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L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

EXPERIENCE WITH RADIOACTIVE WASTE INCINERATION AT CHALK RIVER NUCLEAR LABORATORIES

EXPÉRIENCE AVEC L'INCINÉRATION DES DÉCHETS RADIOACTIFS AUX LABORATOIRES NUCLÉAIRES DE CHALK RIVER

V.T. LE, N.V. BEAMER, and L.P. BUCKLEY

Presented at an 1988 International Conference on Incineration of: Hazardous, R/A, & Mixed Wastes
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Chalk River Nuclear Laboratories

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RÉSUMÉ

Les Laboratoires Nucléaires de Chalk River sont un centre de recherches nucléaires exploité par l'Énergie Atomique du Canada, Limitée. On a contruit un centre de traitement de déchets en grandeur réelle pour traiter les déchets radioactifs de faible et moyenne intensité produits à l'établissement. L'un des éléments installés au centre de traitement est un incinérateur chargé par lots, à deux étages et appauvri en air pour les déchets solides combustibles. Celui-ci est en service depuis 1982. Il réduit constamment les déchets combustibles en cendres inertes, le facteur moyen de réduction de volume étant 150:1 environ. On stocke les cendres de l'incinérateur dans des fûts de 200 L en attendant leur solidification dans le bitume. L'incinérateur et une presse à ballots hydraulique de 50 tonnes assurant le traitement d'un volume combiné d'environ 1300 m^3/a de déchets solides radioactifs de faible intensité. Dans cette communication, on examine les performances de l'incinérateur au cours de ses six ans de service. En plus d'y présenter l'expérience d'exploitation, on y examine une évaluation de la technique d'incinération à l'air appauvri.

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ABSTRACT

Chalk River Nuclear Laboratories is a nuclear research centre operated by Atomic Energy of Canada Limited. A full-scale waste treatment centre has been constructed to process low- and intermediate-level radioactive wastes generated on-site. A batch-loaded, two-stage, starved-air incinerator for solid combustible waste is one of the processes installed in this facility. The incinerator has been operating since 1982. It has consistently reduced combustible wastes to an inert ash product, with an average volume reduction factor of about 150:1. The incinerator ash is stored in 200 L drums awaiting solidification in bitumen. The incinerator and a 50-ton hydraulic baler have provided treatment for a combined volume of about 1300 m^3/a of solid low-level radioactive waste. This paper presents a review of the performance of the incinerator during its six years of operation. In addition to presenting operational experience, an assessment of the starved-air incineration technique will also be discussed.

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Introduction

Combustible solid low-level radioactive waste (LLRW) can be substantially reduced in volume by incineration. Volatile and oxidizable fractions are destroyed and the waste is converted into a more stable inert ash product. Studies have shown that a wide variety of concepts are available for incineration of LLRW and some systems have performed satisfactorily for nuclear facility applications [1,2]. At Chalk River Nuclear Laboratories (CRNL), we have been routinely using a simple, batch-loaded, two-stage, starved-air incinerator to burn solid combustible wastes. The incineration system is one of the processes installed at the Waste Treatment Centre (WTC), which is a full-scale integrated treatment facility to process low- and intermediate-level radioactive wastes generated on-site. Processible solid wastes are segregated at source into two categories, with about 70% classified as incinerable and 30% as non-incinerable but compactible. The incinerator and a 50-ton hydraulic baler have provided treatment for a combined volume of about 1300 m^3/a (46 000 ft^3/a) of solid low-level radioactive waste since 1982. The incinerator has consistently reduced the wastes to an inert ash product, with an average volume reduction factor of about 150:1.

This paper presents a review of the performance data of the incinerator obtained during its six years of operation. Our effort to increase the throughput of the incinerator as well as our experience maintaining the off-gas equipment are described. Good operating features and shortcomings of this type of incineration system are discussed.

Process Description

Starved-air incineration was selected to reduce the volume of CRNL's incinerable solid wastes. It is one of the simplest among the more advanced incineration techniques. The incinerator was designed by Trecan Ltd. (Mississauga, Ontario) according to our requirements. It is a smaller version of a production unit which has been operated by Ontario Hydro since 1977 [3,4], but includes a number of modifications to improve control, instrumentation and corrosion reduction to overcome some of the early operational difficulties experienced by Ontario Hydro.

The system (shown in Figure 1) consists of a vertical stainless-steel primary chamber with conical bottom, a horizontal refractory-lined afterburner and a dry flue-gas treatment system. To minimize radioactivity buildup and refractory maintenance, only the bottom cone of the primary chamber is lined with a refractory. A replaceable heat shield was installed to protect critical parts of the stainless-steel vessel. Waste bags, after being visually inspected but without being opened when received at the WTC, are fed batchwise by gravity into the primary chamber through a loading chamber equipped with interlocking doors. After a short preheating period, the waste is ignited by a propane burner. Primary combustion air is restricted to about one-third of the stoichiometric requirement so that most of the waste is thermally decomposed or pyrolyzed into combustible gases at a bulk temperature of about 500°C (930°F). Combustion is completed in a propane-fired afterburner where pyrolytic gases and particulate carry-over are burned with excess air at a temperature of 850-1000°C (1560-1830°F). The flue gas is cooled to 200°C (390°F) by a shell-and-tube air-to-air heat exchanger. The tube bundle is made of 316 L stainless steel, with tube-sheet insulation and an Inconel 625 ferrule in each tube used to protect the hot end against high temperature corrosion. The cooled flue gas is filtered through a series of filters which include a precoated baghouse filter, roughing filters and HEPA filters before being discharged to the atmosphere. The incinerator bottom ash is separated by a vibrating screen into coarse and fine fractions which are then discharged by gravity into drums, to await further treatment by immobilization in bitumen. The incinerator was designed to burn 10 m^3 or about 1000 kg of solid waste in every 24-hour burn cycle. A more detailed description of the incinerator system as well as its early commissioning and operating experience have been presented previously [5,6]. Our incineration program not only provides volume reduction of site waste but also is aimed at identifying design limitations and modifications necessary to achieve reliable operation. The following sections present the incinerator performance data, our operating experience and our assessment of this incineration technique.

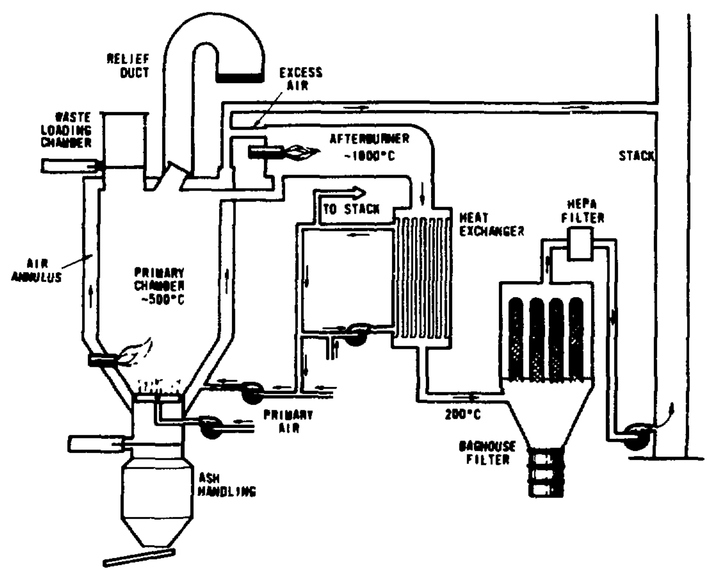

FIGURE 1: SCHEMATIC DIAGRAM OF CRNL STARVED-AIR INCINERATOR

Performance Data and Operating Highlights

The incinerator has been performing satisfactorily for the past six years processing the total CRNL production of incinerable waste. Following are a number of highlights:

- Table 1 summarizes performance data of the incinerator. An operating schedule of at least one burn per week has been maintained, and occasionally operating frequency was increased to two burns per week to keep up with waste receipts. The waste charge has been gradually increased from the design value of 1000 kg/burn to 1600 kg/burn by burning a mixture of uncompacted and baled wastes to improve throughput. It was demonstrated that the incinerator can handle up to 2000 kg charge with no detrimental effects on performance. The reduction in the number of burns each year, corresponding to an increasing amount of waste burned in each charge, has had an economical impact on waste handling.

- The incinerator has consistently produced a fully satisfactory inert ash product with an average volume reduction factor of 150:1 and a weight reduction factor of about 25:1. Fine ash is the most abundant material, constituting about 75% of the bottom ash product. It is of consistent quality, free flowing and containing 1-3 wt% of fixed carbon. The contact gamma radiation field measured on an ash drum averages 3.5 mGy/h (0.35 rad/h), and rarely exceeds 10 mGy/h (1 rad/h). Table 2 summarizes the characteristics of the three ash products collected.

- The air-to-air heat exchanger is the most critical piece of equipment because it has been susceptible to corrosion and deposition problems under high-temperature cyclic operating conditions. Heat exchanger tube damage takes place at the hot inlet end in the form of severe corrosion, embrittlement and impingement attack. Many heat exchanger tubes have failed and are progressively being replaced. A hard deposit forms rapidly on the inside of the tubes mostly at the inlet end, is difficult to remove completely, and results in frequent tube cleaning.

- The insulating Inconel 625 ferrules inserted at the inlet end of the 316 L stainless-steel heat exchanger tubes provided protection for these tubes from high-temperature corrosion failure for about 4 years. An extensive corrosion test program carried out with in-situ coupons of expensive high temperature alloys found no material significantly better than Alloys 625 or 310 for this application [7]. The ferrule design was modified to reduce air turbulence and reduce erosion at the point of contact with the stainless-steel tubes. Ferrule length has also been increased from 23 cm (9 inch) to 61 cm (24 inch). The redesign of the ferrules will hopefully increase the service life of the heat exchanger tubes. As the tubes were replaced, the modified ferrules were inserted. During 1987, the peak afterburner outlet temperature was also limited to about 875°C (1610°F). The temperature control was effective in reducing the rate of heat exchanger tube corrosion while not affecting the combustion efficiency.

TABLE 1

PERFORMANCE DATA OF CRNL INCINERATOR

	1982	1983	1984	1985	1986	1987
Quantity: (m^3)	540	720	790	920	740	720
(Mg)	48	67	84	95	74	71
No. of burns	45	57	62	75	53	44
Average charge (kg/burn)	1070	1170	1350	1270	1400	1620

TABLE 2

ASH CHARACTERISTICS

Type	Quantity (kg/100 kg waste)	Bulk Density (g/mL)
Coarse(1)	0.8	0.7
Fine(2)	2.3	0.6
Flyash(3)	0.1	0.3

NOTES: (1) larger than 12 mm (0.5 inch)
(2) smaller than 12 mm (0.5 inch)
(3) collected in baghouse filter

- A hard deposit layer forms on the heat exchanger tubes when the incinerator cools down. Tube cleaning is required to minimize the pressure drop across the heat exchanger. The hard deposit is difficult to remove solely by brushing. The ferrules restrict the inlet to each tube and prevent effective cleaning of the tubes to their full ID. An expandable cutting tool was designed and tested with limited success. There still remained enough residual deposit on the tubes after cleaning and the resulting rough surface could easily trap flyash particles in subsequent burns. A further test program to characterize the deposits and to seek alternative cleaning techniques has been a success. Analysis of the deposits indicated the presence of a slag layer consisting mostly of low-melting sulphate salts which are liquid at the operating temperature of the heat exchanger. A large fraction of the deposits is water soluble, and by adding water to soften the deposits, more effective deposit removal is now achieved by brushing. With the improved cleaning technique, the incinerator now operates for longer periods (about twice the number of burns) between heat exchanger cleanings.

- In addition to being used to treat site waste, the incinerator has been used as a development tool in a waste characterization program to estimate quantity and radiological characteristics of solid LLRW going to disposal. The incinerator ash is an ideal waste form which can be sampled and analyzed destructively to verify the data produced by a non-destructive waste monitor which measures gamma activity of individual waste bags fed to the incinerator. The incinerator also continues to be a test bed to evaluate the performance of high-temperature corrosion-resistant alloys under an incinerator off-gas environment.

Assessment

Table 3 summarizes the good features and shortcomings of the CRNL starved-air incineration process. Following are some relevant points of discussion:

Good Features

- All operational and maintenance functions have been carried out with negligible contamination and personnel exposure problems. Process upsets such as power failures and explosive pressure surges were infrequent, and when they have taken place the system has responded effectively and quickly to restore the normal operating conditions without any incident of airborne contamination. In general, it is a simple, reliable and controllable incineration process.

- Since the system operates batchwise under a slight negative pressure, radioactivity containment is high. The relatively low flow rate of the primary combustion air limits disturbance of the waste bed, resulting in low flyash carry-over. The baghouse and roughing filters have provided effective removal of the flyash particles; the downstream HEPA filters have not been replaced since the start of the incineration operation more than six years ago. The removal efficiency of the HEPA filters has been routinely checked using a DOT smoke test. Particulate beta-gamma stack releases remain negligible, i.e. normally less than 37 kBq (1 μCi) per burn.

- With a relatively low bulk reaction temperature maintained in the primary chamber, the stainless-steel liner of this chamber has not shown any evidence of corrosion attack. Localized hot zones, however, have caused some deformation of the primary chamber cone. With minimal use of refractory material, the internal surfaces are relatively clean, and radiation fields are low, generally less than 2 mGy/h (0.2 rad/h) at the bottom of the cone on contact. The primary chamber is thus accessible for inspection and maintenance.

- The starved-air combustion process is able to cope with waste items having a wide variety of physical forms. A waste-segregation-at-source program is required to minimize glass, metal and PVC content but no waste pretreatment is necessary. Segregated LLRW from a nuclear power demonstration (NPD) reactor has been routinely mixed and burned with CRNL waste without any difficulty. The incinerator is also able to handle radioactive oils and solvents. A system to convert the afterburner into a dual-fuel arrangement to burn some stockpiled organic liquid wastes has been installed and commissioned. Burning of liquid-scintillation vials has also been successfully demonstrated. Tests with bales of both wet and dry incinerable waste were burned to establish the ability to satisfactorily burn compacted waste as part of total incinerator charge. This practice has been effectively used to deal with wastes accumulated during incinerator shutdown periods for repair and maintenance, and bales now form part of each charge to improve the economic performance of the facility.

TABLE 3

PROS AND CONS OF CRNL STARVED-AIR INCINERATOR

PROS	CONS
- simple, reliable and controllable process - low particulate carryover and high activity containment - low corrosion and radiation build-up in primary chamber - no waste pretreatment - readily adaptable to variable waste production	- waste segregation at source required to minimize wastes containing radioiodines, tritium, PVC, metal and glass - significant modifications required for scale-up to large regional incinerator - high-temperature corrosion and fouling of off-gas heat exchanger

Shortcomings

- Even though the incinerator is able to handle wastes in a wide variety of physical forms, it cannot burn a number of waste items. With no scrubber or absorber included in the existing dry off-gas treatment system, wastes containing radioiodines and polyvinyl chloride (PVC) must be minimized. Waste bags which contain excessive quantities of tritium-bearing wet wastes are also not accepted for incineration to minimize the release of tritium. Waste segregation at source is necessary, and requires a continuing conscious effort of the waste generators.

- Despite some advantages such as flexibility in coping with variable waste generation rate and effective containment of radioactivity, the batch operating mode has a number of disadvantages. Waste preparation and loading, as well as ash discharging, are labour-intensive steps. Thermal cycling has caused some cracking and spalling of the refractory in the afterburner. It may also contribute significantly to stress corrosion at the hot inlet end of the heat exchanger tubes. Although significant time is lost between burns for waste loading, for slow start-up and cool-down periods, and for ash discharge, the incinerator can handle all the incinerable wastes generated at CRNL and from NPD, with the current design and operating frequency of one or two burns per week. The concept is thus quite satisfactory for servicing up to 2000 m^3/a of waste (71 000 ft^3/a). To allow its scale-up to a large regional radwaste incinerator, this incinerator design would require some modifications. An incinerator operating in the continuous mode would solve many of the problems exhibited in the batch mode, and would also avoid significant increase in sizes of the combustion chambers and auxiliary equipment. Continuous ash discharge and feed addition systems as well as a horizontal primary chamber (to house the system in a one storey building) are identified as desirable features for a large-scale regional incinerator.

- The existing off-gas treatment system is unsuitable for continuous operation because interruptions are required to perform tube cleaning (frequently) and tube replacement (occasionally) for the air-to-air heat exchanger. The use of partial air-dilution cooling to lower the off-gas temperature at the inlet of the heat exchanger would reduce high-temperature corrosion failure, minimize deposition rate and facilitate tube cleaning, and thus assist in prolonging service cycles. However, to handle more wastes which contain PVC and radioiodines, it would require a scrubbing system and an impregnated charcoal filter system for the respective removal of HCl and I from the off-gas. These systems would contribute additional secondary wastes but would make the process more flexible by allowing a wider range of waste materials to be incinerated.

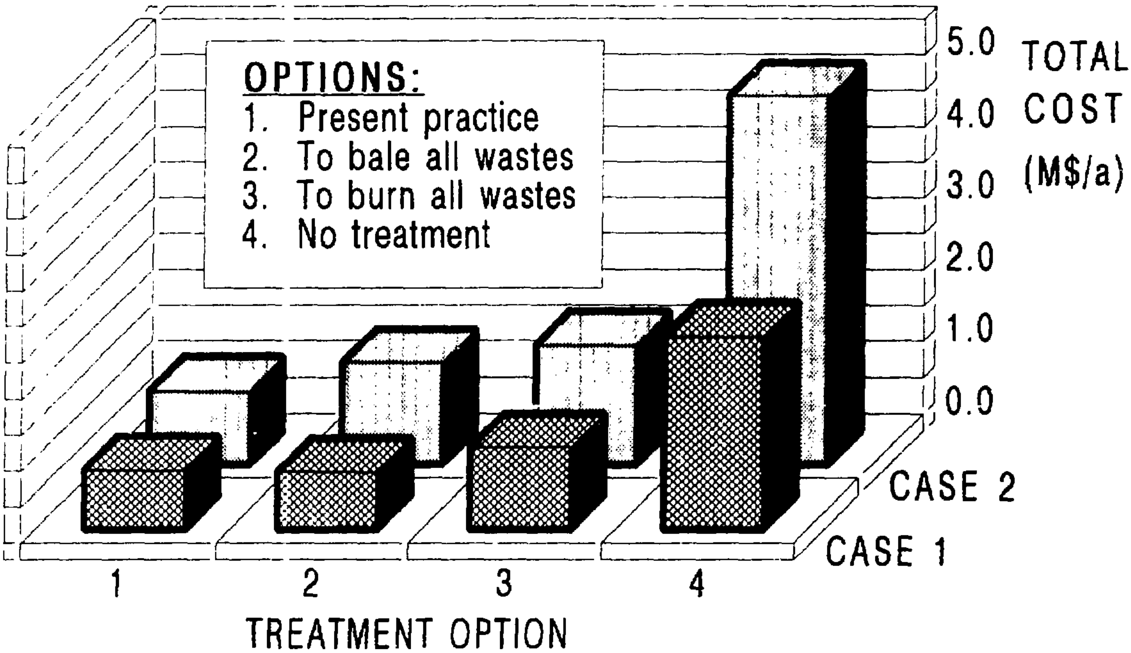

FIGURE 2: ECONOMIC ANALYSIS

Economics

An economic analysis was performed to assess the impact of incineration and baling processes on the treatment and disposal of solid LLRW. Figure 2 summarizes the comparison of 4 treatment options for two cases:

- Case 1, the treated waste goes directly to a permanent disposal facility, and
- Case 2, the treated waste has to be stored for a period before a permanent waste repository is available.

The total cost includes handling, treatment, storage (required for options in Case 2) and disposal costs. The calculations were based on the treatment of 1300 m^3/a of wastes including both incinerable and non-incinerable fractions. The non-incinerable waste was assumed to be all PVC. Other major assumptions included: (i) all processing, storage and disposal facilities were located at CRNL, thus transportation costs were negligible; (ii) 2000 $/$m^3$ waste (57 $/$ft^3$) as cost for storage followed by disposal and (iii) 1000 $/$m^3$ waste (28 $/$ft^3$) as direct disposal cost with no storage [8]. The results shown in Figure 2 indicate that:

- Option 1 (our present practice of waste segregation for baling and incineration) is the most economical for Case 1 when the treated wastes have to be temporarily stored waiting for a repository to become available;

- Option 2 (to bale all wastes) is the most economical for Case 2 when all the treated waste can go directly to a permanent disposal: this option, however, would not provide for the processing of organic liquid wastes such as scintillation liquids;

- Option 3 (to burn all wastes) is more expensive than the above two options for both cases because the requirement to neutralize the HCl in the off-gas would generate significant quantities of secondary wastes and drastically reduce the volume reduction factor achieved by incineration; and

- Option 4 (no waste treatment) is the most expensive, as always expected, among the options considered in both cases.

Conclusions

In summary, we have six years of experience in operating a simple, batch-loaded, starved-air incinerator at CRNL. The incinerator has proved to be a safe and reliable process which is effective in converting combustible low-level radioactive wastes into a stable and highly volume-reduced ash product. The incinerator, in combination with a baler, has provided an effective radioactive waste treatment to minimize space requirements for interim storage while we work on the development of a permanent waste disposal option.

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