Nuclear techniques and the disposal of non-radioactive solid wastes

Heavy metals and other environmental pollutants in solid wastes often are identified and analyzed using nuclear-based methods

by Sheldon Landsberger and Bruce Buchholz

One of the most vital and persistent public health challenges facing local, state, and national governments is the disposal of solid waste produced from industrial, utility, and municipal sources.

There is a growing interest in the monitoring, control, and safe disposal of the chemical constituents arising from these sources. For instance, it is now well known that the release of byproducts from coal-fired power plants—namely airborne particulates, bottom ash, and fly ash — can have adverse effects on air and water quality. Another major concern is the disposal of municipal solid waste by incineration and direct landfilling, which can result in potentially adverse affects on the environment due to the high concentration of heavy metals in the waste itself. The use of very large quantities of minerals in many industrial processes can also lead to somewhat complicated waste management problems.

It is therefore important that reliable chemical analytical techniques are readily available to assess the impact of widespread disposal practices of organic and inorganic chemicals. The use of nuclear and nuclear-related analytical techniques—such as neutron activation analysis, energy dispersive x-ray fluorescence and particle induced X-ray emission—have become widespread in major areas of science and technology. These methods and techniques have important applications in such work since they can be used for both the determination of specific individual pollutants (e.g. toxic heavy metals) and multi-elemental analyses for source identification and apportionment purposes. Other nuclear techniques, such as isotope tracers, have also had wide acceptance in characterizing diffusion patterns for metals in soil and aqueous environments and water pollution flows. These parameters are important in understanding how mobile or immobile leachates from solid wastes are in the water table and to predict their general transport mechanism in the environment.

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Nuclear and related techniques

Neutron activation analysis (NAA). NAA is a technique capable of determining 40 to 50 elements including many environmentally crucial ones (e.g. antimony, arsenic, cadmium, chromium, copper, mercury, nickel, selenium, vanadium, zinc, etc.). It is also capable of determining major elements such as sodium, chlorine, and potassium, as well as many rare earth elements. The determination of the elemental concentrations is based on the measurement of induced radioactivity following the irradiation of the sample in a nuclear research reactor. The radioactive decay of each element produces a characteristic gamma-ray energy spectrum. Hence an individual nuclear "fingerprint" can be measured and quantified.

Activation analysis measures the total amount of an element in a material without regard to its chemical or physical form. It has the following advantages:

- samples for NAA can be liquids, solids, or powders;
- NAA is non-destructive and since no pre-chemistry is required, reagent-introduced contaminants are completely avoided;
- many elements can be readily analyzed simultaneously;
- it is highly sensitive to trace elements.

These factors have pushed the detection limits of many elements of interest to very low levels, not readily achievable by other analytical techniques. NAA is also totally unaffected by

The municipal waste incineration plant in Vienna, whose facade was designed by Viennese painter, Friedensreich Hundertwasser. (Credit: E. Schauer, Vienna)

the presence of organic material in the sample. This organic material is a significant matrix problem in several types of conventional chemical methods.

Energy-dispersive X-ray fluorescence (ED-XRF) and Particle induced X-Ray emission (PIXE). In both of these techniques the quantization of elemental concentrations is based on the detection of X-rays. In ED-XRF, samples are bombarded with X-rays from either a tube or a radioactive source. In PIXE, protons are the usual charged particle, which are used to bombard the samples and induce X-ray emission. The methods have similar advantages to those in NAA. In general, fewer elements can be detected with either ED-XRF or PIXE than with NAA. However, it is not possible to detect elements such as sulphur and lead with NAA, although it is using the other two techniques.

Isotope tracer technique. This technique is based on the principle that very minute amounts of radioactivity in the form of a soluble radioisotope can be injected into a solid or aqueous environmental system and later be detected after it has been transported by some mechanism. This method has been successfully used in hydrology studies, and its application to environmental problems has become more widespread.

Typically isotopes of bromine, cadmium, chromium, caesium, chlorine, sodium, and zinc are used. Most of these radionuclides have relatively short half-lives when compared to nuclear waste. This makes their use ideal for real-time studies.

Worldwide facilities

At present there are more than 250 research reactors in use for routine environmental monitoring and research using neutron activation analysis. More than 100 PIXE facilities and many more ED-XRF units are also available in numerous universities, governmental laboratories, and private institutions.

There are many scientists with significant analytical expertise to warrant continued use of these nuclear and nuclear-related methods in solid waste research. The following sections present a sampling of a few of the wordwide programmes that utilize these powerful techniques.

Airborne particulate matter

Over the last two decades numerous studies have been initiated to identify and study the fate and transport of heavy metals released into the airborne environment by coal-fired power plants, incineration facilities, various smelting processes, automobile exhausts, indoor industrial processes, etc.

There are a variety of reasons to sample and analyze airborne particulate matter. Sampling may be done to determine if the concentrations of total particulate matter may be high enough to adversely affect public health. Thus sampling may be part of an exposure evaluation in which risk is being assessed, information gathered to permit risk management, or monitoring con-

Element	Fly ash	Soil
Silver	31.4 - 60	0.1
Aluminum	1.07 - 11.1%	7.1 %
Arsenic	75.3 - 229	6.0
Barium	<700 - 1300	500
Bromine	1420 - 5180.00	5
Calcium	8.44 - 28.1%	1.37%
Cadmium	80.4 - 314	0.06
Cerium	4.42 - 51.90	50
Chlorine	3.6 - 20.9%	100
Cobalt	4.78 - 37.3	8
Chromium	94.1 - 865	100
Caesium	2 06 - 3 31	6
Iron	0.26 - 2.12%	3.8%
Mercury	18.5 - 209	0.03
Indium	0.49 - 1.91	—
Lanthanum	2.47 - 27.9	30
Manganese	180 - 1000	850
Sodium	1.52 - 2.83%	0.63%
Rubidium	12.2 - 40.6	100
Antimony	618 - 1665	(2 - 10)
Scandium	0.89 - 8.37	7
Selenium	<2.51 - 10 9	0.2
Silicon	<1.21 - 17.0%	33%
Samarium	<0.43 - 4.6	—
Strontium	<600	300
Tantalum	<0.24 - 3.36	—
Thorium	0.79 - 9.10	5
Titanium	0.25 - 2.46%	5000
Vanadium	<9.93 - 81.1	100
Zinc	8690 - 18 200	50

Notes: All concentrations are in micrograms per gram unless otherwise specified. Data are from a study at the University of Illinois, USA

Summary of the abundance of elements in fly ash and soil from municipal solid waste incineration

ducted to support epidemiological studies. Sampling may also be conducted to determine compliance with air quality laws or regulations. Finally, studies of atmospheric transport, transformation, and deposition processes may require intensive particle characterization. Essentially air samplers are placed in strategic areas in urban, rural, and remote locales and then the air filters are analyzed. Subsequent analysis may involve various mathematical models to elucidate the sources of the elemental air pollution and/or evaluate health effects to the general public or industrial workers.

Analysis of air filters, which usually have a very low mass of airborne particulate matter, has greatly benefitted from all the techniques mentioned here. Some countries involved in such investigations in an IAEA-supported co-ordinated research programme include Argentina, Belgium, Brazil, Chile, China, Canada, Czech Republic, Germany, Greece, Hungary, India, Nigeria, Slovak Republic, Turkey, United States, Viet Nam, and Zaire.

Solid waste

Perhaps the most widely analyzed solid wastes by nuclear methods, particularly NAA, are residues from coal burning; namely coal bottom ash and fly ash.

Worldwide there has been a steady increase in the use of coal to generate electricity for various industrial activities, residential homes and commercial buildings, as well as for heating.

However, this massive usage has led to the disposal of millions of metric tonnes of residual bottom ash and fly ash, which must be properly managed. There have also been many studies undertaken to determine which elements, particularly heavy metals such as lead, arsenic, mercury, cadmium, antimony, etc., can leach from the solid waste and potentially become an environmental hazard to groundwater.

In recent years the disposal of municipal solid waste (MSW) has become another important environmental as well as political issue. Landfills accommodate most MSW but the vexing problems of leachate generation from rainwater permeation and methane gas production (from decomposition) persist. Replacing landfills is becoming increasingly difficult and alternative solutions such as recycling only partially alleviate the problem. Incineration of MSW reduces its volume and mass by as much as 80% to 90%. However, the remaining ash contains high concentrations of many heavy metals such as lead, cadmium, mercury, antimony, zinc, and silver. The potential threat to groundwater posed by these metals is real and long-term studies of the chemical composition, elemental distribution, and leaching characteristics are essential.

Recently, the IAEA has published a detailed technical document with guidelines for leaching studies on coal fly ash and other solid wastes with special reference to the use of nuclear methods.* Several important aspects were covered including physical characterization, distinguishing between different leaching tests, field sampling, and application of radiotracers.

In our laboratory at the University of Illinois we have employed a series of neutron activation analysis techniques to determine 30 trace ele-

* *Guidelines for Leaching Studies on Coal Fly Ash and Other Solid Wastes with Special Reference to the Use of Radioanalytical Techniques*, IAEA TECDOC-616, Vienna (1991).

ments in MSW incineration fly ash.* Size distribution is an important physical characteristic. Results have shown that more than 75% of the fly ash consists of particles with diameters less than 63 microns. *(See graph.)* These smaller particles possess a large total surface area with many possible leaching sites. Our data confirm that most potentially toxic elements are concentrated on the smallest particles. When compared with normal soil values, the fly ashes contain extremely elevated amounts of numerous elements.*(See table.)* Elements such as antimony, arsenic, cadmium, chromium, indium, mercury, silver, and zinc are particularly enriched. These elements may serve as source markers.

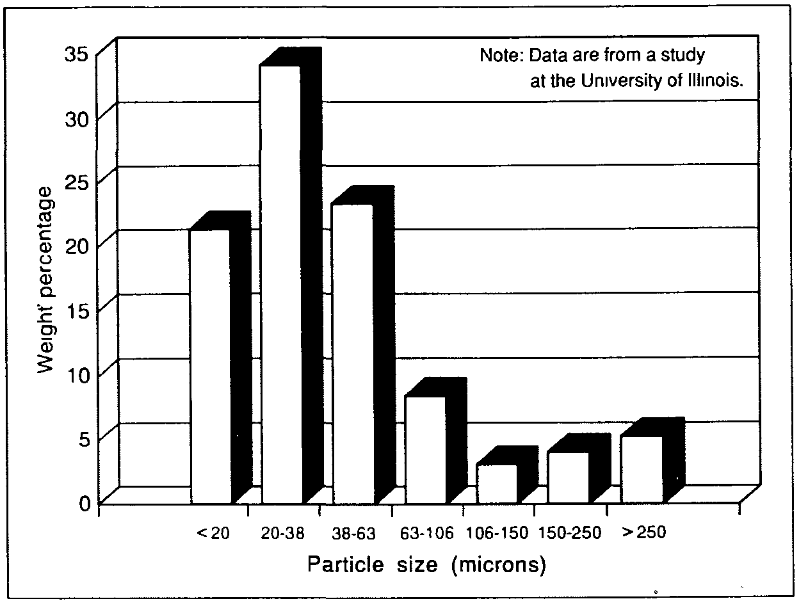
One crucial area which has been neglected by the vast majority of researchers in MSW incineration is the elemental characterization of ordinary household goods. For instance, it is well known that lead-acid and common dry cell batteries contribute significantly to increased levels of lead, mercury, cadmium, copper, and zinc in the incineration ash. Recently, researchers in the Netherlands and Canada, employing NAA, have shown that various plastics from household wastes are a major source of cadmium. It is therefore extremely prudent to identify common household goods which may contain such heavy metals. Identification of heavy metal sources may prompt industries to change their processing procedures and eliminate or drastically reduce the quantity of the heavy metals entering the waste stream.

Another area of great concern is the disposal of industrial solid waste. This differs from municipal solid waste in that there are generally fewer different kinds of heavy metals, but the amounts and concentrations may be orders of magnitude higher. This is particularly true for mineral based industries. Landfills and waterways are the usual recipients of industrial wastes. There are numerous countries using nuclear and nuclear-related methods to chemically identify the waste itself and to study their leaching characteristics.

Isotope techniques, commonly using radioactive tracers, have been successfully employed in many different types of investigations. Some applications were reported recently at the IAEA International Symposium on Applications of Isotopes and Radiation in Conservation of the Environment.** They include studies in the following areas:

- establishment of the pathways of industrial effluent discharges at different tidal stages in Malaysia;
- prediction of pollution transport rates from Hungarian landfills and depositories by radioactive tagging of toxic elements in the soil;
- determination of residence time distributions and flow patterns of waste and sludge in waste water treatment facilities of the Czech Republic and the Slovak Republic;
- investigation of the efficiency of Polish industrial sewage treatment plant devices.

Recent French research employing isotope techniques include risk assessment of iron and steel industry waste, characterization of engineering cover and containment barriers for urban industrial waste sites, and reutilization of wastes in forestry and industry.



Size distribution of trace elements in fly ash from incineration of municipal solid waste

An issue of growing importance

It is unlikely that interest in solid waste disposal will diminish. As developing and developed countries increase their use of fossil fuels, expand their industries, and increase their consumption of goods and services to secure a higher standard of living, solid waste disposal will remain an extremely important issue of waste management.

The methods of nuclear and nuclear-related analytical techniques can be judiciously maximized in the characterization of airborne, industrial, and municipal solid waste and its leachates, and to predict their transport patterns in the environment. ❐

* "Elemental Characterization of Size-Fractionated Municipal Incinerator Ash", S. Landsberger, B. A. Buchholz, M. Plewa and M. Kaminski, *J. Radioanal Nucl. Chem* (in press, 1993).

** See the proceedings of the Symposium, published by the IAEA, STI/PUB/904, Vienna, Austria (1992).