WASTE CHARACTERIZATION STUDIES AT CRNL

G.W. Csullog, S. Kupca
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada
K0J 1J0

ABSTRACT

The strategy of the radioactive Waste Disposal Project at the Chalk River Nuclear Laboratories (CRNL) is to classify waste segments according to potentially hazardous lifetimes and to match these segments to disposal options selected for their abilities to isolate and contain these wastes. In support of this strategy the principal objective of the waste characterization program is to estimate the quantity and radiological characteristics of the CRNL wastes that will require disposal. The initial focus of the characterization program is the development of a practical, cost-effective waste assay system to estimate the radiological properties of solid wastes handled by the Waste Treatment Centre (WTC) where most of the volume of current solid wastes will be processed. The proposed system will characterize these wastes in a high-throughput, production environment, provide data in support of WTC process operation and maintain electronic data files for waste management purposes. This report summarizes the preliminary research effort to develop the assay system. Studies include the characterization of WTC incinerator ash and the nondestructive gamma-ray monitoring of the incinerator feed using sodium iodide and intrinsic germanium detectors. Additionally, specifications are given for a demonstration, nondestructive, solid waste monitor for use at the WTC.

INTRODUCTION

Chalk River Nuclear Laboratories (CRNL) manage a variety of low- (LLW) and intermediate-level (ILW) radioactive wastes which originate both on- and off-site[1,2]. Presently, these wastes are being stored; however, CRNL has initiated a radioactive Waste Disposal Project to demonstrate safe, economical, and publicly acceptable disposal of most of these wastes on-site. The basic plan of the Project is to classify and sort wastes according to their potentially hazardous lifetimes, to match segments to two disposal options selected for their abilities to isolate and contain these wastes and to implement the transition from storage to disposal.

In support of the Project, a waste characterization program was established to provide estimates of the quantity and the radiological characteristics of CRNL radioactive wastes. The objective of the program is to develop and demonstrate practical, cost-effective systems to categorize wastes for disposal.

Radioactive wastes, which have been managed for over thirty-five years at CRNL, have been divided into three temporal categories. These are:

1. **ACCUMULATED:** Those wastes generated by or shipped to CRNL and placed into storage prior to 1982 January. The Waste Treatment Centre (WTC) at CRNL[3,4] which was established to develop and demonstrate processes to convert radioactive wastes to forms suitable for disposal, began to process radioactive wastes in 1982 January.
2. **CURRENT:** Those wastes requiring disposal that were or will be placed into storage facilities at CRNL from 1982 January until on-site disposal facilities become available.
3. **FUTURE:** Those wastes which will be generated by or shipped to CRNL after disposal facilities become available. These wastes could be disposed of without interim storage.

Initially, the research, development and demonstration (RD&D) effort of waste characterization is being directed at **CURRENT** solid radioactive wastes. Preliminary studies were carried out on waste processed at the WTC in four principal areas: the selection and validation of a method to adequately sample incinerator ash; radioanalysis of ash samples; testing of a prototype, nondestructive gamma-ray detection system to monitor incinerable solid wastes prior to volume reduction; and the correlation of analytical data acquired before and after incineration of wastes.

The three topics discussed in this paper are:

1. A summary of the experience gained with the handling and processing of radioactive wastes at the WTC. Wastes at CRNL have a wide range of radiological characteristics; therefore, it is not feasible to develop a single, nondestructive assay device to characterize these wastes. However, a demonstration monitor is being developed that will be modular and flexible in design to permit ready adaptation to a variety of waste characterization requirements. By summarizing the nature of the wastes characterized using a prototype monitor and those to be characterized with the demonstration unit, a reference framework is set up to facilitate evaluation of the preliminary investigations.
2. A summary of the results of the preliminary waste characterization RD&D.
3. The specifications for a demonstration, nondestructive waste monitor to characterize solid LLW handled by the WTC at CRNL.

SUMMARY OF WASTE PROCESSING AT THE WTC

At present, only **CURRENT**, site-generated, solid LLW are being accepted by the WTC. These wastes, normally packed in polyethylene bags, are presegregated at point-of-origin according to the scheme shown in Fig. 1.

During Stage One of WTC operation (1982 January to 1982 December), wastes received by the WTC were inspected and segregation was finalized according to the scheme shown in Table I. Radiation field strengths were measured with portable Geiger-Mueller type survey meters.

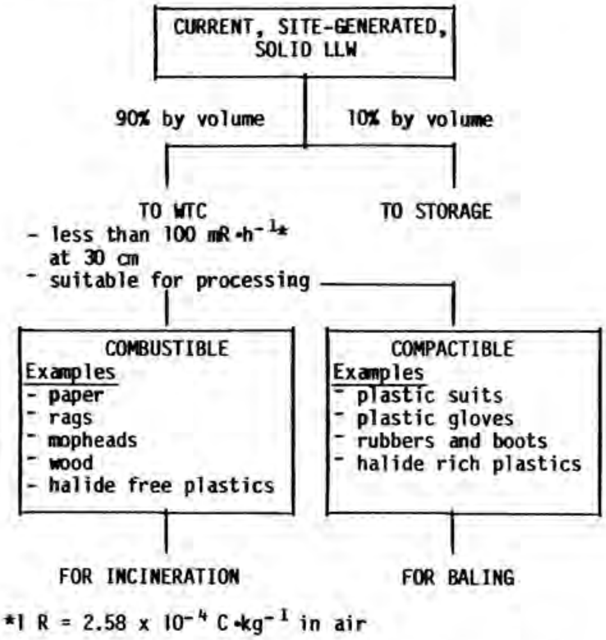


Fig. 1. Summary of waste segregation at point-of-origin for WTC processing.

TABLE I.

Waste Segregation at the WTC in Stage One of Operation

SEGREGATION CRITERION	WASTE SEGMENT: INCINERABLE	COMPACTIBLE	REJECTED
Radiation Field Strength	$\leq$ 5 $mR \cdot h^{-1}$* on contact	>5 $mR \cdot h^{-1}$* on contact and $\leq$100 $mR \cdot h^{-1}$ at 30 cm	>100 $mR \cdot h^{-1}$* at 30 cm
Physical-Chemical Properties	and suitable for incineration	and suitable for compaction	or unsuitable for incineration or compaction
* 1 R = 2.58 x 10^{-4} $C \cdot kg^{-1}$ in air			

In 1983 January, based on the results of incinerator ash analyses from Stage One (discussed later), the radiation field for Stage Two operation was raised to 10 $mR \cdot h^{-1}$ (1 R = 2.58 x 10^{-4} $C \cdot kg^{-1}$ in air) on contact for incinerable wastes.

In 1983 April for Stage Three, the radiation field strength limit for incinerable waste was raised to that set for acceptance of waste by the WTC, 100 $mR \cdot h^{-1}$ at 30 cm. Only a small amount of the waste presently being accepted at the WTC has radiation field strengths greater than 10 $mR \cdot h^{-1}$ on contact.

During the first 21 months of radioactive waste processing, 2200 m^3 of solid LLW have been reduced to 7.3 m^3 of ash (stored in 0.2 m^3 drums), 140 m^3 of bales and 80 m^3 of unprocessed items.

Preliminary characterization studies were carried out on wastes handled at the WTC. During the first two stages of WTC operation, a prototype nondestructive waste monitor was tested. During all three stages, radioanalyses of incinerator ash were performed. These two approaches to waste characterization and their interrelationships are discussed later.

OVERVIEW OF THE INITIAL RD&D

A number of options for the development of waste characterization systems were reviewed and it was decided that a demonstration system for wastes handled by the WTC should be developed based upon existing technology. As technological advances are made in waste monitoring, the demonstration system would be upgraded. The short-term objective is to obtain a working system that would greatly improve waste characterization at CRNL and to develop it to its full potential over the long-term.

At CRNL, the number, types and properties of waste streams can vary considerably and the selection of sampling protocols, even for individual waste streams, can be both costly and time consuming. Survey analysis, the characterization of all items within a waste stream, presents a viable alternative to the sampling-analysis method since RD&D effort need not be expended on the selection of sampling protocols. However, for economic reasons, survey analysis must be conducted nondestructively. With the current technology, only a gamma-ray monitoring system could be utilized to assay wastes in sealed packages (polyethylene bags) in the high-throughput, process environment of the WTC.

One waste stream, incinerator ash, because of its properties, is amenable to the sampling-analysis approach since it:

- has a small volume and can be readily handled.
- can be manipulated (e.g. homogenized) to facilitate sampling.
- can be economically analysed destructively to determine the quantities of radionuclides that do not have significant gamma-ray emissions.

So far, no other solid waste stream has been identified as suitable for this approach to waste characterization.

For the initial RD&D, ash analysis was selected as a method to validate the development of nondestructive characterization systems. The plan is to:

1. select and validate protocols to obtain representative samples of WTC incinerator ash for radioisotopic analysis.
2. develop verified protocols to determine the major alpha-, beta-, and gamma-emitting radionuclides in ash and to correlate their specific activities.

3. monitor incinerable, solid LLW prior to incineration using a prototype gamma-ray detection system consisting of a sodium iodide (NaI) detector for gross gamma estimation and an intrinsic germanium (Ge) detector to quantify the contributions of the major gamma-emitting radionuclides.

4. correlate the results obtained from preliminary monitoring of the wastes prior to incineration with the results obtained from analysing ash. (It is worthwhile to note that such correlations are particularly convenient at CRNL since incineration is carried out on a batch basis.) The objective is to demonstrate the feasibility of using nondestructive gamma-ray monitoring to adequately characterize solid LLW for disposal.

5. specify and acquire a demonstration, nondestructive, gamma-ray monitor and in conjunction with ash analyses to demonstrate the characterization of incinerable LLW for disposal in a process environment.

6. develop the rationale to apply nondestructive monitoring to characterize alternative LLW streams for disposal in a process environment.

CHARACTERIZATION OF WTC INCINERATOR ASH

Initial Samplings

From the first stage of incinerator operation to the present, ash has been segregated into fine and coarse segments and discharged into 0.2 m^3 drums. Initially, samples were collected at equal intervals as the fine ash was being discharged. This method is referred to here as vertical sampling.

From each sample collected, 50 cm^3 subsamples were taken and analysed by gamma spectrometry. Spectral data, which are not reported here, indicated that:

1. the quantities and types of radionuclides in solid LLW at CRNL would be highly variable since wastes are derived from a variety of sources.

2. the distributions of the overall gamma-ray activity and the individual gamma-emitting radionuclides in ash are very complex.

3. the amount of mixing during waste incineration and discharge is inadequate to distribute the radioactivity uniformly in the ash.

4. improved ash mixing or larger sample masses would be required to obtain acceptable confidence levels on estimates of ash radioactivity content. Constraints on the amount of ash collected per burn and the time required for radioisotopic analyses indicated that improved mixing is the preferred option.

The Effect of Mixing on Ash Sample Quality

If a population is normally distributed or if a sampling set is sufficiently large, the sampling distribution of means will be normally distributed[5]. If the sampling distribution of means is normally distributed then the standard normal distribution can be used to determine an interval estimate at a given confidence level for each point estimate made; i.e., a confidence interval can be computed for estimates made of the mean specific radioactivities of ash samples.

As noted previously, for economic reasons large sample sets of WTC incinerator ash cannot be taken. Therefore, attempts were made to blend the ash to normally distribute the radioactivity and to verify this statistically.

A device to tumble drums of ash and to remove samples was constructed. The ash from three consecutive burns in Stage Two of incinerator operation was collected in a single 0.2 m^3 drum. Three samples of ash were taken from the drum without any mixing and three more were taken for each of several stages of mixing using the tumbler device.

If the individual radionuclides in ash are normally distributed then their coefficients of variation (the ratio of standard deviation to the mean) will also be normally distributed[6]. Figure 2 shows a cumulative normal probability plot of the coefficients of variation for 10 radionuclides detected in the ash for some of the stages of mixing. The plot shows that as the ash is further blended the distributions of the coefficients of variation approach a normal distribution (linear plotting).

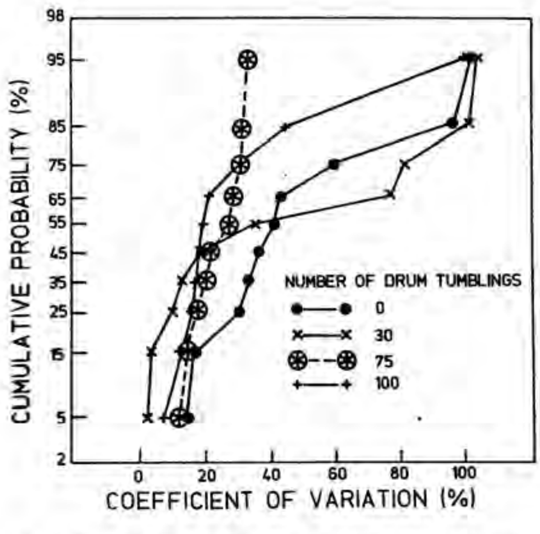
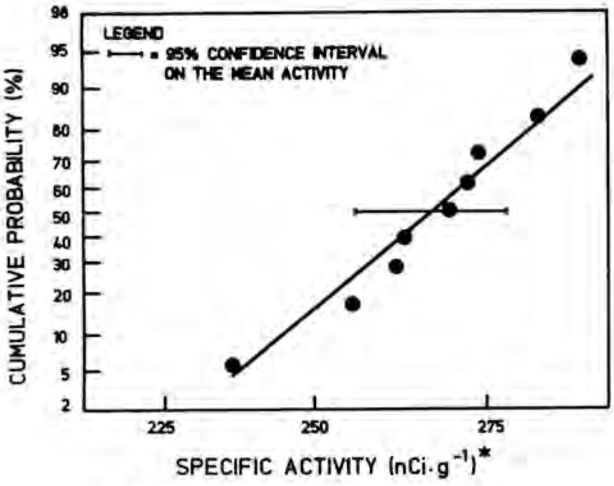


Fig. 2: The effect of mixing on the distribution of gamma-ray activity in ash samples.

The coefficient of variation, since it is a ratio of two statistics, is a very sensitive statistic, especially for small sample sets. The anomaly noted for 100 tumblings of ash is a reflection of this sensitivity. However, these initial data indicated that, if drums of ash were to be tumbled about 75 times, representative samples could be obtained.

Figures 3 and 4 partially summarize the results of gamma-ray spectral analysis of ash from two consecutive burns from Stage Two of incinerator operation. The drum containing this ash had been tumbled 75 times prior to sampling.



* 1Ci = 37 GBq

Fig. 3: Cumulative normal probability plot of the gamma-ray specific activity in ash samples from incinerations I83-012 and I83-013.

Figure 3 shows that the total gamma-ray activity in the ash appeared to be normally distributed and the coefficients of variation (Fig. 4) of all the identified gamma-emitting radionuclides (except for Cs-134) also appeared to be normally distributed. The anomaly, resulting from one unusually high datum in 162 data (18 radionuclides in nine samples), may be attributed to a "hot spot" in the ash. Overall the ash appeared to be well mixed and samples appeared to be representative.

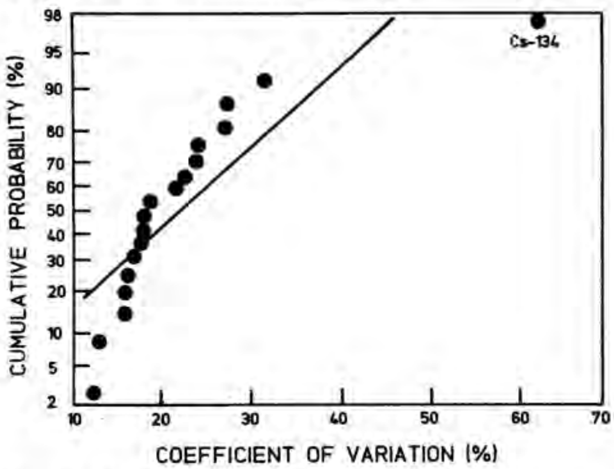


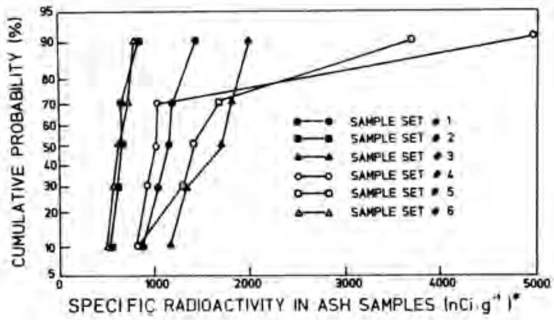
Fig. 4: Cumulative normal probability plot of the coefficients of variation for the 18 gamma-emitting radionuclides in ash samples from incinerations I83-012 and I83-013.

Additional Sampling-Analyses in Stage Three of Incinerator Operation

Ash from the first six months of Stage Three operation of the WTC was routinely discharged into 0.2 m^3 drums. When drums were 2/3 to 3/4 full, they were tumbled 75 times using the tumbler-sampler device and five ash samples were collected from each drum. Samples were analysed to determine the specific activities of gamma-emitters, Sr-90, total beta activity and total alpha activity.

Figure 5 shows a cumulative normal probability plot of the estimates of overall specific radioactivity for each of the samples in all six sets. Figure 5 indicates that:

1. four of the six sample sets appeared to conform well to a normal distribution.
2. the tumbling-sampling protocol provides better sample sets than does the vertical method. However, the technique does not routinely produce normally distributed sample sets.
3. further RD&D into selection of an ash sampling protocol may be required in support of the waste characterization program.



* 1Ci = 37 GBq

Fig. 5: Cumulative normal probability plot of the specific radioactivity in ash samples collected from incinerations conducted 1983 April to 1983 September.

To assess the safety of disposal concepts, computer codes such as the Systems Variability Analysis Code (SYVAC)[7], being developed by Canada's Nuclear Fuel Waste Management Program, permit users to input both parameter values and estimates of parameter variability. As such, the tumbling-sampling protocol may prove sufficient and adequate if, statistically, the variability in radionuclide activities can be estimated with reasonable confidence limits imposed.

Correlation of Total Alpha, Beta and Gamma Radioactivity in Ash

The estimate of total gamma-ray activity in waste may, by itself, be insufficient to estimate the hazardous lifetimes of wastes. Therefore, correlations of alpha-, beta-, and gamma-emitter activities in ash were made to investigate the feasibility of using gamma-ray measurements to estimate the overall radiological characteristics of wastes.

Figure 6 shows the specific activity ratios of total alpha and total beta to total gamma. The points connected by lines represent the samples within each set. The data indicate that;

1. within sample sets, the variation in ratios of activities from sample-to-sample was reduced significantly over that observed for vertical samples.
2. the variation in alpha-to-gamma ratios was higher than the variation in beta-to-gamma

ratios. However, total alpha activity, as detected, was near the limit of detection for the instrumentation used. As such, counting errors themselves contribute substantially to the variation in ratios within sample sets. Beta activity was determined to ± 2 percent counting error while alpha activity was determined to no better than ± 30 percent counting error.

3. the average nominal alpha activity for the six sets was less than one half percent of the estimated total radioactivity.

4. the average nominal beta activity for the six sets was approximately 30 percent of the estimated total radioactivity.

5. gamma measurements may be of significant value in estimating total radioactivity and each of total alpha, beta and gamma activities in waste.

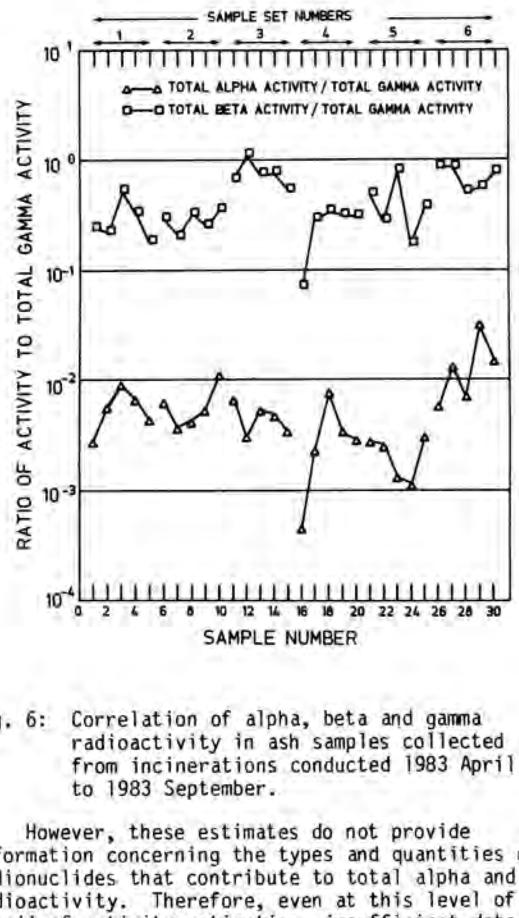


Fig. 6: Correlation of alpha, beta and gamma radioactivity in ash samples collected from incinerations conducted 1983 April to 1983 September.

However, these estimates do not provide information concerning the types and quantities of radionuclides that contribute to total alpha and beta radioactivity. Therefore, even at this level of detail of activity estimation, insufficient data are available to estimate the potentially hazardous lifetimes of waste.

There are two options available. Firstly, detailed alpha and beta determinations can be carried out on ash samples to determine the significant contributors to total activity. Correlations can then be carried out between the activities of individual alpha- and beta-emitters and the total of alpha and beta activities respectively. Then total gamma activity can be used to predict total alpha and total beta activity and detailed correlations can be used to predict the levels of individual alpha- and beta-emitters. With these estimates, sufficient information should be available to estimate the potentially hazardous lifetimes of wastes. Secondly, based on waste origins, theoretical estimates could be made for the relative abundances of alpha- and beta-emitters in total alpha and beta contamination. This technique would provide a first approximation of the hazardous lifetimes of wastes and might require some analytical support to justify the theoretical treatment.

Table II summarizes the comparisons of activity ratios for total alpha, total beta, total gamma and the total of all radioactivity as determined in the ash analysed. The data indicate that the use of gamma-ray measurements to estimate the characteristics of wastes appears highly feasible and the matter will be pursued in follow-up RD&D.

DEVELOPMENT OF A NONDESTRUCTIVE WASTE MONITOR - PRELIMINARY MEASUREMENTS AT THE WTC

Tests at the WTC started early in 1982. The initial effort concentrated on the measurement of gross gamma activity and its statistical distribution among waste packages. Later, the emphasis was shifted to the determination of the gamma isotope-specific composition of several waste charges designated for incineration. Until now, only waste segregated for incineration has been measured, because it is the only stream which allows verification of the measurements (by ash analysis).

Gross Gamma Measurements

Measurement of gross gamma-ray activity of all waste processed by the WTC is part of the facility operating requirement. Current practice at the WTC consists of measuring the radiation field of all waste items by a specified hand-held survey meter. The activity of the waste is inferred from an experimental relationship between gamma-ray field and the activity of five year old fission products. Manual scanning of the waste is not accurate and is manpower intensive. The accuracy of measurement of the gamma activity of waste can be improved by using large volume scintillator-photomultiplier detectors in the pulse counting mode. Such a system provides an output which is proportional to gamma-ray activity and depends only weakly on the gamma-ray energy.

A temporary experimental set up has been tested. It consisted of a 5 cm x 5 cm NaI(Tl) detector assembly mounted on a shielded frame with a rotating platform (Lazy Susan). The distance between the detector and the centre of the platform was approximately 30 cm. The waste activity was measured for one rotation, which was controlled by micro-switches mounted at the base of the platform. This procedure took approximately 20 seconds per waste item. For the typical background activity levels at the WTC, this arrangement allowed activity measurements above 2 to 5 μCi (1 Ci = 37 GBq) per waste item.

The Lazy Susan set-up has been used to monitor the feeds to several incinerations during Stages One and Two of WTC operation. The estimates of incinerator charge gamma-ray activity, as measured with the

TABLE II:

Comparison of the Activity Ratios for Total Alpha, Beta, Gamma Radioactivities in Ash Samples

CORRELATION	AVERAGE RATIO	STANDARD DEVIATION	COEFFICIENT OF VARIATION (%)	95% CONFIDENCE INTERVAL LOWER LIMIT	95% CONFIDENCE INTERVAL UPPER LIMIT
Total beta activity vs. total gamma activity	0.45	0.26	57	0.36	0.55
Total beta activity vs. total radioactivity	0.29	0.11	40	0.25	0.33
Total alpha activity vs. total gamma activity	6.2×10^{-3}	6.1×10^{-3}	98	3.9×10^{-3}	8.5×10^{-3}
Total alpha activity vs. total radioactivity	4.2×10^{-3}	3.7×10^{-3}	90	2.8×10^{-3}	5.6×10^{-3}
Total radioactivity vs. total gamma activity	1.5	0.26	18	1.4	1.6

NaI detector, compared favourably with the estimates based on ash analysis (Table III).

TABLE III:

Comparison of the Gamma Activity of Waste Measured by Direct Monitoring and Ash Analysis

Burn Number	Direct Monitoring (mCi)@	Ash Analysis* (mCi)@
I82-027	4.5	6.5 ± 3.0
I82-039	3.5	2.3 ± 0.2
I83-012 and I83-013	14.0	10.0 ± 0.6

@ 1 Ci = 37 GBq
* does not include the activity in the coarse ash or flyash trapped in off-gas filters

Figure 7 indicates that most of the gamma-ray activity in the incinerator feeds was concentrated in a small number of waste items. Most items contained little if any, detectable gamma-ray activity.

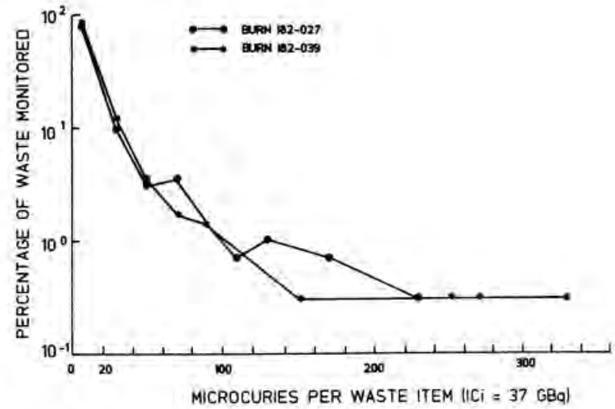


Fig. 7: Distribution of total gamma radioactivity in waste items from Burns I82-027 and I82-039 as determined by direct monitoring with a sodium iodide detector.

Isotope-Specific Measurements

A Ge coaxial spectrometer (15% efficiency) with associated electronics was used in the Lazy Susan geometry to collect spectra from waste bags selected from the feed to incinerations I83-012 and I83-013. Spectra were collected for 120 seconds for each of 74 waste items representing about 13% of the waste feed on a volume basis. All items had contact radiation fields between 2 and 5 $mR \cdot h^{-1}$ ($1\ R = 2.58 \times 10^{-4}\ C \cdot kg^{-1}$ in air).

A comparison of the isotopic composition of the waste monitored[a] with that inferred from the radioanalysis of nine ash samples (Fig. 3) showed good agreement; refer to Fig. 8.

(a) Ru-106 is not included in the composite spectrum from the nondestructive monitoring of the feed. The characteristic gamma-ray at 511 KeV was interferred with by other gamma-rays in this energy region.

This preliminary test clearly indicates that front-end, nondestructive monitoring is feasible to determine the major gamma-emitting radionuclides in **CURRENT**, solid LLW.

A short duration (approximately 5-second) gross gamma measurement can provide quantitative information of total gamma-ray activity. Qualitative information about gamma-ray isotopic composition can be obtained from the spectral analysis of only a small fraction of waste which contains the majority of radioactivity. By combining the two sets of data, quantitative estimates of individual gamma-emitters can be obtained in the high-throughput, process environment of the WTC.

The results obtained also indicate that it is highly feasible to estimate the hazardous lifetime of wastes for disposal purposes by using gamma-ray detectors and by inferring waste properties from radioactivity correlations determined from destructive analyses.

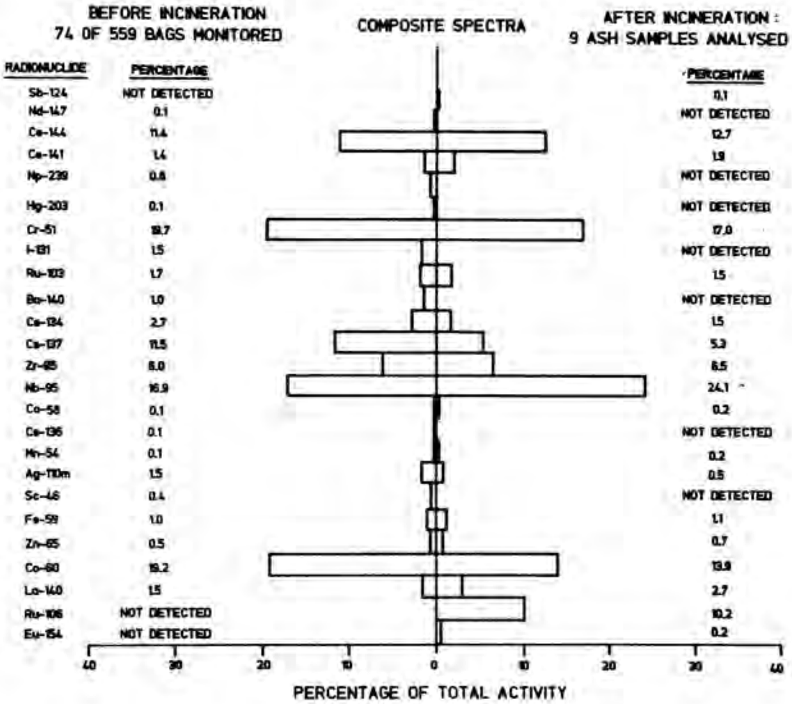


Fig. 8: A comparison of the gamma spectrum obtained from monitoring waste prior to incineration with the spectrum obtained from the analysis of ash for incinerations I83-012 and I83-013

SPECIFICATIONS FOR A DEMONSTRATION MONITOR

The device described here is presently under construction. It is intended for use in the RD&D program for the radiological characterization of **CURRENT**, solid LLW to be processed at the WTC. Experience gained from this equipment will form the basis for the design of a fully engineered system for the characterization of solid LLW for disposal purposes.

The segregation of radioactive wastes according to their physical characteristics is required to optimize the volume reduction methods employed[3] at the WTC. The proposed demonstration monitor will permit the simultaneous segregation of radioactive wastes according to both radiological and physical characteristics.

The demonstration monitor should:

1. not interfere with waste processing; i.e., it should have a large throughput, simple operation and low maintenance requirements. A large throughput can be achieved by monitoring all waste for total gamma-ray activity and by determining isotopic composition using spectroscopy for only waste having gamma-ray activity above a predetermined limit.
2. have sufficient sensitivity for the determination of the total and isotope-specific gamma-ray activity of LLW and if a deminimis activity level is established it should permit the separation of active from nonactive waste (or be adaptable to meet this requirement).
3. be flexible; i.e., be able to monitor wastes of various physical forms, shapes and sizes.
4. provide convenient data accumulation and storage.

Description of the Proposed Demonstration Monitor

The waste monitor will consist of a shielded main frame which will support two monitoring systems and associated electronics. Components include both gross and isotope-specific, gamma-ray measurement instrumentation, and a microcomputer to control the system and to collect, store and process data.

The main frame is modular in design and can be adjusted to accept waste of different forms. The gross gamma-ray detectors (two shielded 7.5 cm x 7.5 cm NaI(Tl) detectors) will view waste items from two sides. The isotope-specific, gamma-ray detector will be a coaxial intrinsic Ge detector (50 cm^3) with an integrated preamplifier-HV supply and automatic protection features. A liquid nitrogen Dewar will provide sufficient detector cooling capacity for one week's operation without refill.

The device will have two operating modes: background sampling and waste monitoring. In the background mode, the monitor will sample and characterize the background gamma-ray radiation in the instrument's environment in 5-second assay intervals. It will activate an alarm if background activity is found to be above a preselected threshold.

The monitoring process will be activated automatically by insertion of waste items into the monitor. Following a preset total gamma-ray assay for a few seconds, the computer will decide if the activity is sufficiently high to initiate collection of a Ge-spectrum for 60 seconds. If the activity is below the threshold, the monitor will complete a 5-second assay measurement of gross gamma-ray activity. In either case, to complete a monitoring sequence, the operator has to select the waste processing required based on the physical form of the waste. The mode selected also determines the electronic filing of data for future analysis. If total gamma-ray activity is above a predefined limit, the operator will be notified by alarm. The computer will automatically log the activity determination in a "REJECTION" file and print out an identification tag for the waste item which must be sent to storage without processing.

During the monitor's operation, data will be temporarily stored locally. When the operator terminates monitor operation at the end of each day data will be dumped to long-term mass storage on the CRNL central computer.

SUMMARY

Preliminary waste characterization studies on LLW at CRNL have demonstrated the feasibility of using nondestructive, gamma-ray monitoring to adequately characterize these wastes for disposal. Both total and isotopic-specific gamma-ray activities can be determined for LLW in a high-throughput, process environment.

The analysis of incinerator ash can be used to verify the use of nondestructive instrumentation for monitoring. In addition, ash analyses can be used to estimate the quantities of radionuclides contaminants that do not have significant gamma-ray emissions. As a consequence, nondestructive gamma-ray monitoring, in conjunction with an incinerator ash analysis program, can be used to estimate the radiologically hazardous lifetimes of LLW.

REFERENCES

1. D.F. DIXON, "Management of Radwaste at Chalk River, Canada - Storage and Disposal", *ANS Transactions, volume 44*, p85, American Nuclear Society, Detroit (1983).

2. J.E. LeSURF, D.H. CHARLESWORTH, "Processing, Storage and Disposal of Low and Intermediate Level Waste in Canada", these proceedings.

3. N.V. BEAMER et al., "Studies of Reactor Waste Conditioning and Disposal at CRNL", AECL-7551, Atomic Energy of Canada Limited (1982).

4. N.V. BEAMER, "Experience with Low-Level Waste Incineration at Chalk River Nuclear Laboratories", these proceedings.

5. N. GILBERT, *Statistics*, p.135, W.B. Saunders Company, Toronto (1976).

6. B. OSTLE, *Statistics in Research*, p51, Iowa State University Press, Iowa (1960).

7. K.W. DORMUTH, G.R. SHERMAN, "SYVAC - A Computer Program for Assessment of Nuclear Fuel Waste Management Systems, Incorporating Parameter Variability", AECL-6814, Atomic Energy of Canada Limited (1981).