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## **Environmental impacts of burials and cremations**

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### **Preamble**

Alkaline hydrolysis is an environmentally desirable alternative to cremation and burials that eliminates much of the energy, materials and land conservation issues involved in those processes. There is evidence showing that the process waste water improves the functioning of water treatment systems. In the US where alkaline hydrolysis has long been used for livestock processing, the runoff water has been utilised without incident on food crops grown for human consumption.

Aquamation is the name of one method of alkaline hydrolysis specially designed in Australia for use with human remains in the funeral industry. It has the capacity to replace demands for incineration and landfill options. Aquamation also means reduced energy expenditure, reduced air pollution and eliminates the need for coffin destruction. The end result from Aquamation is a nutrient rich, sterile waste water.

Queensland residents were the first in the world to be able to reap the benefits of Aquamation as a cost effective and environmentally favourable funeral option for themselves and their loved ones.

This committee has the potential to facilitate the advantages of this greener, more environmentally sensitive innovation in the disposal of human remains which is totally consonant with the overall aims of proactive environmental protection in Queensland. We welcome this considered evaluation as an opportunity for environmental regulatory bodies, the Queensland funeral industry and other stakeholders to gain clarification on this matter.

### **The environmental and land impacts of conventional burials and cremations**

#### *Specific demands and impacts of burial:*

- Space is at a premium for traditional format burials. Making new cemetery land available for burials in this manner would require depleting prime land resources that may be allocated for farming, housing, recreation etc.
- Zoning burial sites in lower demand areas requires bereaved families travelling further to pay respects to buried relatives. This may be more arduous if public transport is not as accessible in these zones or require additional land for car parking if only accessible by road.
- Traditional burial allows the leaching of toxic fluids from coffins into the underground water table as well as methane gas emissions associated with decaying human remains.

### *Specific demands and impacts of cremation:*

- Up to 400 kilograms of Greenhouse gas emissions are created from each cremation. Given a mortality rate around 145,000 of which 65% are cremated, these result in 40,000 tons of greenhouse gas being released annually in Australia (equivalent to 8,000 cars every year).
- Incineration also releases toxic and carcinogenic gases into our airspace. These come from the embalming process and the burning of the coffins that are painted or varnished and their adornments (plastic and metal). Formaldehyde emissions originate from the chipboard and glues. Amalgam fillings remain and are incinerated, releasing mercury and other substances into the air.
- Furthermore, the highly invasive removal of pacemakers is necessary to proceed safely with incineration. If these items remain there is a risk of explosion or other danger to crematorium workers. Crematoria operate at an extremely high temperature, with the inherent danger for workers involved.

### *Demands and environmental impacts common to both burial and cremation:*

- Coffins are used once and are buried or destroyed. Coffins in Australia are commonly made from chip board, wood, paints and glazes, cushioning /upholstery etc. These materials are either burned in cremation or leached into the soil in burial. (The United States Casket and Funeral association estimates that 70,000 cubic metres of quality hardwood gets buried each year in the United States alone as coffins)
- Both burial and cremation make extensive resource demands that can be avoided through this proposed alternative process.

### **Options to reduce these impacts through changes to the practices and materials used**

Cremation and traditional burial utilising best practice have not sufficiently improved to offer any substantial improvements in funeral technology. Looking at new processes is the only way to improve environmental outcomes in any meaningful way. For detailed information on the Alkaline Hydrolysis method, please consult Attachment A.

- Alkaline Hydrolysis is a process which occurs naturally in the decomposition of a human or animal. Aquamation speeds up the process of natural decomposition to a level where it is a commercially and much more environmentally friendly alternative to incineration.
- Aquamation converts the body into its constituent elements - amino acids, peptides, sugars and salts – in liquid form. As with cremation, the remaining bones are returned to the family as 'ashes'.
- Aquamation only uses 5 – 10% of the energy that incineration uses.
- Aquamation eliminates the toxic emissions from mercury, heavy metals, surgical implants, formaldehyde and medicinal drugs retained by the deceased through the treatment of diseases or cancers before death.
- Aquamation does not take up land and the processed remains forms a sterile, nutrient rich fluid which can be used safely on cemetery lawns and gardens or can be disposed of with a beneficial effect through the waste water system.
- As coffins are not destroyed in the Aquamation process, precious timber resources remain intact and no manufacturing energy or poisonous emissions from formaldehyde rich glues, adhesives, paints and varnishes are released.

## The effect of these changes on funeral costs

Offering more options in funerals will have an impact on cost and provide choices for families. The relative ease and safety of operating these units provides an opportunity for new participants and competitors to join the funeral industry in Queensland.

- The cost of an individual Aquamation process is comparable to incineration. The significant cost saving arises due to the coffin being unnecessary. A ceremony/display coffin can be used during the service, as appropriate for mourners' expectations.
- Costs can be further reduced through the use of solar generated electricity and heated water at the site of the Aquamation unit to further reduce the impact on the environment.
- Previously full/closed cemeteries now have capacity to generate income to cover their maintenance and upkeep. Introducing Aquamation as an option (particularly for council owned and operated centres) allows sites to generate income again, reducing their current drain on consolidated revenue.
- Opening up such existing local infrastructure allows for a reduction in the environmental footprint associated with the transport of friends and families attending faraway cemeteries or remembrance/memorial sites.

### The level of interest in, and demand for, alternative disposition options with reduced environmental, land and cultural impacts

A Fairfax Media Poll (Brisbane Courier Mail, Sydney Morning Herald and Melbourne Age) on October 12<sup>th</sup> 2010 found the following response to a reader poll on preferred funeral options:

<b>Aquamation</b>	<b>68%</b>
<b>Cremation</b>	<b>15%</b>
<b>Burial</b>	<b>17%</b>

Based on this response, 4 out of 5 people would choose Aquamation over cremation as their preferred choice.

When the Mayo Clinic was first introducing the Alkaline Hydrolysis process in 2006, families of people who had donated themselves to the program were contacted and offered this new disposal process. Previous to this, incineration was the contractually agreed option. 148 of the 150 families opted for Alkaline Hydrolysis. Since this time families have been given the option of Alkaline Hydrolysis or incineration with only 1 from over 500 families choosing incineration.

Jeff Edwards, a funeral director Ohio in the United States who, since Jan 27<sup>th</sup> 2011, also provides Aquamation has found 49 of 50 families planning a cremation have elected for Aquamation after learning about the process.

In the absence of specific burial instructions in a religion (ie Islam, Bahai) no barrier exists for observers using Aquamation. Catholic ethicist Sr. Renée Mirkes, Director of the Pope Paul VI Institute (Omaha, Nebraska) has stated '... its clear there's nothing unethical or un-Catholic about alkaline hydrolysis.' Some religions and cultures prefer and revere incorporating water in end of life celebrations.

### Whether the need for cemeteries and crematoria is being adequately addressed by government as part of regional infrastructure planning

Queensland could benefit from a broad review around planning issues related to the funeral industry. Out dated categories do not serve the current realities of operating funeral businesses.

Ensuring new and existing Memorial Gardens offer Aquamation along with cremation and burial services will significantly reduce the amount of space taken up by cemeteries. The introduction of this approach to human disposal provides governments at all 3 levels an opportunity to take constructive decisions in favour of the environment.

## The adequacy of existing controls on environmental emissions from burials and cremations

Controls exercised by the Departments of Health, Community Services or Energy Resources were not apparent to the writer of this submission when searching for controls or monitoring of operating crematoria in Queensland. No official register of current crematoria location or ownership/operation was found. Best efforts of private research suggest there are 37 individual crematoria in QLD with some operators having up to 4 individual cremators within their location, with another 12 locations in the pipeline.

The Department of Environment and Resource Management have elected to no longer require a permit to install a cremator, nor to play a role in assessing the adequacy of crematoria equipment around the State to ensure it is operating at its cleanest emitting level possible.

Comparing this to the trend worldwide, the EU has introduced legislation to install equipment to reduce mercury pollution from cremators by 50% by the year 2012. The state of California (USA) is poised to introduce similar legislation aimed at the installation of emission scrubbing systems to existing and future cremators, and most states are expected to follow.

It would seem appropriate that Queensland and the rest of Australia should also follow these leads sooner rather than later.

### **Regulatory and other impediments to reducing the environmental and land impacts of burials and cremations**

The world's FIRST Aquamator for humans was installed in Qld in July 2010 but is not currently operating due to bureaucratic stumbling blocks in relation to the liquid waste left over from the process. Similar liquid from animals is used on food crops for humans in Illinois USA.

#### Current impediments to the disposal of the liquid, applicable only in Qld, are:

- We are prevented from disposing of the residue on gardens or similar areas; although being originally advised that no permits would be required. We have wasted 21 months dealing with dozens of people who say they do not understand it.
- Allconnex Water have also advised that the effluent cannot be disposed of in the waste water system, despite the evidence from the US experience demonstrating that the sterile material involved enhances the operational process. The impact of this position is a requirement for commercial waste disposal at a cost of \$4 a litre or approximately \$1,600 per usage. This additional cost to grieving families and funeral operators is wholly unnecessary and onerous.
- The Requirements of the Environmental Protection (Waste Management) Regulation 2000 have been interpreted in relation to Aquamation in terms of the disposal of human body parts/organs. However, in this instance we are dealing with liquefied whole bodies which do not fall under the classification as either 'clinical' or 'regulated' waste.
- Since the sterile liquid is not a regulated waste it should not be subject to the same permit requirements as for waste that causes environmental harm.
- Alkaline Hydrolysis is not a simple dissolving of the body. The process creates an end-product that has a totally reconfigured chemical constitution and is totally sterile. (This process was developed specifically for the disposal of pathogens and prions involved with 'Mad Cow' disease). It makes little sense to treat this product in the same way as we treat unsterilized body parts and organs or other infectious material.
- Aquamation should not be subject to the same permit requirements as those applied to cremators or cemeteries as harmful emissions or a hazardous waste are not produced. There are no noxious odours and no requirements for a flue to treat toxic or noxious gases.
- Mortuaries currently remove and dispose of internal organs and blood which carries the potential for infection. This exposure to risk is eliminated with Aquamation.

### Our recommendations to this committee are:

- Permit installation and operation of Aquamation units in commercial zones as there are no emissions, noise or odour concerns.
- Clarify in regulation the acceptable use of waste water from Aquamation, enabling use on cemetery garden beds and lawns (recycling).
- Where Aquamation liquid is not being recycled on site, allow disposal through the existing waste water system. This nutrient rich water is a beneficial additive that will optimise the operating environment of the waste water service and reduce odours.
- Amend Planning laws to allow Aquamators in Mortuaries

### Requirements on funeral directors to provide information to clients on burial and cremation options with reduced environmental and land impacts, and the form that this information should take

As public perception is already aligned to a Five Star indicator of energy use, perhaps a similar system may be considered for funeral system alternatives. Options may be explored also to indicate a 'score' for emissions or pollutants created by each method. Whichever method is adopted, the information should be clear and easily accessible to consumers. Savvy consumers are already demanding more eco-friendly funeral options, and with reviewed regulatory support this technology can confidently be offered as a real alternative to current methods. This innovative technology provides a unique opportunity for the funeral industry to review itself and take a significant environmental lead.

Existing businesses may be encouraged by incentives and measures to provide pathways to change. These may include regulatory guidelines, financial and depreciation assistance, or a mixture of the three.

Aquamation and its benefits should form part of the overall objectives within Environmental and Strategic Plans at all levels of government. Local councils have an opportunity to reinvigorate their existing cemetery infrastructure and install and offer Aquamation services to the funeral service providers in their area.

### Other FUNERAL Industry Planning issues

The present categories are time wasting and expensive due to having been based on out dated models.

1 **FUNERAL BUSINESS:** any premises used for the administration/office use only of a funeral parlour. (It is not permissible to conduct the storage of hearses, the sale and/or display of coffins or flowers)

2 **FUNERAL PARLOUR:** any premises used, or intended to be used, by an undertaker for the storage or preparation of bodies for burial or cremation. (The term includes a mortuary and funeral chapel used for this purpose. Funeral Business)

These existing categories should be reviewed and streamlined.

### Some possible suggestions:

The zoning of funeral industry premises should be divided into 8 categories. (It does not make sense that a shop with a coffin on display should be in the same category as a mortuary.) Some possible definitions to remove some of the planning and operating costs associated with the application for a permit.

'Chapel'– as associated with a funeral home

'Office' treated simply as any office, as it is no different to any other office

'Shop front sales', as any shop allowing for the sale of funerals and the display of coffins, flowers etc without the requirements of a mortuary provided no bodies permitted.

'Hearse storage', should be allowed in garage at any premises

### Suggested Funeral Home categories

- Funeral Home A or Ac (with or without Chapel) body placement, **non-mortuary use** ie: bringing a body from place of death, stored in a refrigerator, then placed in coffin prior to funeral service
- Funeral Home B or Bc      A + Mortuary (embalming, remove blood, organs etc).  
Aquamation
- Funeral Home C or Cc      A + B + Cremation and or Aquamation
- Memorial Park              A + B + C + Cremation and or Aquamation
- Cemetery                      A + B + C + Burial of bodies, Mausoleum, Cremation  
and or Aquamation

Respectfully yours

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## Fire Cremation/ Incineration

Pollution 200-400 kgs greenhouse gas

Burning produces heat and air pollution

16% of all airborne toxic mercury pollution in the UK comes from cremators

- hydrogen fluoride (HF),
- nitrogen oxides,
- sulfur dioxide,
- carbon monoxide,
- particulate matter,
- hydrogen chloride (HCl), and
- heavy metals,

Huge energy use of PROPANE gas

Pacemakers Need to be removed or they will explode in cremator

HIP IMPLANTS are melted & add to pollution

Jewellery destroyed

If embalmed. Then carcinogenic formaldehyde adds to pollution with toxic carcinogenic fumes

Bodies often have other things in them such as cytotoxic drugs from cancer treatment, or embalming agents (all carcinogens in themselves)

According to Marika Gandhi, MP, wife of the late Sanjay Gandhi is campaigning to stop Cremation in India

in a population where cremation is practised one in 200,000 people will get cancer every year.

So the replacement of cremators would save 110 lives in Australia every year

Resources Coffins Every year in the US 70,000 cubic metres of timber is used in coffins

## Alkaline Hydrolysis / aquamation

NO Pollution emissions

Only 5-10% of energy used

No need to remove Pacemaker

Hip implants intact & can be reused

Jewellery intact and returned to family

Formaldehyde broken down to constituent chemicals and no longer dangerous

Alkaline hydrolysis destroys all DNA, RNA, all of the U-listed

Cytotoxic agents used in cancer treatment, all biological toxins, all chemical warfare agents (nitrogen mustard, etc.), glutaraldehyde, formaldehyde, and phenol, the elements used in embalming.

No coffin is destroyed so no timber is wasted

## Attachment A

**“The Alkaline Hydrolysis Process”** Authors: Gordon I Kaye PhD, Peter B. Weber PhD, William M Wetzel. *ANL magazine*, September/October (2004)

Alkaline hydrolysis is a simple, natural process by which complex molecules are broken down into their constituent building blocks by the insertion of ions of water ( $H_2O$ ),  $H^+$ , and  $OH^-$  between the atoms of the bonds that held those building blocks together. The process occurs in nature when animal tissues and carcasses are buried in soil of neutral or alkaline pH. In this case, alkaline hydrolysis is aided by the digestive processes of soil organisms. Alkaline hydrolysis also occurs in our small intestines after we eat; the complex molecules of proteins, fats, and nucleic acids are hydrolyzed with the aid of digestive enzymes that function most efficiently at a slightly alkaline pH (~pH8.0 to 8.5). Historically, alkaline hydrolysis has been used to study the chemical structure of biological molecules, to prepare skeletal remains for study, and make soaps from animal fats by cooking the fat with lye to release the fatty acids, then cooling the mixture to precipitate the fatty acids as their sodium salts.

Alkaline hydrolysis as an improved alternative to incineration for disposing of waste biologic tissues and animal carcasses is based on the same chemical reaction, with strong alkali and heat used to speed the process.

### **Chemistry of the Process**

Hydrolysis can be catalyzed by enzymes, metal salts, acids, or bases. Bases are typically water solutions of alkali metal hydroxides such as sodium hydroxide (NaOH) or potassium hydroxide (KOH). Heating the reactants dramatically accelerates hydrolysis. Just as proteins, nucleic acids, polymeric carbohydrates, and lipids were made by organisms via the condensation of building blocks, so can they be depolymerized, or unmade, by hydrolysis.

To form peptides and proteins, amino acids are linked to each other in a peptide (amide) bond in which the carboxyl group of one amino acid is condensed to the amino group of another amino acid with the elimination of water. All polypeptides consist primarily of the elements carbon, hydrogen, nitrogen, and oxygen, along with smaller amounts of other elements, mainly sulfur and phosphorous. Hydrolysis reverses the condensation of amino acids into proteins by the acid- or alkali-catalyzed breaking of the peptide bonds and the addition of water at the break. Alkali, in the form of either sodium or potassium hydroxide solution, or a mixture of both, is used at temperatures ranging from ~100fC to 180fC and higher for rapid dissolution and then hydrolysis of the proteins into small peptides and amino acids in the form of their sodium or potassium salts. Potassium hydroxide or mixtures of potassium hydroxide and sodium hydroxide are the preferred alkali solutions because of the instability of concentrated (50%) stock solutions of NaOH solutions at temperatures below 20fC. All proteins, regardless of their origin, are destroyed by alkaline hydrolysis. An example of the chemical composition of animals is shown in Table 1.

### **Effects of Alkaline Hydrolysis On:**

#### ***Proteins***

Alkaline hydrolysis leads to the random breaking of nearly 40% of all peptide bonds in proteins, the major solid constituent of animal cells and tissues. The vast majority of the

products of the hydrolysis are single amino acids or small peptides in the 2-5 residue range (nearly 98% of the hydrolyzate). Analysis of the hydrolyzate of sheep carcasses digested at a rendering plant in the United Kingdom and subjected to matrix-assisted laser desorption/ionisation-time of flight mass spectrometry (MALDI-TOF MS) analysis showed that the largest peptides found had a molecular weight between 800 and 1,100 Daltons (Da), i.e., were in the range of 7-9 amino acid residues. MALDI-TOF MS is a relatively novel technique in which a co-precipitate of a UV-light absorbing matrix and a biomolecule is irradiated by a nanosecond laser pulse. Most of the laser energy is absorbed by the matrix, which prevents unwanted fragmentation of the biomolecule. The ionized biomolecules are accelerated in an electric field and enter the flight tube. During the flight in this tube, different molecules are separated according to their mass to charge ratio and reach the detector at different times. In this way each molecule yields a distinct signal. The method is used for detection and characterization of biomolecules, such as proteins, peptides, oligosaccharides, and oligonucleotides, with molecular masses between 400 and 350,000 Da. It is a very sensitive method, which allows the detection of low (10<sup>-15</sup> to 10<sup>-18</sup> mole) quantities of sample with an accuracy of 0.1 - 0.01 %. Alkaline hydrolysis generates sodium and/or potassium salts of free amino acids; oligopeptides (small chains of amino acids) are generated as intermediates in the reaction. Some amino acids, such as arginine, asparagine, glutamine, and serine, are destroyed, while others are racemized; i.e., the molecules are structurally modified from a left-handed configuration to a mixture of left-handed and right-handed molecules. In addition, the carbohydrate (sugar) side chains are released from glycoproteins. Under the extreme conditions of temperature and alkali concentration used in the alkaline hydrolysis process, the protein coats of viruses are destroyed and the peptide bonds of prions are broken.

### ***Lipids***

Simple fats consist of three fatty acid chains bound through ester bonds to a molecule of glycerol. During alkaline hydrolysis, all of these ester bonds, as well as the sterol esters and phospholipids of cell secretions and cell membranes, hydrolyze with the consumption of the alkali, producing the sodium and potassium salts of fatty acids, namely soaps. Again, KOH is the preferred alkali because potassium soaps remain liquid as the hydrolyzate cools toward room temperature. Amide groups in glycolipids, another cell membrane constituent, are also hydrolyzed, with consumption of the alkali. Polyunsaturated fatty acids and carotenoids (pigments) undergo molecular rearrangements and are thus destroyed.

### ***Carbohydrates***

As a group of polymers, carbohydrates are the constituents of cells and tissues most slowly affected by alkaline hydrolysis. Both glycogen, the most common large polymer of glucose in animals, and starch, the most common large polymer of glucose in plants, are immediately solubilized. However, the breakdown of these polymers requires much longer treatment than is required for large intracellular and extracellular polymers. Some large carbohydrate molecules, the  $\beta$ (1-4)-linked glycans, such as cellulose, are quite resistant to alkaline hydrolysis, as they are to digestion in the human intestine. On the other hand, cellulosic materials usually occur only in the digestive tracts of grazing animals where, as a rule, they have been macerated and partially digested. Consequently, further degradation, even if slow, usually does not pose a problem. Alkaline hydrolysis also removes critical groups from the molecules of glycoproteins, glycosaminoglycans, and glycolipids, the principal carbohydrates of connective tissue, as well as from the chitinous exoskeletons of insects and other invertebrates (e.g., the carapaces of crabs and lobsters); (1-3)-linked glycans, such as chondroitin sulfates, are slowly degraded. All monosaccharides (simple sugars), such as glucose, galactose, and mannose, are rapidly destroyed by the hot aqueous alkaline solution.

### ***Nucleic Acids***

Nucleic acids are large, unbranched, linear polymers held together by phosphodiester bonds, which are similar to the simpler ester bonds of fats but include a phosphate group as part of the bond structure. These ester bonds are also hydrolyzed with consumption of the alkali, rapidly destroying ribonucleic acid (RNA) and more slowly destroying deoxyribonucleic acid (DNA).

### **Indigestible Materials**

Cellulose-based items such as paper, string, undigested plant fibers, and wood shavings (bedding) are among other items that may be associated with animal carcasses. They are not digestible by alkaline hydrolysis but do not interfere with the process. The same is true of rubber, most plastics, ceramics, and stainless-steel items such as catheters, needles, clips, and staples. Silk and collagen sutures, which are proteinaceous, are rapidly digested. The indigestible materials are completely sterilized by the alkaline hydrolysis process. After appropriate treatment of any sharps, these items can be disposed of as ordinary waste at a sanitary landfill. After alkaline hydrolysis, the undigested residue of animal tissues, specifically the inorganic (calcium phosphate) component of bones and teeth, constitutes approximately 3% of the original weight of the tissue (less than 2% of the volume) and remains in the basket as bone shadows. It is completely sterile and is easily crushed to a powder (Figure 1) that can be used as a soil additive.

### **Applications of the Alkaline Hydrolysis Process**

In addition to its utility for the disposal of routinely generated animal tissues and carcasses, alkaline hydrolysis is particularly useful for the disposal of many difficult-to-handle biologic and biohazardous wastes.

#### ***Low-Level Radioactive Biological Waste***

LLRBW poses a particular problem because of the difficulties and costs inherent in its packaging and disposal at an LLRW burial site. Indeed, the disposal of solid LLRBW has become even more difficult and expensive since 1992. There are still only two LLRW burial sites in the United States. One, in Hanford, WA, accepts LLRW only from the Northwest and Rocky Mountain states; the other, in Barnwell, SC, accepts only limited amounts of LLRW from states other than South Carolina, Vermont, and Connecticut (the Atlantic Compact). The cost of shipping and burying each 55-gallon drum containing radioactive carcasses has increased steadily, as have the surcharges and guarantee fees charged by the sites. The cost of disposing of a single kilo of radioactive animal carcass at Barnwell currently is more than \$250. The cost is scheduled to increase rapidly with surcharges until Barnwell closes its doors to out-of-compact waste in 2008.

In contrast, alkaline hydrolysis not only converts animal tissues and carcasses from solid LLRBW to an aqueous solution that is suitable for release to a sanitary sewer under 10CFR20 and derivative state regulations, but does so at a cost of \$0.07-\$0.13 per kilogram.

#### ***Aldehyde-Containing Fixatives and Embalming Fluids***

The most common fixative used in preparing tissues for histology and histopathology is 10% formalin (4% formaldehyde); that most often used in preparing tissues for electron microscopy is 2% glutaraldehyde. Glutaraldehyde is also widely used in medicine and biomedical research as a disinfectant for instruments and surfaces. The U.S. Environmental Protection Agency classifies both formalin and glutaraldehyde as characteristic hazardous

wastes. It is well known that aldehyde groups react with amino groups to form Schiff bases, thus involving the reactive group of the aldehyde in a stable chemical bond and rendering it harmless. This reaction has been the basis for several commercially available solutions for the disposal of waste aldehyde.

Alkaline hydrolysis of animal tissues produces a hydrolyzate solution that contains 5% to 6% amino acids and small peptides. Waste formaldehyde or glutaraldehyde may be added to tissue digestors at the beginning of the process or, preferably, through an accessory port after the digestion cycle has been completed and the hydrolyzate has cooled to below boiling temperature. After addition of the aldehyde, the solution may be heated again and circulated for 15 to 90 minutes (depending on the temperature at which the reaction is run) to allow the aldehyde and amino groups to react. The hydrolyzate produced from the digestion of 100lbs of animal tissue will provide sufficient amino groups to dispose of up to 10 gallons of waste formalin.

Conventional embalming fluids usually contain phenol, another characteristic hazardous waste, in addition to aldehydes. In a hot alkaline solution, formaldehyde and phenol react to form a plastic, Bakelite, which is completely insoluble, thus rendering both hazardous wastes harmless and leaving Bakelite crystals of molecular dimensions suspended in the hydrolyzate.

### ***Infectious Waste***

Alkaline hydrolysis at elevated temperature destroys all pathogens listed as index organisms by the State and Territorial Association on Alternative Treatment Technologies (see STAATT I [April 1994] and STAATT II [December 1998] reports). These reports call for a system to be able to prove efficacy in the destruction of infectious agents by producing a 6 log 10 reduction in vegetative infectious agents and a 4 log 10 reduction in spore-forming agents. While each state has its own regulations for approving alternative treatment technologies for regulated medical waste, most of them are derived from or equivalent to the STAATT recommendations.

### ***Prions***

Results from different laboratories have indicated that combined treatment with heat and alkali destroys the infectivity of brain macerates or homogenates containing prions (proteinaceous infectious particles), the agents that cause transmissible spongiform encephalopathies (TSE) such as mad cow disease (BSE), chronic wasting disease (CWD), and Creutzfeldt-Jakob Disease. Indeed, the World Health Organization (WHO) recommends combinations of alkali and heat treatment as the only method known to be completely effective for destroying TSE agent infectivity.

The U.S. Department of Agriculture and the Environmental Protection Agency have both recommended alkaline hydrolysis as one of only two acceptable treatment and disposal methods for animal tissues and carcasses infected with or suspected of containing prions (the other being incineration at >900°C). Alkaline hydrolysis tissue digestors are currently being used in both major chronic wasting disease elimination programs of the USDA. Moreover, large-scale treatment and disposal units are currently being developed for disposal of the specified risk material (SRM) that the USDA has defined (revised regulations 9CFR301-9) in response to the first confirmed case of BSE in the US.

### ***Biological Warfare and Bioterrorism Agents***

As recently as the mid-1990s, infectious agents and toxins having potential use as biological-

warfare agents could be purchased from suppliers of bacterial cultures, stocks, and biochemicals. Consequently, the U.S. Congress passed legislation making it a Federal crime, in some instances punishable by death, to possess or transport certain agents without a proper license. In addition, the Department of Health and Human Services was directed to prepare a list of agents that would be subject to these regulations. In a Final Rule published in the Federal Register of 24 October 1996 (Vol. 61; #207), these agents were listed and classified as shown in Table 2. The recent anthrax scare and increased concern about bioterrorism since the events of 9/11 have led to increased awareness of the dangers of these agents, to additions to the list of select agents, and to significant new funding for Biosafety Level 3 and 4 laboratories to study these agents.. Those who are authorized to use such agents for legitimate research purposes must now demonstrate, before purchase or transfer of the agents, that they can be destroyed on site.

All of the infectious organisms and agents listed in Table 2 can be digested by alkaline hydrolysis. Protein toxins can be hydrolyzed in the same manner as any other protein. All of the nonprotein toxins, which are sensitive to alkali even at room temperature, would be destroyed when heated to 120fC to 150fC in 1N - 2N NaOH or KOH. Chemical warfare agents based on nitrogen mustard, as well as most nerve and tear gases, are also destroyed by a hot alkali solution.

### ***Recombinant Organisms and Molecules***

Recombinant organisms and molecules that produce or encode for a factor associated with a disease would be destroyed in the same manner as are natural organisms. The same is true of nucleic acid sequences coding for any of the toxins listed in Table 4 and of their toxic subunits.

Applications in Biosafety Level 3 and 4 Laboratories

Digestion of contaminated animal tissues and carcasses, destruction of infectious agent stocks, and sterilization of animal bedding can all be accomplished by alkaline hydrolysis in tissue digestors sized to fit into both single BSL3-4 Laboratories and central waste processing areas within the barrier in large BSL 3-4 facilities. Tissue digestors can be incorporated into the barriers so that contaminated waste can be loaded on the dirty (hot) side and the sterile residue, both hydrolyzate and bone fragments, emptied on the clean side. In addition, because alkaline hydrolysis systems are agitated only by pumping the alkaline solution during the process, all of the ancillary valving, pumping, and control functions in these units can be located outside the barrier, with only pipes and conduits passing through seals in the barrier.

### ***Chemotherapeutic Agents***

The U.S. Environmental Protection Agency has classified eight commonly used chemotherapeutic (antineoplastic) drugs (Table 3) as U-Listed Hazardous Wastes (40CFR262.22I). Although the U.S. Environmental Protection Agency has not necessarily added to this list any of the new agents that have since been developed, all cytotoxic agents should be treated as hazardous. The alkaline hydrolysis process destroys all of these listed agents, converting them to nontoxic compounds that are completely biodegradable.

### **Resource Recycling versus Waste Disposal**

One truly noteworthy point is that while the animal tissues and carcasses may be called wastes, the sterile hydrolyzate produced from them by alkaline hydrolysis is no longer a waste but a resource. This undiluted hydrolyzate, a 5%-7% solution of amino acids, small peptides, sugars, soaps, and electrolytes, is a valuable and versatile nutrient source that can be

used as fertilizer, either liquid or dried and solid, as an additive to composting systems, or as a feedstock for anaerobic digestion biogas generation plants that produce methane, steam, heat, and electric power. Biodiesel applications for the hydrolyzate are also being actively explored.

The State of Illinois has already issued permits for spraying the undiluted hydrolyzate as a fertilizer on growing corn and soybean crops. Indeed, the Illinois Department of Agriculture is now using this hydrolyzate as fertilizer at two of its own facilities where it operates tissue digestors. In Europe, where there are shortages of both sewage treatment capacity and of energy resources, it is most likely that the hydrolyzate will be used for biogas generation. As alkaline hydrolysis becomes the method of choice for destroying the specified risk material (SRM) generated by application of the new USDA regulations for slaughtering cattle, it is likely that large conversion plants for the manufacture of one or more of these secondary products from the hydrolyzate or for the recovery of the energy stored in that solution will become a significant part of the rendering industry.

### **Conclusion**

We have attempted in this article to illustrate the versatility of alkaline hydrolysis as a process for treatment and disposal of a variety of biologic, biohazardous, and hazardous wastes in a manner that is nonpolluting, more efficient and economical than incineration, and capable of producing secondary beneficial resources. We are certain that as we learn even more about this process, its applications will continue to increase in medical and veterinary research, clinical practice, and education, as well as in other industries that produce significant amounts of biologic waste, and that it will become the standard method for treating such wastes rather than being considered an alternative method to combustion or incineration.