 time higher than to the maximum MTSCAN worker.

CONCLUSION

MTSCAN has a better accuracy than the Survey meter method, and no bias. In addition to this, MTSCAN can reduce the total cost and total exposure dose of workers drastically in comparison with the Survey meter method.

The production version of MTSCAN will offer reduced measurement uncertainty by controlling TMU components suitably and higher throughput by more efficient software coding.

REFERENCES

1. A. SUZUKI, F. BRONSON, M. NODA, N. TAKADA, K. YAMASAKI, “Validation Testing of Canberra-Obayashi TruckScan Calculation Method,” Proceedings of Waste Management WM2015 Conference, Phoenix, AZ, March 15 (2015).

2. A. SUZUKI, F. BRONSON, M. NODA, N. TAKADA, K. YAMASAKI, “Validation Testing of Canberra-Obayashi Mobile type TruckScan Pre-production Unit,” Proceedings of IRPA14 Conference, Cape Town, South Africa, May 12 (2016).

3. B. YOUNT, A. PATIL, M. VICUNA, F. BRONSON, A. SUZUKI, “Performance of Canberra TruckScan Waste Assay Measurement System,” Proceedings of Waste Management WM2016 Conference, Phoenix, AZ, March 7 (2016).

4. R. VENKATARAMAN, F. BRONSON, V. ATRASHKEVICH, B. YOUNG and M. FIELD, "Validation of In-Situ Object Counting System (ISOCS) Mathematical Efficiency Calibration Software," Nuclear Instruments and Methods in Physics Research (A), 422 (1999).

5. Model S573 ISOCS Calibration Software, Canberra Industries, 800 Research Parkway, Meriden CT, USA, www.canberra.com

6. F. BRONSON and B. YOUNG, "Mathematical Calibrations of Ge Detectors and the Instruments that Use Them," Proceedings of 5th Annual NDA/NDE Waste Characterization Conference, Salt Lake City, UT, Jan 11 (1997)

7. M. REGINATTO, P. SHEBELL, and K. M. MILLER, "A Computer Program to Analyze Data from a Series of In Situ Measurements on a Grid and Identify Potential Localized Areas of Elevated Activity," Environmental Measurements Laboratory Report No. EML-590, October (1997) (unpublished).

8. M. REGINATTO, P. SHELBELL, and K. M. MILLER, "An application of the maximum entropy method for assessments of residual radioactivity at contaminated sites," IEEE Trans. Nucl. Sci. 43 (1996)

9. J. SKILLING, "Maximum Entropy and Bayesian Methods", pp. 45-52, J. SKILLING, Ed., Fundamental Theories of Physics Vol.36, Cambridge, England (1989).