Incineration of low level radioactive wastes from non-nuclear sources in the UK

Ciaran McDonnell
HPA Radiation Protection Division, Chilton, Didcot, OX11 ORQ, UK

Introduction

Any type of work with radioactive substances will give rise to radioactive wastes requiring safe disposal, and in the UK high temperature incineration has become a vital component of the overall provisions for dealing with common types of radioactive wastes. This paper describes some important features of how this practice is operated and regulated in the UK, and considers in particular the extent to which it can be viewed as the optimum solution from a radiological protection standpoint. It is stressed that this paper does not consider incineration of wastes from the nuclear sector nor is there any consideration of wastes containing elevated levels of naturally occurring radionuclides.

Typical radioactive waste producers in the non-nuclear sector include hospitals using radionuclides for diagnosis and therapy and research laboratories in universities, other national institutes and industry (e.g. pharmaceuticals and biotechnology). The most common radionuclides in wastes from these sources that are sent for treatment at incinerators are tritium, carbon-14, phosphorus-32, sulphur-35, iodine-125 and iodine-131. Others encountered include chromium-51, phosphorus-33, yttrium-90, and indium-111. Most of the activity is in the form of solid wastes but incineration is also important as the disposal route for organic liquids, including the media used in laboratory scintillation counting. (It is very unusual for aqueous wastes from this sector to be incinerated since most of these are currently disposed of by direct discharge to drains and sewage systems.)

Types of radioactive wastes

The practice of disposal of radioactive wastes is regulated under the Radioactive Substances Act 1993 (RSA93) enforced by the UK environment agencies. A user wishing to dispose of radioactive waste by any route, including incineration, will usually require an authorisation (licence) and, in addition, the operator of an incinerator receiving and processing radioactive waste will need their own authorisation under RSA93. These authorisations will only be granted by the environment agencies when the proposals put to them are radiologically acceptable and compatible with the overall UK policy framework for radioactive wastes, set by government.

For solid radioactive wastes the current options for disposal include:
1. Special national storage facilities - required for many sealed sources.
2. The Drigg repository in Cumbria.
3. Disposal to a nominated landfill site under specified conditions.
4. Incineration with other non-radioactive wastes.
5. Disposal of very low level wastes (VLLW) in normal refuse routes.

Waste suitable for disposal in routes 2, 3 and 4 may all be referred to as low level wastes (LLW) although RSA93 licences will not normally use this phrase but will refer simply to “solid waste”. Almost all waste generated in the non-nuclear sector has activity levels and concentrations that do not require routes 1 or 2, the main exception being waste sealed sources (and recycling is possible for some sealed sources). Routine radioactive wastes from producers in this sector can in principle be considered for routes 3, 4 or 5, and the rest of this paper considers why particular routes are chosen in practice.

Route 5 involves authorised disposal of wastes with low radionuclide concentrations in “normal refuse”. These are the routine bulk wastes that which are collected from businesses and other organisations. The VLLW authorisation formula implies that the radioactive waste will be well mixed with other non-active wastes and specifies that the waste is either sent direct to landfill or that it enters normal municipal refuse disposal routes. In the case of the latter option the waste could be sent direct to landfill or it could go for incineration. It is accepted that some of these municipal wastes may in fact be subject to waste sorting as part of recycling activities although it is at least implicit in the design of this practice that radioactive VLLW would not be exclusively put into a recycling route.

The standard authorised limits and conditions for VLLW are:

1. For most radionuclides, there is a fixed concentration limit of 400 kBq/0.1m^3 and a limit of 40 kBq on the maximum activity associated with any single item in the waste.
2. The preceding limits may be set ten times higher if the waste contains only carbon-14 and/or tritium.
3. Alpha emitters are normally excluded, although a few authorisations permit this with a concentration limit set typically at ten times lower than for condition 1.

The rather unusual expression of the concentration limit (activity per one hundred litres) derives from the historical origin of this legal formula which envisaged disposal of a small bag or bin of wastes being put into high volume normal waste stream. It is important to stress that once disposal takes place there is no "tracking" of VLLW, so clearly it must be safe for any disposal or recycling route into which the radioactive materials might be eventually go. From time to time radiological assessments are commissioned by the regulators and these continue to support the safety of the VLLW disposal practice.

Some users do rely on the VLLW route for disposal of all their solid radioactive wastes, but this is a minority. Reasons why the route will not be used are:

1. The radioactive waste has other hazardous properties (chemical or biological) so that another treatment process (very likely incineration) is required.
2. The waste often includes components that exceed the single item limit of 40 kBq.
3. More generally because it may be difficult to find a suitable "normal" waste stream to place the waste in.

Issue 3 has become increasingly important because of the desire to avoid landfill disposal of wastes, and also other more subtle features deriving from way disposal practices and radioactive waste disposals have evolved in the UK. One factor is the reluctance of some disposal facilities to receive *any* radioactive wastes, even if this is lawful and safety is assured by means of a radiological assessment.

Application of the VLLW formula to incinerators

The main reason for describing the VLLW formula in such detail is that it is vital to the practice of incineration of radioactive wastes because it is the legal formula that is applied to the disposal of the solid arisings from an incinerator. A considerable fraction of the activity of many radionuclides that enter the incineration process will emerge in kiln ash, which obviously requires disposal itself. The volumes of ash produced mean that landfill is likely to be the only cost effective route and it is the standard VLLW formula that is always applied to limit concentrations in the ash. This includes the single item limit of 40 kBq, which requires that the activity in radioactive waste put into the incinerator must be adequately dispersible (and which is why the route is not acceptable for most sealed sources).

The question can be asked of why precisely *these* (VLLW) limits are applied to incinerator arisings, when slightly higher limits could be justified for some of the common lower risk radionuclides. The answer is probably because it is more convenient to stay with a single national criterion that has been repeatedly verified as safe by radiological assessment rather than encourage the possibility of different incinerators pursuing different limits in ash, which might conceivably undermine confidence in the practice.

The key practical consequence of the application of the VLLW formula is that it limits the input activity to the incinerator in direct proportion to the production rate of kiln ash, which in itself is proportional the total amount of waste fed into the incinerator. This is easiest to illustrate using an isotope such as chromium-51 that is not volatile and will essentially transfer completely (100%) to kiln ash. If the incinerator produces 5 cubic metres of ash per day the maximum activity in ash to meet the VLLW formula is 5/(0.1) x 400 kBq = 20 MBq. So the maximum activity that can be put into the incinerator each day would also be 20 MBq. The input limit on activity might be referred to as the "radiological capacity" of the incinerator and the important point is that the limiting factor is *not* radiation dose to persons exposed to the emissions of the incinerator (or the workers at the incinerator) but the need to meet the VLLW formula in the kiln ash. The only foreseeable situation in which this might not be the case would be tritium and carbon-14 containing wastes, as discussed below.

It is clear that if the VLLW formula is to be complied with there must be a suitably large volume of non-radioactive wastes being processed at the same time. The input radionuclides are being diluted throughout the mass of solid incinerator outputs, albeit that a fraction of the volatile radionuclides will also be discharged to air or as a liquid effluent. If there was no other waste incinerated then the effect would be to significantly concentrate radionuclides, and the ash from the incinerator would require special and more expensive disposal, there would be greater risks to incinerator workers, and the issue of doses from direct discharges to air (and any liquid discharges) would become more important. In the non-nuclear sector radioactive waste incineration is only possible because commercially successful incinerators already exist to handle other wastes, e.g. clinical wastes from hospitals and chemical wastes. Historically in the UK there were many smaller incinerators operated by individual users but the modern restrictions on incinerator emissions means that most of the ones now available for incinerating radioactive wastes belong to large commercial operators. Only very few actual users now operate their own incinerator.

Partitioning of radionuclides

Partitioning of radionuclides in the incinerator is relevant because knowledge of where different radionuclides go is required to undertake the necessary radiological assessment for direct discharges and to verify that the input limits are properly matched to the output VLLW limit on kiln ash. Determining partitioning in an incinerator is a challenging task from an analytical point of view partly because of the problems of obtaining representative samples from a continuous process and partly the difficulty of analysing for the many of the common radionuclides in solid and even liquid matrices. Determination of isotopes such as sulphur-35 and phosphorus-32 in kiln ash requires special sample preparations which are laborious and expensive. With gamma emitters analysis is easier because of the minimal sample preparation needed for spectrometry, although not all photon emitters are suitable for this because of absorption within the sample (for example, iodine-125).

Reference 1 describes a review of studies on partitioning and Reference 2 describes a typical incinerator study. Most work has involved short term studies and trials and from this the following general conclusions can be reached.

1. Tritium is perhaps the most predictable isotope, because on conversion to tritiated water it must follow the mass balance of water in the system. There will always be water vapour in the stack discharge and if there is a wet gas cleaning system fitted to the incinerator a significant fraction of the input tritium will also emerge in that stream.
2. Carbon-14 put into the incinerator will convert to dioxide and most of this will discharge to air. Neither dry scrubbers nor wet gas cleaning systems will remove much activity since the chemical conditions make it unlikely carbon dioxide will react.

3. Many other elements are substantially retained in ash, including isotopes of the metallic elements (e.g. chromium-51 and iron-59). Relatively small amounts will be carried onwards through the incinerator process since some fine ash particulates are emitted in the gas stream coming out of the kiln. These could be trapped in dry or wet scrubber systems.
4. Significant amounts of sulphur-35, phosphorus isotopes and iodine-125 will be retained in ash, but there is production of gaseous forms of these which then pass into gas cleaning systems specifically designed to deal with gases such as SO_2 and acid halides. These gas cleaning systems do remove a significant fraction of the volatilised material but some stack discharges must occur. The situation is most complex where there are multiple outputs from the cleaning system (e.g. both a liquid quench and a dry scrubber system).

With the volatile radionuclides it is important to recognise that partitioning may vary from day to day depending on what other wastes are being burned, since this will affect the chemical loading being put on the combustion gas treatment systems and their efficiency.

Radiological assessment of discharges

Radiological assessments are undertaken for all incinerators authorised to handle radioactive wastes and these invariably show low public doses. Worker doses are also low since there are no significant external dose rates and internal exposure is only to very dilute concentrations in incinerator output waste streams. (There are slightly higher risks to workers at the input stage if a radioactive waste container is spilt.) As has already been stated these low doses are a consequence of applying the use of the VLLW formula for output solid wastes. Only if there are very large amounts of tritium or especially carbon-14 could the direct discharge to air (or any liquid discharge) potentially be the limiting factor. The highest assessed doses for stack discharges come from modelling local food consumption near to the incinerator, most notably transfer of carbon-14 to vegetables grown in a hypothetical garden within a kilometre of the site, and even for the largest carbon-14 incinerator source term in the UK the assessed dose to the critical group is only of the same order of magnitude as the normal UK exposure to natural (cosmogenic) sources of carbon-14, which is about 12 microSieverts per year [3].

Monitoring and quality assurance

Partly because it is expected that public doses will be low there is generally no systematic monitoring for radioactivity in stack discharges or liquid effluents from incinerators working in this sector. However, it is common to use hand held gamma detectors, typically sodium iodide based and backed up with compensated GM tube dose rate meters, to monitor incoming waste containers and around kiln ash skips. Incinerator operators can be trained to undertake these checks and the waste input checks help verify that sealed sources such as caesium-137 or cobalt-60 do not enter the incinerator. The limitations of this sort of simple external monitoring are obvious: clearly it would not detect a pure alpha or beta emitter, but it could detect attempts to put uranium, thorium and radium containing materials into the incinerator. Where anomalies are detected the situation is investigated further, and the waste may be returned to the sender. Very occasionally potential sealed sources are detected in incoming wastes but a more likely scenario is finding iodine-125 in a waste container that is supposed to contain only a beta emitter such as tritium. The availability of portable hand held gamma spectrometers has made it easier to investigate waste containers, although these are at the moment only available to radiation protection specialists that the incinerator operators employ as advisers.

Monitoring of ash skips serves to demonstrate that nothing unexpected has transferred to the ash (e.g. a large sealed source) and it is possible with some photon emitters to derive approximate calibrations to allow monitoring of compliance with the VLLW limit.

Given the lack of direct analysis of samples of wastes it is relevant to stress the importance of other quality assurance elements. Those sending wastes to the incinerator are required to comply with documented “conditions for acceptance” criteria and to provide if requested their own records of the monitoring that supports their declarations of activity levels in their wastes. The incinerator operator would be expected to monitor each waste sender’s compliance and investigate any consignor who consistently breaches the rules. The consignor may be reported to the regulator who may pursue this separately.

Is incineration the optimum solution?

Finally it may be asked if incineration the optimum route for the wastes currently treated in this way, or would it from a radiological optimisation standpoint be preferable that these wastes were sent to landfill, as VLLW if possible, or if not under specified precautions, or even sent to the Drigg repository. The last option is ruled out on the basis of cost especially given that additional expenditure would be required to convert some wastes into chemically stable forms that would meet the Drigg acceptance criteria (that route would probably become necessary for an incinerator burning *only* radioactive waste inputs).

The table at the end of this paper identifies some relevant factors and presents a matrix of qualitative judgements on the way these apply to the three routes considered.

Incineration is clearly a good method for dealing with many radioactive wastes that have other hazardous properties, including organic scintillants, clinical wastes from medicine and other biologically hazardous materials). Some of the materials currently incinerated could probably be safely put into landfill but the possibility of some leaching of chemically or biologically hazardous substances into groundwater would remain, while incineration removes any such doubt. Some chemically or biologically hazardous wastes could be pre-treated by other means to make them suitable for landfill, for example using autoclaving for infectious materials. However, this adds costs and worker risks.

For wastes where radiation is the only hazard it would in principle be possible to segregate these so that those materials that meet the VLLW formula could be disposed of in normal refuse, whereas those that could not would be incinerated. However, this is likely to be impracticable unless all the waste is below VLLW levels. Segregation would need to be done by the individual laboratory scientists in larger organisations and might not be reliable.

The other key issue is the lack of availability of special landfills to take material above VLLW levels. Only a very few users in the UK now have access to this type of disposal route and new authorisations have not been forthcoming. Lack of public acceptance is a key factor in this, and it is slightly strange that there is apparently less concern that the same radioactive wastes are sent to incinerators (after which the same radionuclides in kiln ash are deposited at landfill sites). This could change depending on the outcome of current UK discussions on low level waste strategy, for example if landfill became acceptable for large volume wastes arising out of the nuclear industry and some non-nuclear wastes could be accommodated within any new disposal arrangements

From a narrow radiological standpoint it might be though that incineration is a less desirable method of disposal since there will be a small initial discharge of volatile radionuclides to air. However, because of non-radiological hazards of many wastes only a fraction of the activity in these wastes could practicably be diverted from incineration and this taken with the low public doses for the direct discharges and the current lack of availability of the direct landfill alternative means that incineration will continue to dominate UK disposal practice in this sector. This is an example of how in many cases radiation dose makes very little if any impact on overall decisions on protection options.

References

[1] Kyle S and Bellinger E, Radioactivity partitioning in incinerators for miscellaneous radioactive wastes. Report DOE/RW/88049 (Ref. PECD 7/9/426) (UK Department of the Environment) March 1988

[2] McDonnell C E, Welham D, Knott J A and Miller T. Partitioning of ^{3}H, ^{14}C, ^{32}P, ^{35}S and ^{125}I in a modern waste incinerator. Journal of Radiological Protection Vol. 17 No. 2 (1997) pp 95-104.

[3] Hughes J S (1999) Ionising Radiation Exposure of the UK the Population: 1999 Review. NRPB-R311 ISBN 0 85951 439 0 (HMSO)

[4] IAEA Safety Series 108 (1992) Design and Operation of Radioactive Waste Incineration Facilities ISBN 92-0-103292-7 (IAEA, Vienna)

Considerations for the choice of disposal route for low level radioactive wastes

Factor	Disposal route and issues		
	VLLW	***Landfill with special precautions***	***Incineration***
Availability	Should be commonly available but there are practical difficulties	Very restricted supply: Currently only a few users have access an authorised landfill. Current review of UK policy might make this route more available to UK non-nuclear uses but this is uncertain.	Readily available and existing "radiological capacity" seems adequate for non-nuclear sector needs.
Cost	Lowest cost option	Higher than VLLW (but limited data on current costs as there are so few disposal sites)	Expected to be the highest cost option
Activity levels	Fixed concentration and single item limit	Higher concentrations than VLLW (but expect to exclude many sealed sources)	Would expect to allow higher concentrations and activities than VLLW. Single item limit means that activity must be properly dispersible (this rules out sealed sources)
Chemical hazards	May be acceptable subject to hazardous waste regulations. Not suitable for liquid wastes	May be acceptable subject to hazardous waste regulations. Not suitable for liquid wastes	Process destroys many hazardous chemical substances (although potential problems with heavy metals, etc) Obvious route for radioactive organic liquids
Biological hazards	Low risk materials may be suitable: Others would require pre-treatment (e.g. autoclaving)	Low risk materials may be suitable: Others would require pre-treatment	Clearly capable of eliminating this hazardous property and does not require any pre-treatment
Public doses	Very low (short half-life radionuclides decay in the landfill)	Very low (short half-life radionuclides decay in the landfill)	Low dose from stack and any direct liquid discharges. Very low dose from solid arisings sent to landfill.
Doses to operators	Very low: Concentration and single item limits makes this practice "safe by design"	Low, but some risk of exposure to spilt waste packages prior to emplacement in the landfill	Low, but risk of exposure to spilt waste packages prior to loading into the incinerator
General public acceptability issues	Little public knowledge of the practice. Some disposal operators cautious about accepting radioactive wastes	General concerns about landfills: Considerable concern about radioactive wastes being sent to specific named landfills (strongly influenced by nuclear industry issues)	Little public knowledge of the practice. General concerns about incinerators usually related to possible chemical emissions.