Validation Testing of the Canberra Mobile Feed Roll Assay System – 15404

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ABSTRACT

Japanese farmers grow various grasses as feed for cattle. These are rolled up and sealed for future use. Canberra has created a special truck to monitor these Feed Rolls, called "Feed Roll Assay System [FRAS]". On the bed of the truck is the shield containing a large NaI detector. The detector is 3x5x16" in size, the same size as used in the Canberra FastScan Whole Body Counter. The detector is also LED-stabilized, to keep the gain constant under the wide range of temperature variations expected for this outdoor measurement instrument. The Canberra Osprey digital MCA is connected to the detector. The detector and the MCA are housed in a water proof box, which is surrounded on the bottom and all sides by a 15cm thick steel shield. A portion of the shield at the top is open where the detector can view the Feed Rolls placed there. A single ethernet cable goes to a laptop PC which provides power to the MCA and detector, and also transmits the signal to the PC. The system was calibrated using MCNP for a variety of different densities, and Feed Roll sizes. The Japanese version of the Canberra Genie software is used to analyze the spectra and compute the Bq/kg concentration of the Feed Roll.

The shielding is sufficient so that at a 5 uSv/hr background doserate, no Cs-137 or Cs-134 peaks were detected in a 1 hour count. Measurements were performed in 0.2 uSv/hr doserate, using uncontaminated Feed Rolls at various counting times. The MDA for Cs-137 was 11.9 Bq/kg at 30 seconds, 8.2 Bq/kg for 60 seconds, and 1.1 Bq/kg at 3600 seconds count time.

The relative measurement uncertainty of the FRAS measurements was 9.4 to 13%, as compared to assays of samples extracted [30-45%] and in-situ Ge measurements [6.0 – 7.1%]. The FRAS measurement results have considerably better precision than measurements of samples extracted from the Feed Rolls, and are much faster than the in-situ Ge measurements and have just about the same uncertainty.

INTRODUCTION

The accident at the Fukushima Nuclear Power station in Japan has caused much of the agricultural land in the Fukushima Prefecture to become contaminated with radioactive materials. Today, 3 years after the accident, the dominant radionuclides are Cs-134 and Cs-137, with Cs-137 being about 3x the concentration of the shorter lived Cs-134. The agricultural land is used for many types of crops, one of which is grass or hay to feed cattle. This material is traditionally harvested and sealed in large sacks, so they can be stored for future use; they are called Feed Rolls. These Feed Rolls come in various sizes, but are all are cylinders approximately 1m diameter and 1m tall. Due to the accident, cattle in a wide region of Fukushima Prefecture cannot be fed locally harvested Feed Rolls, but must import them from other regions. This is more costly to the farmer, so they are anxious to know if their local crops meet the acceptable criterial for cattle feed – which is 30 Bq/kg total Cesium.

The Feed Roll Assay System [FRAS] requirements and design:

- Assay requirement: able to measure a Feed Roll containing 30 Bq/kg of Cs137 within 30-60 seconds with a precision of about 10-15% and with an MDA of less than 15Bq/kg;
- Quick assay results: within a few seconds after the count is completed so that the operator knows the disposition of the Feed Rolls;
- Quick operation: Short time to begin the counting after arriving and to be on the road after finishing the counting. It is now approximately 10-20 minutes. All that is necessary is to turn on the PC, and then do a few Quality Control counts, then the FRAS is ready to start counting the Feed Rolls.
- Compact and light weight vehicle: due to the small roads, the maximum vehicle weight is about 8 metric tons and the maximum vehicle length is 7 meters;
- Shield: Figure 1 shows the drawing of the shield. Shield is made of low background iron and weighs about 2300kg. The shield is 15 centimeters thick. The collimator can be arranged in six positions depending upon Feed Roll activity and local background.
- Detector: The detector is a large NaI crystal, 3” x 5” x 16” (rectangular). This is the same size that is used in the Canberra FastScan Whole Body Counter that was widely used in Japan following the accident. This detector has Canberra’s patented LED Stabilization circuitry, which will keep the gain stable over a -20 to +50 deg. C temperature range. The typical resolution which is 8% at 662keV.
- MCA: Canberra’s ‘Osprey’ Digital Signal Analyzer is used. This compact and low-power MCA allows it to be mounted in the same weatherproof housing as the detector and is powered by a single POE Ethernet cable to the PC.
- Detector Box: Figure 2 shows outline of the weatherproof housing. It is made of Aluminum and with a 0.5mm aluminum window at the top facing the Feed Roll. The detector and MCA are surrounded by 2.5cm foam to prevent any damage due to thermal shock, and minimize the risk of damage due to physical shock during operation and transportation. The detector box is 14cm x 20cm x 85cm, has waterproof gaskets, and has waterproof LAN connector for power and communication. Fig.3 shows the top view of

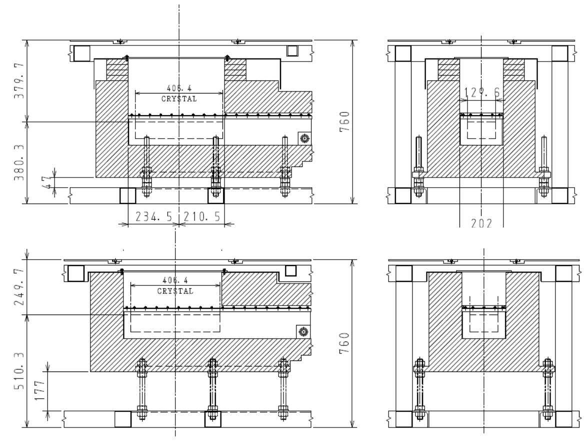

Fig.1. The drawing of shield

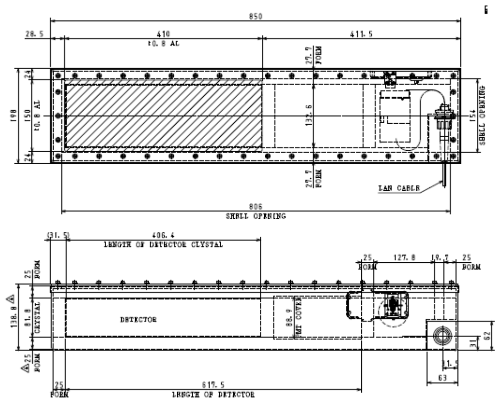

Fig.2. The drawing of detector box

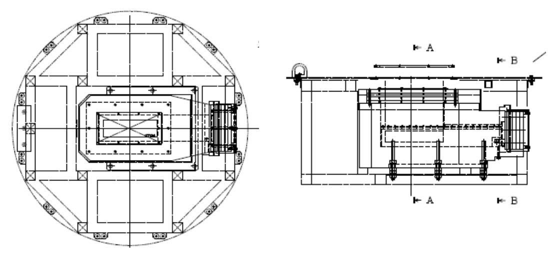

Fig.3. The drawing of detector frame

the detector inside the shield and surrounded by the frame to support the Feed Rolls.

- Vehicle: It is necessary to drive to the field where the farmer's Feed Rolls are stored. Therefore the Detector frame and shield are installed on a flat-bed cargo vehicle; this is a very common type of vehicle in Japan. The vehicle has a crane which is able to lift Feed Roll and to place it on top of the shield so the bottom of it covers the shielded opening. Figure 4 shows the vehicle with one of the test Feed Rolls next to it.
- Software: Japanese version of Canberra Genie is the core analysis software. All the operator needs to do is define the size of the Feed Rolls that will be counted and the average weight, and then press the start button when the Feed Roll is on the shield.
- Analysis method summary: The calibration is computed mathematically with MCNP. The density of the Feed Rolls in Japan ranges from 0.12g/cc to 0.25g/cc. Calibrations have been performed every 0.01g/cc. The Genie software computes the net peak area of the Cs-134 and the Cs-137 peaks, using the regions on both sides of the peak as the background. This is possible since the shield effectively removes all Cs peaks from the background spectrum.

Fig. 4. The Feed Roll Assay System

The FRAS is able to measure various sizes and types of Feed Rolls, as long as we have the proper calibrations. It is also capable of measuring the numerous large approximately 1 cubic meter canvas sacks [Super Sacks] that have been filled with contaminated soil and vegetation from the clean-up efforts in Fukushima and surrounding areas.

The Validation Testing Results

Validation tests were carried out to demonstrate to the authorities that the device can perform as promised. To validate the accuracy of the measurement, 4 independent assays of a few selected Feed Rolls covering the expected range of elevated radioactivity was performed.

First, a group of 20 Feed Rolls was counted on the FRAS. Each Feed Roll was counted with the bottom facing the detector and then with the top facing the detector. The average activity of the group was computed, as well as the Top/Bottom ratio. The results were shown in Table 1. The Top/Bottom ratios, for both the Feed Roll and the sample measurements showed that the concentration at the top is about 10% ± 9% higher than the concentration at the bottom. It is speculated that during the fermentation process that happens after the bags are sealed, water has migrated to the bottom, and this "not-very-radioactive" water has increased the density, thus reducing the apparent concentration.

Four Feed Rolls, representing low, medium and high activity were selected for more detailed analyses. Moisture content was measured, Ge in-situ assays were performed, samples were extracted and analyzed by CsI and Ge spectroscopy, and measurements were performed with the FRAS. Table 2 presents the results.

The moisture was measured by both oven drying and an electronic moisture meter. Measurements or samples were taken at multiple locations on the top, the sides and the bottom. The results show the moisture content at the top is the lowest, the sides higher, and the bottom 50-100% higher than the top. This result is consistent with our previous speculation about why the top concentration is higher than the bottom.

Samples were extracted from the Feed Roll. Some samples were taken from the top, some from the sides, and some from the bottom. The number of samples is shown in sixth column of Table 2. The samples were analyzed with a shielded CsI detector and also with a shielded Ge detector. The CsI system was calibrated with JCSS certified radioactive sources, with appropriate density corrections. The Ge system is the Canberra ISOCS [1, 2, 3] system in the sample counting mode. It was calibrated with the ISOCS mathematical efficiency calibration software. The average

Table 1 The results from Top and Bottom measurements in Bq/kg Total Cs

Name	Bottom	Top	Top/Bot. ratio	weight(kg)
Sample1	275	315	1.15	220
Sample2	234	271	1.16	240
Sample3	313	292	0.93	200
Sample4	486	607	1.25	260
Sample5	299	318	1.06	180
Sample6	358	404	1.13	240
Sample7	273	305	1.12	240
Sample8	227	216	0.95	220
Sample9	365	409	1.12	260
Sample10	304	328	1.08	260
Sample11	432	426	0.99	240
Sample12	350	392	1.12	220
Sample13	309	278	0.90	240
Sample14	399	464	1.16	200
Sample15	508	551	1.08	220
Sample16	383	425	1.11	180
Sample17	421	519	1.23	220
Sample18	344	404	1.17	200
Sample19	322	356	1.11	220
Sample20	401	438	1.09	220
Average	350	386	1.10 (0.09)	

Table 2 The results of the 4 Feed Rolls

Sample	Moisture content (wet%)			Detector	Measurements	Radioactivity and (1SD) (Bq/kg)			1SD
	Top	Side	Bottom			Cs134	Cs137	Total-Cs	
Low contaminated Feed Roll (Sample 21)	15.7[#2] 1 time	19.2 1 time	32.2 1 time	Ge	16 samples	9.7 (4.1)	28.5 (13.0)	38.3 (17.0)	45%
				CsI	16 samples	-[#6]	-	34.4 (15.1)	46%
				FRAS	5 times[#5]	9.2 (2.2)	24.2 (2.7)	33.4 (3.7)	13%
Middle contaminated Feed Roll 1 (Sample 22)	34.3[#1] (1.2) 3 samples	46.4 (7.8) 4 samples	62.1 (6.3) 3 samples	Ge	10 samples	152 (46)	427 (132)	578 (184)	40%
				CsI	10 samples	144 (50)	387 (134)	553 (178)	31%
				FRAS	52 times[#4]	126 (11)	326 (44)	452 (51)	13%
				ISOCS	4 directions	134 (8)	358 (5)	492 (5)	6.0%
High contaminated Feed Roll (Sample 23)	43.1[#1] (5.4) 5 samples	36.5 (5.8) 6 samples	58.7 (8.2) 5 samples	Ge	16 samples	227 (60)	584 (145)	811 (204)	30%
				CsI	16 samples	227 (64)	637 (178)	864 (240)	28%
				FRAS	40 times[#3]	186 (18)	483 (43)	668 (53)	9.4%
				ISOCS	4 directions	212 (13)	489 (14)	701 (18)	6.5%
Middle contaminated Feed Roll 2 (Sample 24)	No data	No data	No data	FRAS	6 times	192 (22)	443 (20)	635 (37)	7.0%
				ISOCS	4 directions	178 (16)	448 (17)	626 (28)	7.1%

#1 The moisture content of sample 21 and 22 are calculates by dried oven method.
#2 The moisture content of sample 23 is calculated by electric moisture content rate meter.
#3 Top and Bottom are 20 both measurements.
#4 Top and Bottom are 32 and 20 measurements, respectively.
#5 Bottom measurements only
#6 In low Cs level, CsI detector works as Cs-134+137 ROI counting analytic system. Therefore it outputs Total-Cs only.

concentration of the samples was computed, as well as the standard deviation of the sample measurements.

Next, the Feed Rolls were counted with a Canberra ISOCS system, which is a collimated HPGe detector, calibrated with the ISOCS mathematical efficiency calibration software. Figure 5 shows the ISOCS system counting a Feed Roll Each Feed Roll was counted 4 times from the side, each count at 90 degrees from the previous measurement. The counting time is 30 minutes every measurement. The average concentration was computed from the 4 measurements.

Fig. 5. The ISOCS in-situ Ge measurement

All 4 sets of measurements are statistically consistent with each other, with the +/- 1sd ranges overlapping

The ISOCS measurements of the Feed Roll from the 4 sides had the lowest uncertainty (6.0-7.1%). This is because the side measurement geometry is relatively insensitive to top-bottom variations in radioactivity. The measurements of the extracted samples had the highest uncertainty (28-46%). The Ge and the CsI uncertainty values are about the same, which means that this uncertainty comes from the sample-sample variation of the samples from the same Feed Roll, rather than measurement statistics uncertainty. This indicates the contents of Feed Roll are quite heterogeneous; therefore any measurement method that uses a small sample extracted from the large Feed Roll may be unsuitable to show that the Feed Rolls are suitable for use.

At this time, the official inspection method is to analyze 5 samples from all of the Feed Rolls from each 1000 m^2 area. This method appears to have poor reliability. Moreover the process of extracting samples and analyzing them takes a lot of labor, and there is a long waiting time for the laboratory assay results. Furthermore, the sampling method is not good for the Feed Rolls; the grass in the Feed Roll begins to rot as soon as the wrapping of the Feed Roll is broken, which is necessary to extract the samples. We believe that the inspection method of FRAS is superior to the sampling method, because of low cost, short counting time, immediate reporting of the results, low uncertainty of the results, and not harming the integrity of the wrapping on the Feed Roll.

The Feed Roll sample 23 was sampled at 16 points, 5 from the top, 6 from the side and 5 from the bottom. The density of these samples was carefully measured by Tokyo University. The average density of the top samples is 0.158 g/cc, and the bottom is 0.183 g/cc. This is consistent with the moisture content values for the top and the bottom, and the FRAS top:bottom concentration ratios.

Therefore, in practical operation, the concentrations will be measured from the bottom only, and the results increased by ½ of the top:bottom ratio of the results. A few Feed Rolls from each measurement area should be measured from both the top and bottom to confirm that the values used in this report are appropriate, or to determine site-specific values.

The next set of measurements was to confirm that the desired MDA can be met with a suitably short counting time. A 1-hour background was first measured, under the typical 0.2 uSv/h background doserate at the test site. No Cs peaks were detected. Then a typical 120cm diameter x 120cm height and 220kg uncontaminated Feed Roll was measured for various counting times. No Cs-137 or Cs-134 peaks were detected. Table 4 and figure 6 show the actual MDA as computed by the Genie software, using the Currie method [MDA ~ 4.65sd], which will be higher than the Japanese MDA method [3sd]. The MDA for Cs-137 was 11.9 Bq/kg at 30 seconds, 8.2 Bq/kg for 60 seconds, and 1.1 Bq/kg at 3600 seconds. The regulatory limit is 30 Bq/kg for feed to dairy cattle. It was concluded that 60 seconds is sufficient to give a high reliability that each Feed Roll measured will be properly categorized if it was near the 30 Bq/kg level.

Now, public inspections [4, 5] are being conducted with Ge and NaI laboratory detectors, with measurements in a 2 liter Marinelli beaker (Japanese standard) and 2000 sec counting time. In this condition, MDA (3sd) is about several Bq/kg for Cs-134 and Cs-137 for each individual sample. While the measurement standard deviation is similar to that of the FRAS, the sampling uncertainty must be taken into account to properly represent the actual Feed Roll activity – which these tests have shown range from 28-46%.

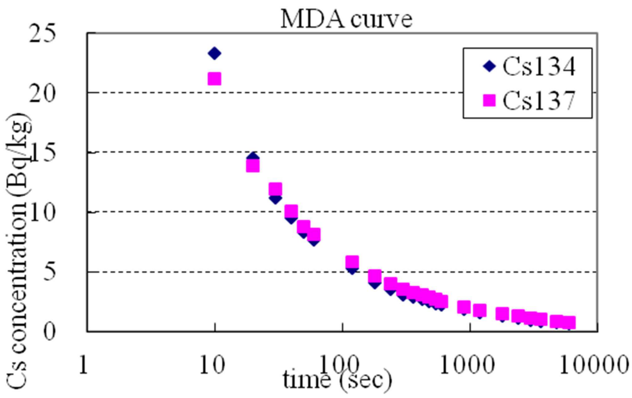

Fig. 6. MDA curve of FRAS

Table 4 MDA of various counting times

Time (sec)	Cs-134	Cs-137
10	23.3	21.2
20	14.5	13.9
30	11.2	11.9
40	9.5	10.1
50	8.4	8.8
60	7.7	8.2
120	5.3	5.8
180	4.1	4.6
240	3.5	4.0
300	3.1	3.6
600	2.2	2.6
1200	1.6	1.8
3600	0.90	1.1

Figure 7 shows the background spectrum of FRAS at 0.2 uSv/h and 5uSv/h. The red region of each spectrum is the area where the Cs-134 and Cs-137 peaks would be, if they were present. The vertical line in the center of the red region is 662 keV. There are no peaks in each spectrum other than cosmic annihilation 511 keV. The background of FRAS is very low, because of the 15cm of steel shielding, and because the opening for the samples points toward the sky.

The last test was to see if there was a difference between the very careful placement of the Feed Rolls in these tests and what is more practical to do in the field. For these tests, one person was near the shield to guide the equipment operator, to assure that the Feed Roll was exactly in the center of the shield. For normal operations, the equipment operator will do it alone. For this test, 5 different Feed Rolls were selected. Each was measured 8 times, under normal field conditions. After each measurement, the Feed Roll was removed, placed on the ground, and picked up again, and placed on the shield again for the next count. Table 5 shows these results. The relative uncertainty ranged from 6.8 to 15%. This is comparable to the careful placement results in Table 2 which ranged from 7.0 to 13%. Therefore, the second person and careful positioning is not needed.

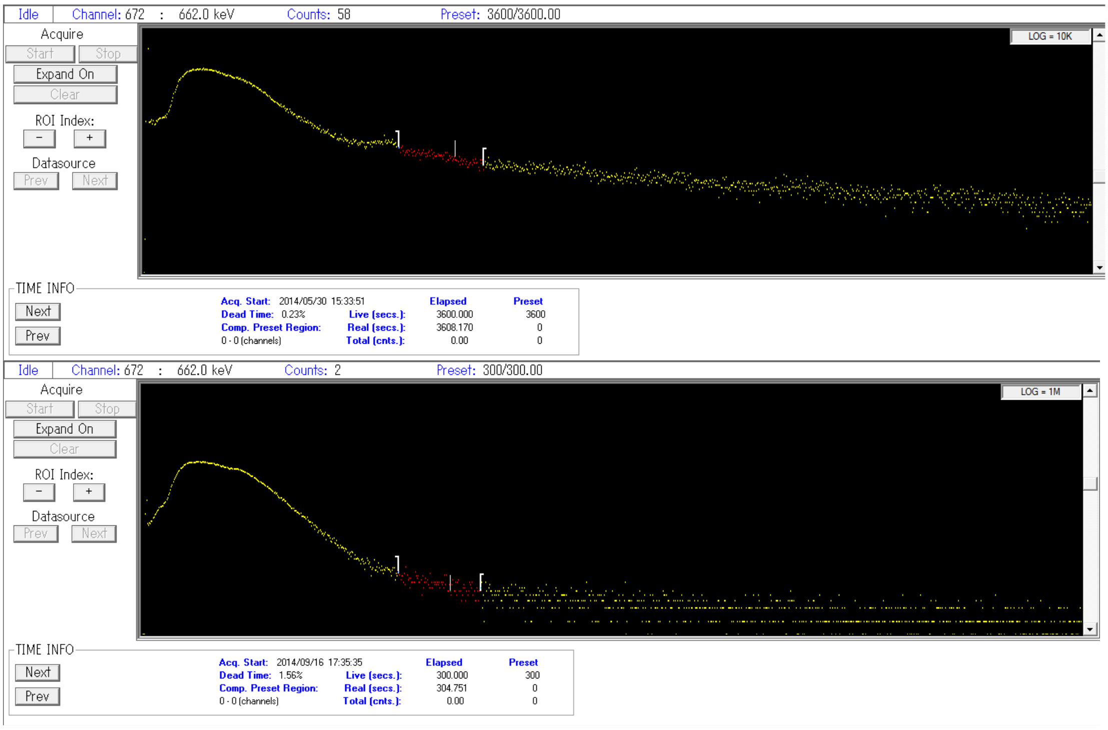

Fig. 7. Background spectra; top = 3600 sec at 0.2 uSv/h; bottom = 300 sec at 5 uSv/h

Table 5 The results by routine inspection operation: measure → lift down → lift up → measure.

Unit: Bq/kg

	Time (sec)	Cs134	1SD	Cs137	1SD	Total-Cs	1SD	1SD
Sample25	60	72	5	177	10	248	13	8.5%
Sample26	60	104	6	278	12	382	13	6.8%
Sample27	60	43	4	97	14	140	17	15%
Sample28	60	67	7	173	20	240	27	13%
Sample29	60	79	3	202	12	280	13	8.2%
Careful operation								7.0 to 13%

CONCLUSION

We have shown from these intercomparison tests that the FRAS can measure the Feed Rolls accurately. We have shown that the FRAS can measure the Feed Rolls with a typical uncertainty of less than 15% with less than a 1 minute counting time. We have also shown that any process that relies on assaying only a single sample from the total Feed Roll will have an uncertainty of 30-50%. We believe that the FRAS is a technically superior method to any method that only assays a fraction of the Feed Roll, and that the low labor cost for measurements and the immediate presentation of the results should make it the preferred method for these measurements.

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