Installation and Performance Test of a LL/ILW Drum Assay System at KAERI – 14387

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ABSTRACT

In order to evaluate the radionuclide inventory of the LL/ILW drums at KAERI, an assay system was procured and installed in a purpose-built facility. The building was constructed using concrete. Areas of low predicted radiation were constructed with 20 cm thick walls. All other areas were constructed with 30 cm thick walls. Based on characteristics (waste types, matrix, activity and etc.) of the LL/ILW, KAERI installed a Wide-Range SGS (Segmented Gamma Scanner) manufactured by ANTECH. The Wide-Range SGS uses a non-destructive method and can measure gamma-emitting radionuclides contained in most LL/ILW generated at KAERI. The LL/ILW drums with significant matrix inhomogeneity of either density (absorber) distribution or activity distribution cannot be accurately measured by the SGS mode, as very large errors will arise. The TGS (Tomographic Gamma Scanner) capability has been incorporated into the WR-SGS in order to measure the small population of drums with significantly inhomogeneous matrices. The radioactive waste drum assay equipment consists of conveyors (In-feed and Out-feed), detector plinth, rotary carriage and control cabinet. KAERI carried out the SAT (Site Acceptance Test) with the assistance of the manufacturers. Gel, sand and sawdust drums representing various densities of radioactive waste drums at KAERI were assayed using SGS mode respectively. Sources with known activities were placed at two different vertical (middle or top) and three different horizontal positions (center, at the edge or 2/3 of the way out from the center) in the drums respectively. The analysis results were compared with those simulated using MCNP (Monte Carlo N-Particle transport) code. Three randomly selected drums which represented the most common types of LL/ILW at KAERI were used to confirm reproducibility of the equipment. Each drum was measured five times in SGS mode. Through comparison of energy spectrum and activity of detected radionuclides, the accuracy of the analysis results was verified. Results will be further verified by comparisons with drum assay equipment at KORAD (Korea radioactive waste agency) responsible for management of the final repository of the LL/ILW.

INTRODUCTION

According to construction schedule for the final repository at Kyeong-ju in the southeast of Korea, a disposal program for the LL/ILW drums at KAERI was required. In order to ensure the waste package meet the acceptance criteria given by KORAD, the radionuclide inventory of all LL/ILW drums at KAERI should be measured. To characterize the LL/ILW drums at KAERI, a radioactive waste drum assay facility equipped with a Wide-Range SGS system manufactured by ANTECH has been constructed.

Characteristics (physical properties, matrix, gamma dose rate) of LL/ILW drums stored at KAERI was reviewed and the material handling issues related to processing multiple drums were considered in the selection of gamma nuclides assay equipment. Those are related to surface dose rate value of Co-60 representing radionuclides of KAERI radioactive waste. Waste characteristics and operational mode of WR-SGS are shown in Table I.

The selected Wide-Range SGS can be operated as not only TGS mode but also SGS mode.

Helical scanning for SGS mode has the advantage of a reduced measurement time as data is acquired while the detector is moving.

TABLE I. Characteristics of waste stored at KAERI and operational mode of WR-SGS [1] (Equivalent Co-60 activity at 30 cm)

Waste Types	**Matrix**	**Percentage of total inventory**	**~0.001 mSv/hr (%)**	**~0.02 mSv/hr (%)**	**~2 mSv/hr (%)**	**~20 mSv/hr (%)**	**Over 20 mSv/hr (%)**
Combustible	Homogeneous Heterogeneous	39.39	18.15[a]	15.64[e]	5.61[e]	0	0
Non-combustible	Soil/Concrete (Homogeneous: 19%)	37.54	5.02[a]	1.69[e]	0.42[e]	0	0
	Steel (Heterogeneous: 63%)		16.67[b]	5.60[c]	1.38[c]	0	0
	Mixed (Heterogeneous: 18%)		4.76[b]	1.60[c]	0.40[c]	0	0
Spent filter	-	0.17	0.08[a]	0	0.08[e]	0	0
Spent filter drum	Homogeneous	2.63	1.78[a]	0.77[e]	0.07[e]	0	0
Waste form	Homogeneous	2.49	0.26[a]	0.76[e]	1.26[e]	0.21[d]	0
Spent resin	Homogeneous	1.50	0	0.02[e]	1.24[e]	0.25[d]	0
Hot cell waste	-	0.39	0	0	0.03[c]	0.11[d]	0.25[d]
Decommissioning Waste	Soil/concrete (Homogeneous: 86%)	15.89	14.05[a]	0	0	0	0
	Steel (Heterogeneous: 13%)		1.83[a]	0	0	0	0
	Mixed (Heterogeneous: 18%)		0.02[a]	0	0	0	0

[a]: possible clearance levels-count rate low
[b]: possible clearance level-count rate will be low for TGS
[c]: drums requiring for TGS
[d]: drums too active for TGS/SGS
[e]: drums requiring for SGS

The Wide-Range SGS uses a non-destructive method and can measure gamma nuclides contained in most LL/ILW generated at KAERI. The higher activity or most non-combustible waste types can be assayed using the TGS mode. In the SGS mode, a drum is rotated about its vertical axis during horizontal segments are scanned. This allows for any inconsistencies in the axial matrix density while building a vertical profile of gamma-ray transmission and nuclide concentration. The TGS mode uses transmission corrected and single photon emission computerized axial tomography to determine the spatial distribution and quantity of radionuclides in a drum. A transmission source allows the determination of a 3-D spatial map of the attenuation coefficient at any energy by interpolating between the gamma-ray peaks of the transmission source at several energies. Once the attenuation coefficient maps have been established for the sample, emission tomography is used to determine the distribution of selected radioisotopes within the sample. Two measurements (transmission followed by emission) are then performed.

The SGS technique produces an average linear attenuation coefficient for each horizontal segment of the drum. The TGS technique provides source (emission, transmission) images (Figure 1) for each segment with this average linear attenuation coefficient. The typical spatial resolution of the emission image for the TGS is about 50 mm.

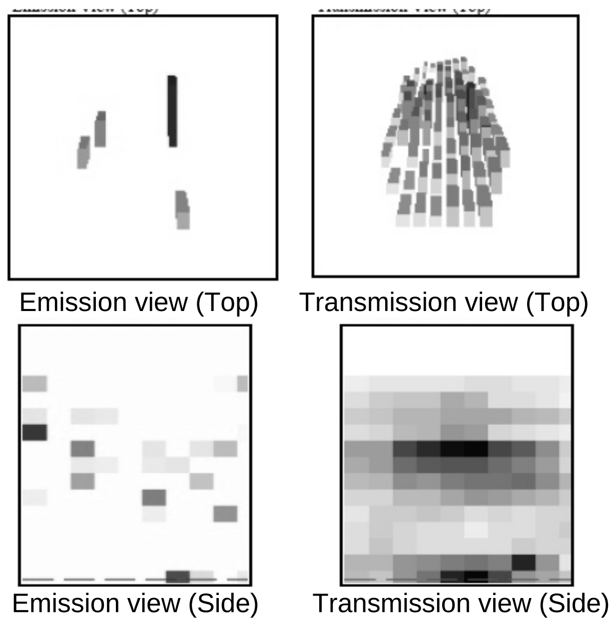

Fig. 1. TGS analysis results images

SYSTEM INSTALLATION

Radioactive Waste Drum Assay Building

The building was constructed using standard commercial concrete. Walls were built to be 30 cm thick for radiation shielding. The areas where relatively low radiation doses were expected had 20 cm walls. To minimize effect of external radiation, shielding wall in detector zone was designed to 30 cm thick. Figure 2 shows a floor plan of the building. Its dimensions are as follows:

- Area: 150 m^2
  - Assay building: 144 m^2
  - Passageway: 6.44 m^2

- Height: 5.15 m
  - Internal height: 5 m
  - Ceiling wall thickness: 15 cm

The internal area of the building is divided into a radiation controlled zone and a non-radiation zone. The radiation controlled zone consists of a detector zone and a temporary storage zone. The non-radiation zone is comprised of a control room, a locker room and a meeting room. Equipment or handling tools installed in each zone or room are described below.

- Temporary storage zone: Drums for assay, calibration drums, calibration source storage, crane
- Detector zone: Radioactive waste drum assay equipment, barcode system
- Maintenance zone: Forklift
- Control room, Locker room, Meeting room

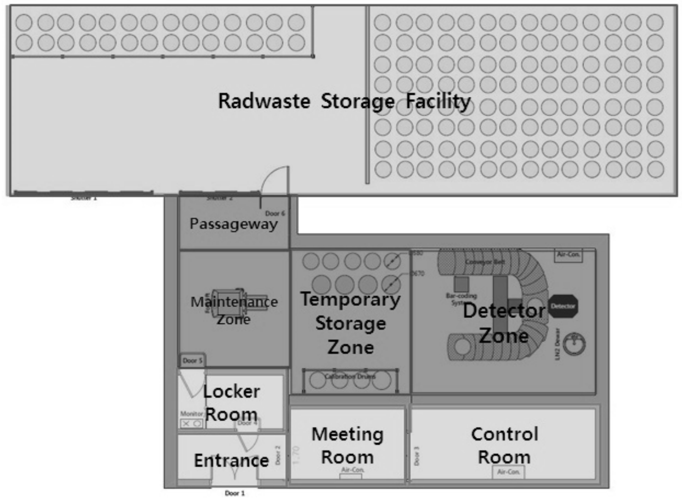

Fig. 2. Floor plan of the radioactive waste drum assay building

Radioactive Waste Drum Assay Equipment

The radioactive waste drum assay equipment (Figure 3) consists of conveyors (in-feed and out-feed), detector plinth, rotary carriage and control cabinet. Specification of the drum assay equipment is described below in TABLE II.

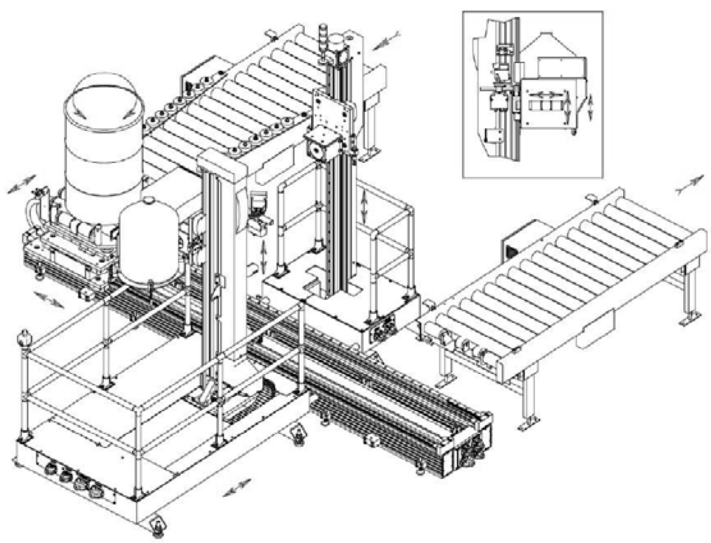

Fig. 3. WR-SGS drum assay equipment [2]

The WR-SGS was chosen due to easy operation, reduced measurement time and automated control. In the SGS mode, the scanning process follows the following steps:

1. Loading
2. Barcode reading (for identification of drum)
3. Pre-scanning: Geiger-Muller dose-rate detector and weight scale
4. Transmission scanning
5. Straight-through measurement

6. Dead-time source measurement
7. Emission scanning
8. Unloading
9. Analysis report making

TABLE II. Specification of the drum assay equipment

Operating Modes	SGS (for Homogeneous waste drums)
	TGS (for Heterogeneous waste drums)
Drum size	200 liter or 320 liter drums
Variable collimator range	1mm-70mm (Motorized & automatic)
Germanium coax Detector efficiency	40% + (typical) with LN_2 cooling FWHM 1.85keV@1.33MeV
Transmission source	Eu-152, 10mCi 2ea. (20mCi.) In Tungsten shield
Detectable activity range	Up to 10E12 Bq
Density range	Up to 2100 kg/m^3
Barcode reader	2-D reading
Surface dose measurement	GM based counter
Manufacturer	ANTECH in England

WR-SGS has several design features. First, the drum density is determined by the weight scale (load cell) and the dose-rate of overall drum is determined using the dose-rate probe during a pre-scan measurement of the drum. This pre-scan information is then used to choose appropriate VAC (Variable Aperture Collimator) for transmission and emission measurements, as well as the detector distance from the drum. Second, for the SGS mode equipment can operate in helical scanning mode for emission and transmission measurements. This can reduce the measurement time as data is acquired while the detector is moving. Finally, the TGS capability has been incorporated into the WR-SGS in order to measure the small population of drums with significantly heterogeneous matrices. The TGS mode has the advantage that maps or images can be generated as both the drum density (absorber) distribution and activity distribution [3].

Site Acceptance Test

SAT (Site Acceptance Test) is a step to confirm equipment performance prior to last hand-over. KAERI carried out the SAT with ANTECH engineers. Gel, sand and sawdust drums representing various densities of radioactive waste drums at KAERI were assayed using SGS mode. Sources with known activities were placed at various vertical (middle or top) and horizontal positions (center, at the edge or 2/3 of the way out from the center) in the drums. In this test, vertical position is fixed in the middle of drums. The results are presented in TABLE III.

In order to compare point source measurements with the results of SGS measurements (which assume distributed sources), the apparent activity or “Corrected Activity” of a distributed or volume source that produces the same response in the detector as the point source is calculated. The corrected activities fall within from 86% to 106% of the source activities. While sand which is denser than sawdust or gel shows large variation, sawdust which is less dense than other two materials shows little variation. So, a correlation between density and activity variation should be further studied.

TABLE III. SAT results [4]

Type	Matrix (Drum)	Source			VAC (mm)	Pillar position	Measured Activity (Bq)	Corrected Activity (Bq)	Variation (%)
		Nuclide	Activity (Bq)	Position Radially					
SGS	Sawdust	Co-60	3.16E+04	Center	70	Front	2.63E+04	2.94E+04	93
		Co-60	3.46E+07	2/3	14	Back	3.04E+07	3.21E+07	93
		Co-60	3.46E+07	Edge	14	Back	3.29E+07	3.20E07	93
		Cs-137	7.83E+05	2/3	70	Front	7.19E+05	7.47E+05	95
		Cs-137	7.83E+05	Edge	70	Front	7.63E+05	7.17E+05	92
	Gel	Co-60	3.46E+07	Center	70	Front	1.76E+07	2.99E+07	86
		Co-60	3.46E+07	2/3	14	Back	2.70E+07	3.02E+07	87
		Co-60	3.46E+07	Edge	14	Back	3.86E+07	3.09E+07	89
		Cs-137	7.83E+05	2/3	70	Front	6.53E+05	7.12E+05	91
		Cs-137	7.83E+05	Edge	70	Front	1.04E+06	7.28E+05	93
	Sand	Co-60	3.46E+07	Center	14	Back	1.17E+07	2.90E+07	84
		Co-60	3.46E+07	2/3	14	Back	2.86E+07	3.26E+07	94
		Cs-137	7.83E+05	Center	70	Back	1.80E+05	8.26E+05	106
		Cs-137	7.83E+05	2/3	70	Front	6.25E+05	8.00E+05	102
		Cs-137	7.83E+05	Edge	70	Front	1.04E+06	6.45E+05	82

PERFORMANCE TEST

More than 95% of all radionuclides contained in radioactive waste should be identified for final disposal. Radioactivity concentration of some radionuclides (H-3, C-14, Fe-55, Co-58, Co-60, Ni-59, Ni-63, Sr-90, Nb-94, Tc-99, I-129, Cs-137, Ce-144, Gross-α) also should be identified according to acceptance criteria regulated by government [5]. Co-60 and Cs-137 are the main radionuclides in LL/ILW drums at KAERI.

For a performance test, three randomly selected drums which represented the most common types of LL/ILW at KAERI were used to confirm reproducibility of the equipment. Each drum was measured 5 times in SGS mode. Through comparison of detected radionuclides activity, the reliability of the analysis results was verified. The results are presented in TABLE IV.

TABLE IV. Detected radionuclide activity [for Cs-137]

Scan ID	9201965	9201964	9201963	9201962	9201961	Maximum margin of error
Activity (Bq)	8.07e+04 +- 2.29e+03	8.86e+04 +- 2.58e+03	8.29e+04 +- 2.34e+03	8.16e+04 +- 2.35e+03	8.32e+04 +- 2.37e+03	8.91 %

Net area counts from each segment of a drum were also compared. TABLE V shows the results. The net counts of the 661 keV Cs-137 peaks are very similar, even if the peak wasn't detected in some segments. Uncertainty range is from 2.99 % to 20.09 %.

TABLE V. Detected net area counts for Cs-137 peak

Scan ID	9201965		9201964		9201963		9201962		9201961	
Segment No.	**661 keV**	**Uncert. (%)**	**661 keV**	**Uncert. (%)**	**661 keV**	**Uncert. (%)**	**661 keV**	**Uncert. (%)**	**661 keV**	**Uncert. (%)**
1	ND	ND	46	16.37	32	17.68	42	16.96	42	16.84
2	35	18.90	33	19.41	32	17.68	34	19.40	30	19.66
3	43	15.25	28	20.09	36	17.50	ND	ND	33	17.41
4	48	15.07	44	16.88	53	13.74	41	18.21	46	14.74
5	96	10.21	100	10.40	95	10.61	98	10.10	ND	ND
6	199	7.09	219	6.86	216	6.93	231	6.71	217	6.86
7	336	5.46	318	5.67	325	5.59	321	5.64	299	5.86
8	537	4.42	465	4.72	498	4.53	459	4.71	533	2.99

ND: Non-detection

CONCLUSIONS

To accommodate the radioactive waste drum assay system, a purpose-built radioactive waste drum assay building was constructed. According to the evaluation results, the thickness of those concrete walls was enough to shield the radiation from the radioactive source.

WR-SGS has several design features. Through a pre-scan measurement, many variables such as VAC values and detector distance are determined. Helical scanning in the SGS mode can reduce measurement times. Also, the TGS mode for heterogeneous matrix waste produces assay reports with maps or images showing both the drum density (absorber) distribution and activity distribution.

SAT was carried out using drums with various matrices, source positions and source activity. Repeated measurements of a real drum stored at KAERI confirmed the reproducibility of the results.

The analysis results will be further verified using drum assay equipment at KORAD (Korea radioactive waste agency) responsible for management of the final repository.

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