醫療廢物處理技術
方案檢討報告書

Review Of Alternative Technologies For The Treatment Of Clinical Waste

香港特別行政區政府
環境保護署
廢物政策及技術支援組
Waste Policy & Services Group
Environmental Protection Department
The Hong Kong Special Administrative Region Government

二零零零年十二月
December 2000

EPD/TR5/00

目　　錄

附錄 (祇提供英文版本)

摘要

1

1.1 醫院及診所產生醫療廢物的潛在危險，包括病原體及利器(針頭、手術刀、玻璃等尖銳物品)。為減輕對廢物處理者及市民造成的危險，醫療廢物在棄置之前，必須予以適當的分類、收集及處理。雖然本港醫院及診所已致力透過廢物分類方法，減少醫療廢物的產生，但仍有少量醫療廢物需加特別處理和棄置。現時把醫療廢物運往堆填區棄置的做法並不理想，因此有需要制訂完善的管制計劃，及以符合環保標準的方式處置醫療廢物。

1.2 政府在詳細研究各種醫療廢物處理方案，並參考外國採用的方法後，提出使用化學廢物處理中心安裝的高溫焚化設施處理香港的醫療廢物。為正視區內居民的關注，政府亦已進行環境影響評估(下稱"環評")。環評結果確定在化學廢物處理中心安裝的高溫焚化爐，因具備完善的消減污染系統，故能完全燒毀醫療廢物的生物危害性，並符合嚴格的空氣排放標準。有關環評結果已諮詢環境諮詢委員會的意見，並取得其支持。

1.3 政府亦就使用化學廢物處理中心焚化醫療廢物的建議諮詢葵青區議會。鑑於葵青區議會的關注、綠色和平提出的反對，及立法會環境事務委員會及衞生事務委員會提出的要求，政府已聘請專家進行檢討，以重新研究各種處理醫療廢物的技術。

1.4 自環保署於一九九三至九四年度進行的醫療廢物管理方案檢討後，另類處理技術(主要為高壓蒸氣滅菌法[蒸壓法]、微波處理及化學消毒方法)越來越普及，尤其在美國一些州內。然而，焚化處理仍是經證實可行的主流技術，廣為歐洲、澳洲，以及日本、新加坡、馬來西亞及台灣等亞洲地區所採用。

1.5 與某些人士所稱的言論相反，這些另類技術仍會產生氣體及液體排放物，並同樣需要採取妥善的消減污染措施。沒有控制地排放揮發性有機化合物(VOC)的問題尤為嚴重，如在醫院安裝這些設備，會有很嚴重的局限。此外，為提高這些系統的處理效能而使用的切碎機或碾碎機，亦可能會引致職業健康問題；這是由於切碎機容易被硬物損壞及阻塞，當工人在維修期間打開機器時，可能會接觸傳染性廢物或有害的微生物煙霧體(microbial aerosol)。另類技術與焚化技術有所不同，有關確定及量化這些技術對環境及健康可能構成的風險的研究及文獻根據不多，因此另類醫療廢物處理技術並沒有引起跟焚化技術同等程度的公眾關注。

1.6　　由於這些另類技術不能處理含有藥物、細胞毒素廢物(可致癌、引致細胞突變或引致畸胎等)及化學品(如葯綿及敷料內的藥膏)等醫療廢物，故應用這些技術時須採用更嚴格的醫療廢物分)類措施。此外，鑑於以蒸壓、微波或化學方法處理人體有違傳統觀念，故這類廢物亦需經分類處理，然後才可以棄置。

1.7　　進行廢物分類可減少需要特別處理的醫療廢物的數量，及避免葯物及其他化學品混入醫療廢物內。但因為在醫療機構內進行的很多不同的活動，都會產生醫療廢物，所以很難確保醫療廢物不會混入了其他化學物。再者，每次使用另類技術處理醫療廢物前，打開醫療廢物的包裝來檢驗其中有否混有其他化學品的做法亦是不可行的。因此，以蒸壓法或微波處理醫療廢物是很可能產生有毒的排放物。在這方面，焚化方式肯定較另類處理方法較為優勝，因為混在醫療廢物內的化學物會在高溫焚化時被徹底銷毀，而醫院無須作過度嚴格的廢物分類。

1.8　　本報告對其他熱能處理技術(如熱解及氣化)亦有研究。這些技術跟焚化相似，均是利用廢物的能量達致熱能銷毀的效果，亦同樣需要補燃器，以完全銷毀未被熱解或氣化的剩餘部分。根據極少數較大型廠房的經驗，採用熱解及氣化技術需要對廢物的成分作小心控制以減少二噁英的產生。

1.9　　我們亦留意到許多歐洲國家現正依據歐洲委員會有關堆填區的新訂指令，限制含有機物質的廢物棄置於堆填區內。焚化技術作為經證實可行的技術，在減少廢物體積方面所起的作用將越來越重要。因此，醫療廢物經這些另類技術處理後，可能仍須送往能源回收處理廠，與都市固體廢物一併焚化。

1.10　　根據上述檢討，採用新興的另類處理技術確有一些優點，但除了其他限制及一些未知的風險以外，這些技術亦不能提供一個萬全之策，以處理所有種類的醫療廢物。因此，我們建議利用焚化技術作為處理醫療廢物的方法，並應盡早改裝化學廢物處理中心，以提供更環保的醫療廢物處置方法。

引言及背景

2

2.1 醫療廢物是在醫院、診所、病理及醫療研究所等醫療機構產生。目前，本港產生的醫療廢物大部分棄置於堆填區，而小部分人體組織，則運往醫院管理局轄下兩個焚化爐或食物環境衞生署所營辦的火葬場焚化。把醫療廢物運往堆填區傾倒的做法並不理想。

2.2 為妥善處理本港的醫療廢物，政府建議改裝化學廢物處理中心，以便能同時焚化各類醫療廢物。

2.3 政府在一九九七年五月三十日及十月二十四日，把有關建議提交當時的立法局及臨時立法會轄下環境事務委員會及衞生事務委員會，但建議仍須視乎就化學廢物處理中心處置醫療廢物而進行的環境影響評估(環評)結果和諮詢公眾的意見後才作決定。與此同時，環保署在一九九七年初就這項建議諮詢葵青區議會的意見。

2.4 上述兩個事務委員會的委員及葵青區議會的議員，均關注實施這項建議會否對附近地方造成不良環境影響。

2.5 上述環評在一九九九年三月完成，評估結果證實化學廢物處理中心能以環保方式處理化學廢物及醫療廢物。政府其後於一九九九年五月三日諮詢環境諮詢委員會的意見。環境諮詢委員會贊同環評研究的結果及建議，惟須加入一些次要的規定。政府答允在實施建議的工程項目時，遵照環境諮詢委員會提出的所有規定。

2.6 本署亦已於一九九九年五月十三日，就環評研究的結果諮詢葵青區議會的意見。葵青區議會仍然反對使用化學廢物處理中心處理醫療廢物的建議。

2.7 政府其後分別於一九九九年十二月十四日及二〇〇〇年一月七日，就化學廢物處理中心焚化醫療廢物的建議及環評研究結果，向立法會環境事務委員會及衞生事務委員會諮詢意見。此外，政府亦邀請一名國際專家，於二〇〇〇年五月五日向上述委員會的委員簡介本港二噁英的排放情況。鑑於綠色和平及葵青區議會在事務委員會會議上，曾就使用化學廢物處理中心處置醫療廢物一事表示關注，事務委員會委員乃要求政府就本港醫療廢物的處置安排作出決定前，再行研究另類醫療廢物處理技術。主席並請政府提供更多資料，尤其採用這些技術後污染物的排放及對環境造成的影響等資料，以

供兩個事務委員會再作研究。

2.8 為回應事務委員會委員及市民的關注，環保署於二〇〇〇年年中聘請一名醫療廢物管理方面的獨立國際專家，覆檢現行的醫療廢物處理技術及國際間處理醫療廢物的方法，以及找出在本港使用這些技術的限制。此外，環保署的專業人員亦在海外技術考察期間或透過其他通訊途徑，分別蒐集有關各種醫療廢物處理技術的資料。本報告撮載政府及醫院管理局過往進行的醫療廢物處理技術檢討、專家的檢討結果、和環保署所蒐集的相關資料，並就本港處置醫療廢物的安排提出建議。

過往就醫療廢物處理技術進行的檢討

3

政府進行的檢討

3.1 在制定醫療廢物管制策略的初期，政府曾檢討世界各地管理醫療廢物所採用的方法(ERM HONG KONG [1994年]。*中央焚化設施：醫療廢物管理國際及地區評估比較。*最終報告。)

3.2 這報告於一九九四年完成，指出本港產生的醫療廢物與許多其他地方及國家十分相似，其類別繁多，包括：人體組織及截除的器官；染有血迹及其他身體分泌物的敷料；利器；傳染物；微生物培養物；染有藥物、化學品、細胞毒性廢物及消毒劑的容器；受病菌感染或受污染的動物屍體，及進行醫療研究過程中曾暴於感染病原菌之動物承載床等。報告指出，許多國家及地方均選擇以焚化方式處置這些種類繁多的醫療廢物(例如德國、法國、意大利、西班牙、新加坡、台灣、日本、加拿大、英國及美國)。發展中國家如菲律賓、印尼及泰國等，則選擇把醫療廢物與都市廢物一併棄置於堆填區。報告並指出，美國及德國正在開發一些另類醫療廢物處理技術。各國家及地方採用的醫療廢物處理方法，撮載於附錄A。

醫院管理局(醫管局)進行的檢討

3.3 一九九八年中，醫管局安排四名主要人員前往紐約，參加由「美亞環境保護交流計劃」(USAEP EEP)及美國環境訓練學院(USETI)所舉辦，為期五天的醫療廢物處理技術工作坊。參加這項活動的目的，是要汲取美國開發及使用另類醫療廢物處理技術的第一手知識。

3.4 其後，鑑於在醫院內自行處理廢物可能有助減低收集及處置醫療廢物的整體開支，醫管局聘請了一名負責舉辦USAEP EPP工作坊的美國顧問，研究使用蒸壓器處理醫管局轄下機構所產生醫療廢物的可行性。(INSCITE [1999年]。*另類處理技術：醫療廢物蒸壓法。為香港醫院管理局進行的研究報告。*)顧問擬備的報告指出，使用蒸壓器會有下列限制：

(a) 蒸壓器不能處理可辨別的人體解剖廢棄物，即使該類廢物已用切碎機切碎；

(b) 蒸壓器不能處理化療廢物或其他毒性化學廢物及放射性廢物；

(c) 蒸壓器祇可處理有限的液態醫療廢物；

(d) 蒸壓器可產生令人厭惡的臭味；

(e) 蒸壓器可能排放揮發性有機化合物(VOCs)；

(f) 採用蒸壓器可能需要醫院改變醫療廢物分類的方法；及

(g) 蒸壓器一般不設回熱功能。

3.5 報告指出，雖然蒸壓法是經證實有效，可用來消毒醫療儀器，或作實驗室培養菌於棄置前作前處理之用，然而，這技術並非適用於全部種類的醫療廢物，故不算萬全之策。

3.6 報告亦把其他方法(如微波、化學及熱解處理)的優點與缺點，跟焚化方法的作簡略比較。比較結果撮載於附錄 B。

3.7 報告並引述一項較早前為確定另類技術產生的排放物的性質及數量而進行的研究(Jones & Konheim,1994)(附錄 L)。該項研究的結論如下：

(a) 蒸壓器排放多種致癌化合物(如甲醛及苯)，但焚化爐則不會排放該類致癌化合物；

(b) 如果焚化爐及蒸壓器排出污染物擴散特徵相同，則因直接吸入排放物而致癌的風險差不多；

(c) 一般蒸壓器從沒有煙囪的建築物所排出的排放物，引致的直接吸入風險顯著地超出大小相同的焚化爐所引致的風險。在若干情況下，致癌風險可高於 10^{-5}；及

(d) 所有熱能處理設施(如蒸壓器及微波裝置)應與焚化爐接受相同的規管，以確保造成較低風險。

3.8 該顧問亦研究醫管局轄下醫院所採用的醫療廢物管理方法。該項研究指出醫管局轄下醫院所產生的醫療廢物量比很多國家為少。醫管局轄下醫院每張病床每天平均產生 0.12 Kg 醫療廢物。英國、美國及荷蘭醫院每張病床每天則產生 5.5, 2.2 及 0.6 Kg 醫療廢物。該項研究顯示醫管局轄下醫院能貫徹執行醫療廢物分類。

專家檢討結果摘要

4

4.1 為回應立法會事務委員會委員及市民的關注，環保署於二○○○年中聘請了一名醫療廢物管理方面的獨立國際專家(英國 Torgam 發展有限公司的 William K. Townend 先生)，檢討現行的醫療廢物處理技術及國際間處理醫療廢物的方法，並確定這些技術適用於本港的範圍。Townend 先生是英國廢物管理學會(IWM)的上一任主席，亦是國際固體廢物協會(ISWA)醫療廢物工作小組主席。Townend 先生曾任職英國環境局，在醫療廢物管理方面具有豐富的經驗。此外，他亦是世界衛生組織(WHO)的顧問，並且是世界衛生組織出版的"Teacher's Guide:Management of Wastes from Health-care Activities"的作者之一。這檢討工作亦獲英國 Brunel 大學環境研究中心的 John D. Donaldson 教授及 Sue Grimes 博士協助。檢討的研究指引及檢討報告，分別載於附錄 C 及 D。有關結果的重點，則撮述於下文各段。

4.2 檢討報告指出，醫療廢物有潛在危險，而且具厭惡性。醫療廢物處理有以下重要功能：

(a) 對醫療廢物內的傳染性物料作消毒及/或滅菌處理，以減輕其微生物危害性；

(b) 銷毀醫療廢物內的利器，以盡量減輕其割刺的危險性(以及防止地下市場再使用即用即棄的針筒)；

(c) 使醫療廢物變得難以辨認及減少其厭惡性；及

(d) 大幅減少廢物体積。

4.3 任何獲選用的醫療廢物處理技術，應能以環保、安全及符合成本效益的方式執行上述功能。要達致這效果，任何處理方案應：

(a) 設有自動控制及內置保險機制；

(b) 設有妥善的監察及記錄系統；

(c) 設有適當系統可確保醫療廢物不能繞過正常處理程序；及

(d) 符合相關的職業及安全標準。

4.4 檢討報告指出，近年來有數個國家推出了各種種另類醫療廢物處理技術。專家在報告中對每項技術作出了較詳細的說明，並把這些技術劃分為：較廣泛使用的技術(如焚化、蒸壓、微波及無線電波處理，以及化學消毒法)；

其他熱能處理技術(如熱解及氣化)；及創新技術(如輻射及電漿技術等)。專家指出，創新技術是一些新興技術，一般而言在商業上並尚未廣為證實可行。至於較廣泛使用的技術，專家亦指出另類技術(如蒸壓、微波處理及化學消毒)雖然在近年來逐漸普及，但焚化仍是許多發達國家沿用多年的主要醫療廢物處置方法。

4.5 專家在報告中就較普及的醫療廢物處理技術作出詳細比較。專家認為在選擇合適的技術時，下列多項考慮因素尤為重要：

4.5.1 殺滅傳染性微生物的效力

4.5.1.1 醫療廢物處理的其中一個主要目的，是對廢物進行消毒或滅菌，以減少其傳染性及生物危害性。處理技術在減少傳染性物料方面的能力，稱為“效力”。 其中“滅菌”是指完全去除微生物。微生物是不可能絕對地消滅，亦難以證實，所以通常是以一或然率去表示有多少微生物可以在處理後仍然生存，而"滅菌"通常是指把微生物量減少 10^6倍，亦即減少 99.9999%。至於“消毒”，由於個別消毒程序的效果不同，故難以列出消毒的定義。美國疾病控制中心的指引把消毒程序劃分級別如下：

(a) *高級消毒*—可銷毀所有微生物(大量細菌芽孢除外)；

(b) *中級消毒*—把結核桿菌無性繁殖細菌、大部分病毒及大部分真菌的活性減除，但不一定能殺滅細菌芽孢；

(c) *初級消毒*—只能殺滅大部分細菌、一些病毒及一些真菌；不能用以殺滅抵抗力強的微生物如結核桿菌或細菌芽孢。

4.5.1.2 由於焚化是以高溫燃燒廢物，以徹底銷毀各類細菌、病毒、真菌及其他傳染體，故焚化可視為對廢物進行滅菌的最有效技術。焚化後剩下的殘餘物是少量經徹底滅菌的無機灰燼，可棄置於垃圾堆填區。

4.5.1.3 檢討報告指出，另類技術(蒸壓、微波及化學處理)在消毒醫療廢物方面的效力，須視乎多項操作因素及情況而定。在這方面，暫時仍未有任何國家標準可以用作評定另類技術的滅菌效力，而美國國家及地方另類處理技術協會(一個非政府機構)(STAATT)則仍在制定用以評估另類處理技術滅菌效力的標準程序，並提議另類技術應先經建議的評估程序測試，然後才被批准使用。專家亦指出，是否能利用這些技術適當地消毒醫療廢物，很大程度上取決於多項因

素，例如廢物處置工人的技巧(因這些工人在處理醫療廢物期間決定實際的運作情況)；醫療廢物的性質；醫療廢物的包裝；廢物有否經適當切碎；運作的溫度及處理的時間。要確保各類病原體在任何時間均能完全被銷毀，可能相當困難。因此，操作另類技術處置醫療廢物時，有關人員必須實施妥善的監察系統，以確保消毒的效力。例如定期把某些選定品種的細菌、病毒及真菌混入醫療廢物內，然後監察及測量另類設施的消毒程度。

4.5.1.4 檢討報告指出，由於熱解及氣化程序以非常高的溫度處理廢物，從而銷毀各類微生物，故也可對醫療廢物進行滅菌。跟焚化相似，剩下的殘餘物是極少量經徹底滅菌的無機灰燼，可棄置於垃圾堆填區。然而，由於不能熱解或氣化的廢物成分須用補燃器予以徹底銷毀，故使用這些技術時須對廢物成分善加控制，確保輸進的廢料成分合適。無論如何這些技術與焚化十分相似，而荷蘭 Zavin 營辦的醫療廢物處理廠，實際上是一具"熱解"焚化爐。

4.5.1.5 至於輻射及電漿技術等創新技術，由於本港需要安全可靠的處置安排，故專家並不鼓勵香港政府試用這些技術。

4.5.2 去除利器割刺的危險性及減少其厭惡性的適用情況

4.5.2.1 醫療廢物處理技術應能銷毀利器、減輕其割刺的危險性、令醫療廢物難以辨別，和擁有銷毀剩餘藥物及化學品方面的能力。由於焚化技術可完全銷毀各類醫療廢物，並把廢物轉為類似灰燼的物質，故在這方面最為適用。另類技術一般而言不能銷毀利器及使醫療廢物變得難以辨別，除非附設強力切碎機。

4.5.2.2 許多國家不建議使用蒸壓、微波及化學處理等另類技術，以處理人體組織或切除肢幹。如這類廢物未經徹底切碎，有關技術不能進行有效消毒。此外，對這些人体切除肢幹進行切碎、再加以蒸壓或微波處理，然後和一般都市固體廢物般棄置，這種做法對於許多國家和地方(包括香港)而言，屬有違傳統文化的做法。

4.5.2.3 檢討報告亦指出，應用幾種另類技術(如蒸壓、微波、無線電波及化學處理等)前，需要先將醫療廢物切碎，然後才處理，以確保蒸氣或化學品更有效地滲入廢物內部。而切碎機往往會出現問題, 因硬物(如可能混在醫療廢物中的受污染金屬髖關節及儀器)可能會損毀切碎機的刀刃或阻塞切碎機。因而另類處置設施須經常關閉

作維修保養。此外，當破碎機打開時，未經處理的醫療廢物及刀刃必然外露，這情況可能危害操作員的健康。

4.5.2.4 另類技術未能處理各類醫療廢物，意味着不適用於這些技術的醫療廢物必須分隔出來另行處理，(通常會採用焚化方式處理)。這種更嚴格的廢物分類，需要護理專業人員耗用更多時間和精力把廢物分類，從而減少了對病人的照顧，故就醫療廢物的管理而言普遍不受歡迎。額外的分類要求，在人手不足的醫院來說不大可行，有時甚至完全不可能。例如從用過的針筒或其他醫療廢物中把剩餘的化學品及藥物分隔出來。此外，從職康及安全的角度來看，要求另類技術處理設施的工作人員，打開所有廢物盛載器來確定廢物是否已作妥善分類，是既不可行，又危險的做法。

4.5.3 氣體及液體排放物

4.5.3.1 檢討報告指出，所有醫療廢物處理技術均會或多或少產生氣體及液體排放物。

4.5.3.2 焚化技術的主要問題是氣體排放物，如二噁英及水銀。焚化對健康造成的影響已被深入研究及公認。然而，如果醫療廢物焚化爐裝上合適的空氣污染控制設備以符合嚴格的氣體排放標準，焚化醫療廢物不會對環境及市民的健康構成任何的不良影響。檢討報告指出，焚化醫療廢物仍然是許多歐洲國家、澳洲、台灣、日本、新加坡、馬來西亞及美國處置醫療廢物所採用的主要方法。

4.5.3.3 檢討報告指出，另類技術雖然不會引致二噁英問題，但會產生其他潛在有害的氣體排放物，如已知蒸壓設施會散發很多種類含毒性的揮發性有機化學品。這是由於醫療廢物(如用過的針筒或安瓿)會含少量化學品、藥物及含細胞毒素(抗癌)藥物。用以清潔儀器及醫療設施的葯棉，亦可能含有剩餘的化學消毒劑。弄污的敷料亦可能含有藥膏及化學品。低溫的熱能處理，如攝氏 100 度的蒸氣或攝氏 95 至 100 度的微波處理，可能不足以銷毀混在醫療廢物內種類數以百計(至千計)的各類化學品。在加熱後，新的化學品亦可能會形成。此外，如醫療廢物內混有水銀或水銀化合物，在加熱達攝氏 90 至 130 度時，水銀便會從廢物中蒸發出來。

4.5.3.4 專家指出，辨別這類有害排放物的性質的研究，數目十分有限，另類處理醫療廢物技術對環境及健康可能造成的風險仍屬未知之數。在世界各地，就這些另類技術的氣體排放物進行的相應規

管及研究工作明顯較少，部分原因是對這些系統產生的排放物缺乏認識，部分原因則是市民不大關注。專家指出這些排放物須由合適的空氣污染消減裝置(一如其他醫療廢物焚化設施內設的裝置)所控制。無論如何，由於欠缺這方面的研究，現時尚未有設計這些設施的詳細指引或排放標準。

4.5.3.5 另類技術亦可能會產生液體排放物，須予以適當處理，然後才可排放。液體排放物的數量會因應所採用的技術而各有不同。

4.5.3.6 醫療廢物經熱解及氣化後會產生二噁英，如焚化一般，須安裝妥善的空氣污染控制裝置，以去除二噁英及其他含毒性的排放物。

4.5.4 職業健康問題

4.5.4.1 雖然在妥善控制的設施進行焚化，實際風險非常低，但專家認為市民想像到焚化醫療廢物的風險可以十分大。另一方面，專家指出另類醫療廢物處理技術可引致某些職業健康風險，較市民所想像的焚化引致的風險更為真實。例如，美國國家職業安全及健康學會(NIOSH)在一九九七年報告了一個微波醫療廢物處理設施曾發生微波泄漏的事件。據發現，泄漏入工作環境的微波，超出健康標準許多倍。此外，美國疾病控制中心(CDC)亦報告，美國一個另類處理設施(無線電波)最近亦發現懷疑與職業相關的結核病在職員間傳播。三名職員感染了活性結核病，其中一個患有多重耐藥性的結核病。其中一名工人染有的結核菌株的種類，跟另一名在某醫療機構接受治療的肺結核病人的菌株種類相同。而該醫療機構是有把醫療廢物送往上述醫療廢物處理設施處理的。

4.5.4.2 疾病控制中心的報告指出該另類處理設施有各種問題，包括有害的微生物煙幕體(microbial aerosol)、設計問題、技術問題、工作流程問題，以至火警危險等。報告並指出，處理醫療廢物並非像購置設備及按掣操作那麼簡單，而是必須實施完善、環保及安全的管理制度，以保障市民及處理廢物的工人的健康。

4.5.5 經處理的廢物其後的處置安排

檢討報告指出，醫療廢物往往含有剩餘的化學品、藥物及細胞毒素。因此，即使經蒸壓、微波或化學處理，醫療廢物仍可能受各種剩餘的化學品及含毒性物質所污染。例如，若醫療廢物含有水銀或細胞

毒素，經處理的醫療廢物仍存有水銀或細胞毒素。因此，這些經處理的廢物應予以妥善分類、處理、運送及處置(如採用焚化方式)。

建議

4.6 專家在檢討報告中評估了採用各種醫療廢物處理技術的限制，其中特別參照了香港建議的醫療廢物管制計劃，也審慎考慮了各種本地因素。

4.7 依據比較各種優點及缺點的結果，以及在本港採用另類處理技術的限制，專家認為政府應實行使用化學廢物處理中心以處理醫療廢物的建議。

4.8 長遠而言，專家建議政府：

(a) 跟進各地正進行的獨立研究的發展，並觀察各種處理技術的效力及環境測試的國際標準的發展概況；

(b) 跟進各地另類技術(包括創新處理技術)的發展；及

(c) 在獲取更多有關 a)及 b)項的資料後，考慮在較長遠的時間於一處合適地點安裝另類處理設施。

其他來源蒐集的資料

5

5.1 環保署另外亦搜集了有關醫療廢物處理技術的其他資料。環保署人員過去數年曾前往海外的醫療廢物處理設施進行技術考察，以了解醫療廢物處置技術的發展。有關目的為：

(a) 向有關政府官員蒐集關於其國家管制或批准各種醫療廢物處理技術的資料；及

(b) 透過參觀不同設施及與設施營辦商直接討論，以獲取第一手資料。

5.2 在以上考察期間就醫療廢物處置作業蒐集的資料摘要，夾附於附錄 E。此外，其後亦透過與相關政府機關、組織及供應商通訊獲取資料則夾附在附錄 F 及 G。這些資料現撮述如下：

焚化

(a) 高溫焚化仍是歐洲(如荷蘭、奧地利、法國及英國)和亞洲發展較佳國家或地方(如日本、新加坡、馬來西亞及台灣)最普及的醫療廢物處理方法。

(b) 在這些國家，由於個別醫院缺乏資源及技術妥善建造及營辦這些設施，故這些國家通常會建造一個或多個區域性焚化爐，以便集中處理醫療廢物。

(c) 許多焚化爐的設計，可供同時焚化危險廢物及醫療廢物。其中一個原因是，焚化醫療廢物與其他危險廢物，在處理溫度及污染消減設備方面均差不多。

(d) 雖然各地的規例可能有差別，但所有焚化設施均符合當地的氣體排放規例。尤其在歐洲，許多設施均符合歐洲委員會有關焚化處理的指令所定下十分嚴格的氣體排放建議規定。

另類技術

(e) 在這些國家中，一些國家(如法國、澳洲及英國)亦同時採用另類技術(蒸壓、微波及化學處理)，但這些設施的數目遠遠少於焚化設施的數目。

(f) 另類技術可能仍會引致二噁英以外的排放問題(如揮發性有機化合物及臭味)，這些問題沒有受到市民太大的注意。然而，這類排放問題應透過進行獨立研究及安裝合適的空氣污染控制設備，加以妥善處理。

(g) 另類技術在美國較為普及。在美國，蒸壓及微波處理越來越普遍，部分原因是區內居民較少反對(雖然這些技術仍可能產生氣體排放物)，而部分原因則是改裝舊焚化爐所需費用高昂。一些個案顯示，即使新設的焚化爐能符合最嚴格的氣體排放標準，區內居民仍然反對使用有關設施。據知在數個州內，經另類技術處理的醫療廢物，仍會作為垃圾衍生燃料在水泥窰焚化。此外，這些另類技術在滅菌方面的效力仍有待根據發展中的國家標準證實。

(h) 在一些歐洲國家(如法國)，經微波處理等另類技術"先行處理"後的醫療廢物，是與都市固體廢物放入能源回收焚化爐一併焚化。英國一家廢物管理承辦商亦正計劃一俟歐洲委員會有關堆填區的指令於未來數年實施後，便會效法這做法。

處理費用

5.3 當政府向立法會環境事務委員會及衞生事務委員會諮詢意見的時候，曾提及有關在化學廢物處理中心處置醫療廢物的估計開支。改裝化學廢物處理中心所需的修訂非經常費用為 5,200 萬元(見附錄 H)，而按每日處置 10 公噸醫療廢物計算，每年的營運費用為 2,200 萬元。

5.4 大部分設施供應商聲稱，非焚化技術所需的建設費用及處理費用，較焚化所需的便宜。環保署已嘗試從不同途徑，蒐集更多有關各處理技術費用幅度的資料(附錄 H 至 J)。而估計一部蒸壓器所需的建設費用會多於化學廢物處理中心方案，而營運費用則少於化學廢物處理中心方案。微波設施所需的建設費用及營運費用，均與蒸壓設施相若。

5.5 很多供應商聲稱表面上較低的建設費用，往往是由於其費用只涵蓋處理設施本身，而並未包括本港整體醫療廢物處理設施及運作的許多其他重要設施。該類重要設施包括：

(a) 用以容納蒸壓/微波/化學裝置、切碎機及壓縮機的建築物；

(b) 接收醫療廢物的地方及可供處理把醫療廢物運送到各設施的車輛的相關建築物；

(c) 量度車輛/醫療廢物重量，及計算每批廢物的處理費用的設施；和追查廢物行踪的相關電腦設施；

(d) 把裝有醫療廢物的“清運子車”(Transit Skip)自動裝卸至焚化或處理設備的設施；

(e) 供擺放盛載動物及人體組織和切除器官的清運子車的冷凍貯存設施；

(f) 供清洗及消毒醫院及診所使用的所有醫療廢物清運子車的清洗設施；

(g) 安全設施、通風及氣味控制設施，以及醫院、診所及收集商使用的清運子車的臨時貯存設施；

(h) 一般機電裝設；及

(i) 管理工程項目的費用、土地機會成本及後備費用等。

5.6 提供這些不可缺少的基建設施的費用，通常遠遠超出處理設施本身的費用。

5.7 關於另類技術的營運費用較低一事，英國 NHS(衛生部門)在其發出的技術備忘錄曾指出「*大部分另類處理技術的生產商就其產品的營運費用報價。這些數字按一些不統一的假設計算出來—例如折舊、息率及剩餘物處置等—故不應用作揀選技術的準則。*」一些人士就另類技術的營運費用所報價格，純屬營運有關設備的直接成本。這價格通常被低估而並未包括(但不限於)下述重要工序所需費用：

(a) 交回給醫療廢物收集商前，清洗及消毒所有的運送醫療廢物子車的費用；

(b) 修理及更換損毀的運送子車的費用；

(c) 如遇醫療廢物外泄事故，提供後備醫療廢物收集服務的費用；

(d) 控制及監察氣體及污水排放的費用；

(e) 進行例行微生物試驗，以確保在運行情況下成功殺滅指定類別的微生物，並獲認可試驗所核證；

(f) 編訂運載記錄、擬備有關所有醫療廢物收集商收集醫療廢物的資料，並把資料提交政府；

(g) 提供經核准的安全及環保訓練，以妥善營運設施；及

(h) 實施一套完善的環境管理系統。

5.8 紐西蘭的經驗顯示，一些蒸壓設施的營運費用，並不比焚化設施的營運費用便宜(附錄 F)。世界銀行發出的《醫療廢物管理指南》亦指出，無線電波處理可能較焚化昂貴，而蒸壓的費用與焚化的費用則十分接近(附錄 K)。

5.9 附錄 H 表內所載的費用比較，撮錄了在化學廢物處理中心焚化及在蒸壓設施處理醫療廢物的建造費用及營運費用總額。但須注意的是，該表並不包括下列費用：找尋用地的顧問費、初步可行性研究、環境影響評估、工程可行性研究、場地勘探、擬備招標文件等。這些費用相當可觀，在評估另類技術時須予以考慮。

結論及建議

6

6.1 專家檢討的結果及環保署人員蒐集的資料指出，儘管另類技術在美國及一些國家越來越流行，大部分歐洲國家、澳洲、新加坡、台灣、馬來西亞及日本等地，仍把焚化處理醫療廢物視為經證實可行的主流技術。有關二噁英、水銀及其他氣體排放問題，已透過安裝合適的污染管制設備，得以圓滿解決。

6.2 在美國，另類及創新醫療廢物處理技術發展迅速，部分原因是如把原有的醫院焚化爐改裝，既要符合近年引入的嚴格氣體排放標準，又需專門人員負責妥善操作焚化爐以免違反氣體排放標準，所需費用着實不菲；至於促進發展技術的主要動力，則是由於市民反對在住所附近築建焚化爐。

6.3 使用另類技術(如蒸壓、微波及化學處理)，雖然建造費用及營運費用均可能較為便宜，但其限制包括所能處理的醫療廢物類別，及未有就職康及安全方面進行有文獻根據的研究。這次檢討及技術考察期間所蒐集的資料指出，這些處理廠確實產生液體及氣體排放物，故應安裝妥善的污染消減系統。然而，目前仍未有足夠的指引資料，亦沒有經科學研究支持的排放標準。如在醫院安裝這些系統，便須考慮這重要因素。

6.4 癈物分類可以幫助減少醫療癈物的產生量，亦可確保葯物及化學品不會混入醫療癈物其中。但是，因為醫療機構內的很多不同的活動，都會產生醫療癈物，所以很難避免化學物進入醫療癈物內，故此有些醫療癈物可能受葯物及化學品污染。再者，打開每個醫療癈物的包裝袋去檢查及確保其中沒有化學物的做法是不適當及不可行的，故此以蒸壓法或微波技術處理醫療癈物會產生有毒排放物。在這方面，焚化方式肯定較優勝，因高溫焚化可完全銷毀醫療癈物內的化學物，而亦無須要求醫療機構實行非常嚴格的癈物分類。

6.5 使用另類技術往往需要先把醫療廢物切碎，再行處理，以確保蒸氣或化學品有效滲入醫療廢物。然而，切碎機存有無可避免的問題，可能會對設施的操作人員帶來潛在的職康風險。此外，近期在美國一個另類處理設施發現因職業感染的結核病的個案，反映出有需要就這些技術的環保、職康及安全方面匯集更詳盡的資料，以量化有關風險。

6.6 專家進行的檢討指出，一些創新技術(如以電漿為主的技術)亦可對醫療廢物進行滅菌，因這些技術以極高的溫度處理廢物，從而消滅各類微生物。

與焚化相似，這些技術的剩餘物是極少量經徹底滅菌的無機灰燼，可棄置於垃圾堆填區。然而，由於這類技術屬新興的先進技術，故專家認為香港政府暫時不要試驗這類技術。

6.7 我們留意到有些地方亦將經另類技術處理後的醫療廢物，送往能源回收設施與都市廢物一併焚化，而非棄置於堆填區。由於歐洲國家正減少採用堆填區作為處置都市廢物的方法，而較多採用焚化來處理不能循環再造的可燃燒廢物，當歐洲委員會就堆填區新訂的指令實施後，上述做法在歐洲將越來越普及。

6.8 總括而言，採用新興的另類處理技術雖有某些優點，在大部分歐洲國家，焚化作為經證實可行的醫療廢物處理技術，其使用範圍日益重要。環評結果已確定化學廢物處理中心的焚化設備足以處理所有種類的醫療廢物，並且完全符合最嚴格的排放標準。因此，現建議採用焚化技術作為處理醫療廢物的方法，並盡早改裝化學廢物處理中心，俾能以更環保的方法處置這類廢物。

BIOHAZARD

REVIEW OF CLINICAL WASTE TREATMENT TECHNOLOGIES

CARRIED OUT FOR

ENVIRONMENTAL PROTECTION DEPARTMENT

THE HONG KONG SPECIAL ADMINISTRATIVE REGION GOVERNMENT

FINAL REPORT

TORGAM

TORGAM DEVELOPMENTS LTD
18 Royal Avenue House
47 Kings Road
LONDON SW3 4QD
United Kingdom

November 2000

CONTENTS

TORGAM DEVELOPMENTS LTD

This document has been prepared

by

W K Townend, OBE

Chairman, Torgam Developments Ltd

With assistance from

Professor J D Donaldson
Dr S M Grimes
Centre for Environmental Research
Brunel University
Uxbridge
United Kingdom

And

Mr D Elphick
Researcher
Hopeman Associates Ltd

CHAPTER 1 EXECUTIVE SUMMARY

1.1 All four of the objectives set out by The Government of the Hong Kong Special Administration Region in the Contract as follows are covered in the present review:

a) To identify available clinical waste treatment technologies world-wide.

b) To compare the pros and cons of the various clinical waste treatment technologies and where treatment technologies provide partial treatment or pre-treatment to advise on appropriate further treatment.

c) To review the development and current situation of clinical waste disposal practices in countries overseas.

d) To advise on the scope of applying various clinical waste treatment technologies to Hong Kong and the operational precautions if such technologies are adopted.

1.2 In this Executive Summary, the scope of study and the methodology used are outlined; and a précis of the results and advice are presented.

1.3 METHODOLOGY

1.3.1 Key data and information from the following sources have been obtained:

The British Library
The Internet
Trade journals
Published academic research
Manufacturers' brochures
Regulatory Organisations
Non Governmental Organisations
National and International Bodies

1.3.2 Detailed information on the practices involved in clinical waste management has been obtained from Europe, North America and the Far East. The efficacy testing criteria for the technology have been researched. The health and safety issues and environmental aspects of alternative technologies have been analysed.

1.4 SCOPE OF STUDY

The available clinical waste treatment technologies worldwide have been identified and researched. Most countries listed in the contract document have been covered and some countries not listed have also been included.

1.5 IDENTIFICATION OF DIFFERENT TECHNOLOGIES

1.5.1 The treatment technologies analysed from a process point of view are as follows:

- Incineration Treatment Technology
- Alternative Treatment Technology
- Novel Treatment Technology

Incineration Treatment Technology

1.5.2 This is now a well-established traditional practice, to which increasingly stringent emission and environmental control standards are applied. Modern plants, as in Hong Kong, can meet the current stringent environmental standards. Similar thermal treatment technologies (pyrolysis and gasification) have also been considered.

Alternative Treatment Technology

1.5.3 Established alternative treatment technologies, which fall under the generic heading Thermal Disinfection (excluding incineration) or Chemical Disinfection, have been dealt with. Four specific categories have been analysed:

- Wet thermal treatment (autoclaving)
- Dry thermal treatment (hot screw feed technology)
- Electromagnetic wave irradiation (microwave and radio-wave)
- Chemical disinfection

Novel Treatment Technology

1.5.4 Two new novel alternative treatments have also been considered:

- Plasma based systems
- Irradiation (by electron beam or radioisotopes)

1.6 COMPARISON OF DIFFERENT TECHNOLOGIES

1.6.1 The advantages and disadvantages, which are common to all three systems, are set out in full in Chapter 4 and 5 of the report.

a) The main advantage of the alternative technologies is the lower capital cost of some of the package plants, and possibly operating costs when compared to incineration.

b) There would also be less public resistance to the installation of the alternative technologies in other countries probably because they are smaller installations with less obvious air emissions.

1.6.2 The main point of concern is the fact that the efficacy of killing micro-organisms, environmental and safety standards and risk assessment for the alternative technologies are not yet fully developed and further independent research and testing are required.

1.6.3 One of the disadvantages of the alternative technologies identified is

the potential of releasing volatile organic compounds (VOCs), mercury and other un-characterized air emissions into the environment. Offensive odour may also be produced from autoclave. These can theoretically be minimised by installing appropriate air pollution control equipment. The air pollution control systems applied to incineration plants may be dissimilar to those applied to alternative technologies mainly because the waste is not being subjected to a combustion process in the alternative technologies. The control systems are likely to be simpler and less expensive but further research needs to be carried out to evaluate this issue.

1.6.4 Another limitation of the autoclave (and microwave, radio-wave, chemical treatment) system to treat human and animal tissue and body parts, pharmaceuticals, chemicals and cytotoxic drugs (which may be carcinogenic, mutagenic or teratogenic) are real at the present level of the development of the system and impose restrictions on the use of such system.

1.6.5 Grinding or shredding of clinical waste is necessary prior to treatment by various alternative technologies to ensure better penetration of the steam, chemical disinfectant, or proper heating in order to achieve better killing of micro-organisms. This is also necessary for removing physical hazards presented by sharps and to render all other types of clinical waste unrecognisable. However, the shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care must be paid to operator safety in the removal of the untreated waste and in the handling of the equipment (e.g replacement of damaged blades or removal of obstructions such as metal hips) which will have become contaminated. Furthermore, shredding of clinical waste may lead to the formation of microbial aerosols in the working place; this should be properly controlled to prevent occupational health risk.

1.6.6 Whilst incineration can destroy all micro-organisms and clinical waste, disinfection efficacy of various alternative technologies relies greatly upon operational conditions. A system must therefore be present for the alternative technologies to ensure achieving adequate disinfection because the treated, untreated or partially treated clinical wastes have similar appearance. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.

1.6.7 A moderate level of research and development work is being carried out on the novel treatment technologies. They may achieve complete destruction of micro-organisms and all types of clinical waste. Some tend to be more expensive both in capital and operating costs (than autoclave, microwave, and chemical treatment) and some more expensive than incineration. In most cases waste treated by irradiation can be disposed of by incineration at the Waste-to-Energy facility or properly designed landfill (obtaining where necessary the approval of the appropriate regulator), whereas waste treated by plasma technology could be directly landfilled.

1.7 PRACTICES IN OTHER COUNTRIES

1.7.1 A review of practices of using different clinical waste treatment technologies worldwide has been carried out. Whilst it has not been possible to obtain information from all of the countries listed in the contract, the information obtained from the countries where it has been possible and the additional ones gives a good representative sample of different sizes of population, geography, economic development and development of clinical waste management.

1.7.2 Three important observations have been noted:

a) Incineration is still a very important and common disposal method particularly where landfill is limited and where there is the pressure to reduce biodegradable waste being disposed of in landfill sites as in the European Union. High temperature incineration is also still the most common method of clinical waste treatment in the more developed countries or places in Asia (Japan, Singapore, Malaysia and Taiwan).

b) There is a wide divergence in the number of treatment and disposal systems both between countries and internally within countries (e.g. USA).

c) There is an increasing use of the alternative technologies mainly due to cost consideration and public perception of the risks associated with incineration.

1.8 ADVICE ON THE APPLICATION OF VARIOUS CLINICAL WASTE TREATMENT TECHNOLOGIES IN HONG KONG

1.8.1 The constraints of applying the different treatment technologies have been assessed and researched with specific reference to the Hong Kong Government's proposed Clinical Waste Control Scheme and also giving due consideration to the local factors in Hong Kong.

1.8.2 The conclusions and the advice are set out in paragraph 7.4 and are based on the observations and findings contained in the present report.

1.8.3 Based on the findings of the advantages and disadvantages, and the constraints on the use of various alternative treatment technologies for Hong Kong, it would be more appropriate for the Government to proceed at once with its proposed use of the Chemical Waste Treatment Centre (CWTC) to incinerate clinical waste. Incineration is a well established and proven technology which produces the smallest amount of residues and such residues can be disposed of in a properly designed landfill site. There are also clearly established air emission standards for its regulation.

CHAPTER 2 BACKGROUND AND OBJECTIVES OF THE STUDY

2.1 BACKGROUND

2.1.1 The Government of the Hong Kong Special Administrative Region proposes to implement a Clinical Waste Control Scheme (CWCS) to provide legislative control over the collection, transportation and disposal of clinical waste in Hong Kong. The Government also proposes to modify the Chemical Waste Treatment Centre (CWTC) for the safe incineration of clinical waste. The reasons are as follows:

a) The CWTC is equipped and designed to meet the most stringent air emission standards adopted by developed countries. It has sufficient capacity to handle all the clinical waste projected to arise over the next ten years.

b) By modifying the CWTC, rather than building a new facility, significant resources and development time can be saved.

c) Land can be saved, as there is no need to find another site for the incineration facility.

d) Incineration offers a total solution to the treatment of different kinds of clinical waste without imposing stringent requirements on waste segregation.

2.1.2 To assess if it would be environmentally acceptable to dispose of clinical waste at the CWTC, an Environmental Impact Assessment was conducted in 1998. Various aspects were assessed, in particular the possible health risks due to emissions of dioxins and furans. The findings indicate that the maximum predicted concentration of such chemicals is equivalent to only 0.09% of the background concentration, and the calculated daily intake via inhalation is equivalent to 0.001% of the internationally accepted Tolerable Daily Intake standard of 1 pg TEQ kg^{-1} d^{-1}. The results from a trial burn also indicated that emissions due to incineration of clinical waste would readily meet the proposed stringent emission standards, which are comparable to those adopted in other advanced countries. Overall, the results confirmed that the incineration of clinical waste together with chemical waste at the CWTC would not cause any adverse environmental impact.

2.1.3 The Hospital Authority also employed a consultant in early 1999 to carry out a preliminary study on the use of autoclaving to treat clinical waste; the study indicated that such alternative waste treatment technology might emit Volatile Organic Compounds and other toxic emissions to the atmosphere.

2.1.4 In December 1999 and January 2000, the Joint Panel on Environmental

Affairs and Health Services of the Legislative Council (LegCo) was consulted on the Government's proposal to modify the CWTC for the incineration of clinical waste. The HA report has also been submitted to the Joint Panel for information. The Greenpeace representatives at the meetings criticised the proposal. Greenpeace considered that the Government should adopt other safer and cheaper alternative clinical waste treatment technologies such as the use of autoclaves and microwaves, which they said, had been widely employed in the U.S. Their main concern with the incineration of clinical waste was the possibility of toxic air emissions, particularly dioxins and mercury.

2.1.5 In view of the objection and the claim that there was an increasing use of alternative technologies in some other countries, some LegCo Panel Members considered that the Government should review such alternative technologies before proceeding with the use of the CWTC facility to incinerate clinical waste in Hong Kong.

2.1.6 The Government is also concerned with various environmental and health risks associated with alternative technologies, noting that such risks have not been well documented in the literature.

2.2 THE OBJECTIVES

2.2.1 In the light of the concerns that have been identified, the Hong Kong Government has decided to engage an international expert on the subject to carry out a review of all available alternative clinical waste treatment technologies world-wide and to examine their advantages and disadvantages. The review will assist the Government to formulate their response if an individual hospital or a private company decides to establish one of these facilities for the treatment of clinical waste.

2.2.2 The international expert will carry out the following detailed tasks to achieve the overall objective of the study:

a) Identify the clinical waste treatment technologies that are available world-wide.

b) Compare the various alternative clinical waste treatment technologies and identify the advantages and disadvantages of each one. Where treatment technologies provide partial treatment or pre-treatment, advise on appropriate further treatment.

c) Review the development and current situation with respect to clinical waste disposal practices in other countries.

d) Give advice on the scope of applying various alternative clinical waste treatment technologies to Hong Kong, and the operational precautions that will be required if such technologies are adopted.

CHAPTER 3 THE SCOPE OF THE STUDY AND METHODOLOGY

3.1 GENERAL BACKGROUND

The social, economic and cultural background to the situation in Hong Kong and an appraisal of the work already carried out to implement a Clinical Waste Control Scheme will be studied first. This will be followed by an assessment of the report published by the Hong Kong Hospital Authority "Alternative Treatment Technology: Autoclaving for Clinical Waste".

3.2 DETAILED SCOPE OF THE STUDY

3.2.1 Research into and identify the available clinical waste treatment technologies worldwide by reviewing international literature and consulting the relevant agencies and organizations.

Obtain the necessary details so that an account may be given of the advantages and disadvantages of those clinical waste treatment technologies which have found wide application in overseas countries including, but not limited to, the following technologies: autoclaving, microwave treatment, chemical disinfecting systems.

The parameters to be compared shall include, but not be limited to, the following:

- Generation of toxic emissions and wastewater;
- Operational safety and health;
- Reliability and ease of maintenance;
- Volume reduction of waste;
- Handling of waste treatment residues;
- Waste treatment costs;
- Space requirements;
- Public perception; and
- Further treatment requirements prior to final disposal.

3.2.2 Carry out a review of the development of current clinical waste disposal practices in various countries. The countries and places reviewed shall include but be not limited to the following: U.S.A., Canada, UK, Germany, Australia, Japan, Taiwan and Singapore.

3.2.3 Identify if there is an increasing trend in the application of alternative technologies in overseas countries, particularly in the U.S., and the rationale behind such changes.

3.2.4 Assess and advise on the constraints of applying the clinical waste treatment technologies taking into account the following local factors in Hong

Kong:

- Nature and quantity of clinical waste;
- Clinical waste management practices;
- Environmental impacts;
- Health and safety aspects;
- Control and enforcement;
- Siting issues;
- Capital and operating costs;
- Availability of other existing and planned disposal facilities;
- Time of implementation etc.;
- Government's proposed Clinical Waste Control Scheme; and
- The study conducted by the Hong Kong Hospital Authority – " Alternative Treatment Technology: Autoclaving for Clinical Waste".

3.3 METHODOLOGY

3.3.1 Upon the commencement of the study, a visit was made to Hong Kong by the author of this report and there was an opportunity taken to visit a government clinic and a government hospital (Queen Mary Hospital) where the current practice of clinical waste management was examined on site. To fulfil the objectives of the study, the current situation with respect to alternative and novel technologies for the treatment of clinical waste has been analysed as follows:

a) Available data and information on existing systems and their use have been researched using a variety of data sources including the British Library, The Internet, Trade Journals, Manufacturers Brochures, Professional Journals, International and National Regulatory Organisations, Non Governmental Organisations and published academic research.

b) Information on the practices involved in clinical waste management has been obtained from countries in Europe, North America and the Far East.

c) The available information on the efficacy testing criteria for the technology has been acquired.

d) Available data obtained on the research that has been carried out on the health and safety issues associated with the alternative technologies.

3.3.2 The results of the research are detailed and discussed in Chapters 4, 5 and 6. In Chapter 7 advice is given on the scope of applying alternative technologies in Hong Kong. An Executive Summary of the study is given in Chapter 1.

CHAPTER 4. IDENTIFICATION OF DIFFERENT TECHNOLOGIES

4.1 INTRODUCTION

4.1.1 Since the beginning of the 20th century hospitals in a large number of countries have had access to on-site boiler plant and incinerators for the disposal of waste produced in healthcare. About 25 years ago a number of events combined to act as a catalyst for the changes that led to the development of the large-scale alternative technologies for the treatment of clinical waste. The events that led to entrepreneurial companies to take the opportunity of developing large-scale waste treatment plants based upon existing techniques of disinfection were:

a) The greater awareness of the environment identified and promoted by the first United Nations Conference on the Environment held in Stockholm in 1972;
b) The emergence of new global epidemics such as human immunodeficiency virus (HIV) and hepatitis B virus (HBV) creating fear and concern of the general public;
c) Changes in waste management legislation and recognition of the risks associated with clinical waste
d) Growth in the use of disposable articles, equipment and packaging used in healthcare activities and disposal by old incinerators;
e) The introduction of legislation to achieve cleaner air emissions;
f) The expense of providing new incineration plant and the expense of gas cleaning equipment for upgrading old incinerators;
g) Public reaction to the siting of new incineration plants and old incinerators; and
h) The resulting closure of a large number of hospital incineration plants due to lack of funding to retrofit these plants.

4.1.2 These events took place mainly in the United States of America and were triggered there to some extent by the changes in 1978, which led to the State waste management legislation in California as well as Clean Air legislation in the rest of the USA.

4.1.3 Definition of disinfection and sterilisation

One of the main functions of treating clinical waste is to minimize the biohazardous nature of the waste. It is necessary to define the terms "disinfection" and "sterilisation" before discussion of the different treatment technologies:

a) **Sterilisation** means rendering free of micro-organisms. This can never be absolute but it should effect a reduction in the number of micro-organisms by a factor of more than 10^6 (i.e. more than 99.9999% are

killed).

b) **Disinfection** is difficult to define, as the activity of a disinfection process can vary. The guidelines of the USA Centres for Disease Control (Garner & Favero, 1985) allow the following distinctions to be made: -

High-level disinfection: can be expected to destroy all micro-organisms with the exception of large numbers of bacterial spores.

Intermediate disinfection: inactivates Mycobacterium tuberculosis vegetative bacteria, most viruses, and most fungi; does not necessarily kill bacterial spores.

Low-level disinfection: can kill most bacteria, some viruses, and some fungi; it cannot be relied on to kill resistant micro-organisms such as tubercle bacilli or bacterial spores.

4.1.4 In this chapter, the alternative treatment (chemical, wet thermal and dry thermal, electromagnetic wave treatment), thermal (incineration, pyrolysis and gasification) and novel (plasma, irradiation) treatment technologies are described and the advantages and disadvantages of each technology identified.

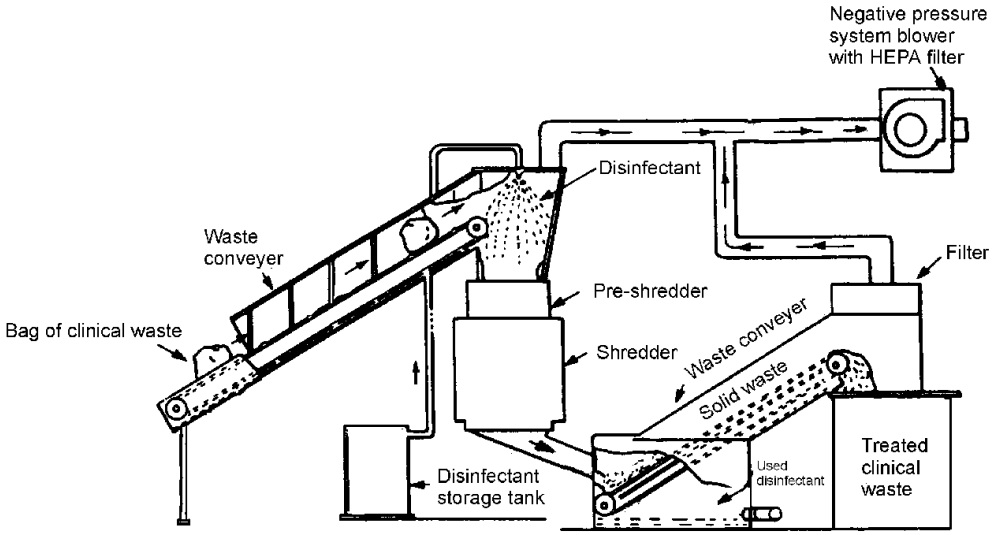
4.2. CHEMICAL DISINFECTION

4.2.1. Chemical disinfection is used in all clinical facilities on a routine basis to kill micro-organisms found on all types of surface particularly medical equipment, and the internal surfaces of buildings. Whilst chemical disinfection is commonly used to treat liquid waste (e.g. urine, blood etc), it has only been developed for the treatment of other clinical waste in the recent years.

4.2.2 The process involves the addition of powerful chemicals (disinfectants) to the waste to kill or inactivate the pathogens. Mechanical shredding of the waste is essential as a pre-treatment to ensure maximum contact of the chemical with the waste and to break up any voids due to packaging. Shredding is usually effected mechanically by the use of rotating blades. Water may also be added during the shredding process to cool the process and provide a medium for the chemical disinfection to take place. Chemicals in gaseous form can also be used for chemical disinfection; the agents used are ethylene oxide or formaldehyde (N.B. both are human carcinogens). This system is used mainly for the treatment of clinical items intended for reuse and which cannot be subjected to heat and moisture.

4.2.3 The waste is disinfected rather than sterilised. Some chemical disinfectants are specific in inactivating only certain types of micro-organisms whilst others can effectively kill all types. Knowledge of the types of micro-organisms present in the waste is therefore essential so that a proper chemical disinfectant can be used. Microbial resistance to different disinfectants has been well documented and it is possible to list the major groups of micro-organisms from most to least resistant as follows:

- bacterial spores
- mycobacteria
- parasites
- hydrophilic viruses
- viruses
- vegetative fungi and fungal spores
- vegetative bacteria



Schematic Diagram of a Chemical Disinfection System

4.2.4 The types of chemicals used for disinfection of clinical waste are mostly aldehydes, chlorine compounds (e.g. sodium hypochlorite or bleaching solution), ammonium salts and phenol compounds. The selection of the chemical disinfectant will depend upon:

- the technology to be employed
- the effectiveness of the chemical
- the risks to human health and the environment associated with the disinfectant
- the range of micro-organisms that are likely to be encountered in the process

4.2.5 There are two further methods of chemical disinfection that are in the development stage:

a) The use of ozone for the disinfection of waste is at present under investigation. Ozone is a strong and relatively safe chemical.

b) The second method is being developed by the Matrix Technology PTY of Australia. The waste is first pre-treated with peroxide and then undergoes shredding and alkaline oxidation by the addition of calcium

oxide (burnt lime) followed by encapsulation in a siliceous mass. The treated waste is then suitable for final disposal in a landfill site.

4.2.6 Advantages and Disadvantages of Chemical Disinfection System

The advantages are:

a) The capital investment costs are generally lower than incineration.

b) Depending upon the chemicals used and subject to the approval of the Regulators, the treated waste may be disposed of into landfill sites if the process has been properly carried out.

The disadvantages are:

a) Shredding or milling of clinical waste is required prior to treatment with the chemical disinfectant. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care is required in the removal of the untreated waste should that be necessary and also in the handling of the equipment which will have become contaminated.

b) Powerful disinfectants are required to kill the most resistant microorganisms. Such chemicals are also likely to be hazardous (e.g. glutaraldehyde and bleaching solution) and should be used only by well-trained and adequately protected personnel. For example, a worker was killed in a recent accident in HK due to the suspected inhalation of the commonly used bleaching solution during cleansing work (Apple Daily, 17 Aug 2000). Depending on the types of chemicals to be used, they may be irritating, corrosive, carcinogenic or generate unpleasant odour. Some may be explosive if not properly used. For example, the US National Institute for Occupational Safety and Health reported that ethylene oxide was involved in 10 explosions at industrial sterilization facilities between 1994 - 1998 and one of the explosions caused 1 death and 59 injuries (NIOSH, April 2000).

c) Disinfection efficiency depends on operational conditions, e.g. it depends on the concentration of active ingredients and the degree of acidity or alkalinity. It is important to ensure that the chemical used will not be diluted in the treatment process beyond its effective concentration. Some disinfectants may be inactivated when mixed with blood or serum in the clinical waste. Some disinfectants cannot kill all bacteria spores, or with questionable virucidal action, or may be incompatible with some rubber or plastic in the clinical waste. A system must be present to ensure that adequate disinfection is achieved, as the treated, untreated or partially treated waste looks the same. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.

d) Only the surface of solid waste will be disinfected. Hence, it is

important to ensure proper shredding of clinical waste to expose all surfaces to the chemicals. Any surface that is not exposed may still harbour pathogens.

e) The system introduces an additional chemical burden on the environment and the most common chemicals that are used are chlorine based.

f) Air and liquid emissions, which may be generated need to be properly controlled. For example, acidic components if present in the clinical waste may release chlorine from chlorine-based disinfectants (such as bleach). Chlorine gas is toxic and should be properly controlled.

g) The system is unsuitable for:
   i. cytotoxic drugs
   ii. human and animal tissue and body parts
   iii. pharmaceuticals
   iv. chemicals

h) The treated waste is likely to be wet. Care should therefore be taken to allow the waste to dry in a properly drained area before transport on road or delivery in a watertight vehicle/container so as to avoid spillage.

4.2.7 This system is only rarely used for the treatment of clinical waste due to the potential exposure of workers to the hazardous disinfectants. Treated materials can contain residual amounts of toxic chemicals that can be released over a period of time.

4.3 THERMAL DISINFECTION (WET, DRY AND ELECTROMAGNETIC WAVE TREATMENT)

4.3.1 Introduction

Thermal disinfection can be categorised as follows:
a) Wet thermal treatment (Autoclaving)
b) Dry thermal treatment (Hot screw feed technology)
c) Electro magnetic wave treatment

4.3.2 Wet Thermal Treatment (Autoclaving)

Thermal disinfection using steam has been in use in healthcare facilities since the beginning of the 20th century as the principal method for sterilising reusable surgical and laboratory equipment. It has also been used for treating microbiological specimens before they are disposed as solid municipal waste. Autoclaving or steam sterilisation systems use superheated steam to sterilise the waste in metal pressure vessel of sufficient strength to withstand the required pressures and in a controlled manner. They are designed to allow the waste to be in direct contact with the steam for sufficient time at the required temperature and under the necessary pressure so that the pathogenic micro-

organisms present in the waste are killed. There are four main phases in the complete autoclave cycle:

a) Phase 1 - Introduction of steam

The saturated steam can be introduced into the autoclave vessel in two ways. They are: -

- by air displacement and the use of gravity where the cold air sinks to the bottom of the vessel being replaced by the saturated steam,
- a vacuum is created in the vessel by exhausting the air present prior to the addition of the steam.

b) Phase 2 - Temperature raising

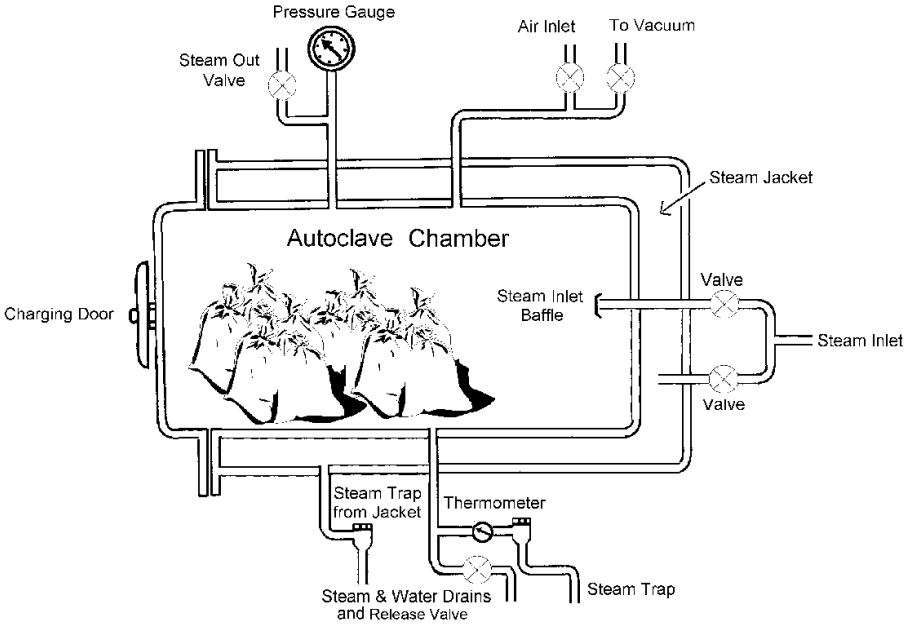
As the steam is added the pressure and temperature increase until such time as the requirements for a successful operation have been met.

c) Phase 3 - Exposure

The waste in the autoclave is then held in the vessel and exposed to these conditions until such time as the waste has been disinfected.

d) Phase 4 - Cooling

This is a cooling down period when the steam is slowly exhausted from the vessel and the pressure returns to that of one atmosphere.



Schematic Diagram of An Autoclave (With No Shredder)

Autoclaving is conceptually simple and has been proven over many years in the healthcare sector. Its development and use for waste management is of more recent origin. It has become accepted as a suitable system for the treatment of clinical waste in the USA and is more commonly employed than other alternative technologies. Its use is increasing world-wide both as a pre-treatment system prior to final disposal in the municipal Waste-to-Energy plants and for disposal in highly controlled situations in landfill sites. There is a

wide variety of manufacturers and of systems in operation and the manufacturers are usually prepared to design a system to meet the particular needs of the customer.

The systems can be divided into the following categories:

a) Small table-top Autoclaves
These are normally used in laboratories or operations having small quantities of clinical waste to dispose of such as the surgeries and the clinics of doctors, dentists or veterinary surgeons. They will produce the steam required within the system by adding water and will treat one charge only before adding more water. They are usually between 60 and 200 litres in size.

b) Laboratory Autoclaves
They are floor standing and can be connected to the hospital steam lines. They are used in laboratories for the disinfection of laboratory waste prior to its leaving the laboratory for either further treatment by shredding or for final disposal.

c) On-site Autoclave Treatment Plants
They are free-standing devices that can be sited outdoors in specifically designed and specified areas. They are fully insulated and will either be connected to the steam lines within the hospital or have their own dedicated steam boiler and pump if a pre-vacuum system is used.

d) Large Scale Wet Thermal Treatment Systems
These facilities are usually designed to treat the waste from more than one hospital and can either be operated by a group of hospitals or by a commercial operator. They can be either sited on land belonging to one of the hospitals or a site belonging to the merchant operator depending upon the circumstances.

There are a variety of ways in which these systems can be designed:

a) Simple steam disinfection of the containerised waste without any pre-treatment or post-treatment and the containers of treated waste are transported for final disposal at landfill sites or at Waste-to-Energy plants.

b) Pre-treatment of the waste by shredding after which the waste is placed in the treatment vessel. After treatment the waste is bagged and then ready to be taken for final disposal as in (a).

c) Disinfection of the containers of waste in the autoclave followed by shredding and compaction prior to final disposal as in (a).

d) Bags of clinical are placed into a pressure vessel with a separate rotating internal drum. High-pressure steam is then added causing the containers of waste to become soft and during agitation in the rotating

drum the bags will disintegrate. The disinfected waste is then subjected to a vacuum condensing system to dry the waste, which is then passed through a size reduction system (e.g. a shredder) before being delivery for final disposal as in (**a**) above.

e) The wet thermal treatment system can also be combined with a chemical treatment system. For example, one patented system is designed to sterilise, render unrecognisable and make reusable all forms of clinical waste (except pathological and pharmaceutical waste). This is achieved by first subjecting the waste to shredding and pulverisation with the simultaneous introduction of sodium hypochlorite (bleach). This is claimed to sanitise both the equipment and the waste. The system then separates excess fluids from the waste using an auger press for re-circulation. The last stage of the process has an encapsulated auger where steam is injected onto the waste in temperature-controlled conditions. It is claimed that the residual waste is sterilised and has nearly dry constituency. It can then be sent for recycling as it is no longer infectious and falls out of the category of for example the European Union definition of hazardous waste or to final disposal. The sterile waste can then be passed through a patented recycling system where the waste is fed into a rotating gravity separator where water is again added to float the lighter material from the heavy fraction which fall to the bottom of the system. The lighter fraction will flow to a de-watering centrifuge. The treated waste is then classified by being passed over jets of air - the heavier particles drop to the floor of a chamber and the lighter particles pass into another chamber. The plastic waste after this process is polypropylene and polyethylene and can be used to produce waste containers such as sharp's containers and other products such as fence posts etc. The sale of the recycled plastic waste will depend on regional market requirements. Recycling of plastic clinical waste will normally only be considered if a business case has been made to justify the investment in the patent recycling system. For example, if there is already supply of cheaper raw or recycled plastic materials (e.g. in Hong Kong), it may not be economically viable to recycle the plastic from clinical waste.

There are many factors which affect the process of autoclaving and hence the efficacy of disinfection:

a) Presence of residual air within the autoclave chamber prevents effective sterilization by reducing the temperature of the steam regardless of the pressure. This may lead to inadequate sterilization of clinical waste. Some autoclaves overcome this problem by using vacuum to pull all residual air from the chamber and to burst the bags containing the clinical waste. Alternatively, the bags should be shredded. However, this will lead to the formation of microbial aerosols which may be released to the outside of the chamber (Marshall et al, 1999). Proper microbiological filter must be present to minimize the microbial hazard. However, few commercial units are equipped with H.E.P.A. (High Efficiency Particulate Air) filters on their vacuum exhaust systems to

address this issue. The third way is to require the waste facility workers to open the bags, but this is not recommended because this will place the worker at risk due to microbial aerosol in the bags.

b) Factors that can cause incomplete displacement of air include: improper loading (which may prevent the circulation of steam within the chamber) and the accidental use of heat resistant plastic bags.

c) Waste such as large body parts, large quantities of animal bedding and fluids inhibit direct steam penetration and may lead to inadequate sterilization under standard conditions.

4.3.3 Advantages and Disadvantages of Wet Thermal Treatment Systems

The advantages are:

a) The capital investment costs are lower than incineration.

b) The treated waste, if the process has been properly carried out, may be disposed of into landfill sites or to Waste-to-Energy plants subject to the approval of the Regulators.

c) Hospital staff is familiar with operations of small-scale autoclave and steam sterilisation systems.

The disadvantages are:

a) Clinical waste may require shredding prior to treatment to ensure better penetration of steam into the waste. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care is required in the removal of the untreated waste should that be necessary and also in the handling of the equipment which will have become contaminated.

b) Autoclaving heats the clinical waste to 121°C-131°C. Vapour will be formed during this heating process. Chemicals such as residual amount of pharmaceuticals, disinfectants and cytotoxic drugs unavoidably associated with clinical wastes would be vaporised and escape into the environment. Mercury, if present in the clinical waste, would also be vaporised at this temperature due to its high volatility. There is also a possibility of the production of offensive odours. Hence, air emissions may need to be properly controlled. Autoclaving also makes the waste wet; liquid emissions may be formed and need to be controlled.

c) Disinfection efficiency depends on operational conditions, e.g. residual air in the chamber may reduce efficacy of killing pathogens, cold spots may be present if waste is too closely packed or the chamber over-loaded, steam may not be able to penetrate if the bags of clinical waste are tied too tight etc. A system must be present to ensure achieving adequate disinfection, as the treated, untreated or partially treated

waste looks the same. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.

d) There will be with certain systems an additional chemical burden on the environment. The most common chemicals that are used are chlorine based.

e) The system is unsuitable for:
   i. human and animal tissue and body parts
   ii. pharmaceuticals
   iii. chemicals
   iv. cytotoxic drugs

f) The treated waste is likely to be wet. Care should therefore be taken to allow the waste to dry in a properly drained area before transport on road or delivery in a watertight container/vehicle so as to avoid spillage.

g) To treat the waste with steam above 100^{o}C would require treatment under high pressure. Special safety precautions are required and requirements may have to be complied with under the Boiler and Pressure Vessel Ordinance in Hong Kong. Dry hypochlorides or any other strong oxidizing material must not be autoclaved with organic materials such as paper, cloth etc (i.e. oxidizer + organic material + heat may produce an explosion) (California State Polytechnic University, 1995).

4.3.4 Dry Thermal Treatment (Screw-feed Technology)

One type of the dry thermal disinfection processes is based upon screw-feed technology where the waste is first shredded and then heated by a rotating auger. Patented systems based upon continuous feed augers are already operating in a number of applications. The system requires the waste to be shredded to a particle size of about 25mm. The waste then enters the auger, which is pre-heated to a temperature of 110°C-140 °C by oil circulating through its central shaft. The waste is then propelled through the auger during a 20-minute retention time. There is no direct contact between the hot oil and the clinical waste. The waste residues are then compacted for final disposal to landfill sites or Waste-to-Energy plants.

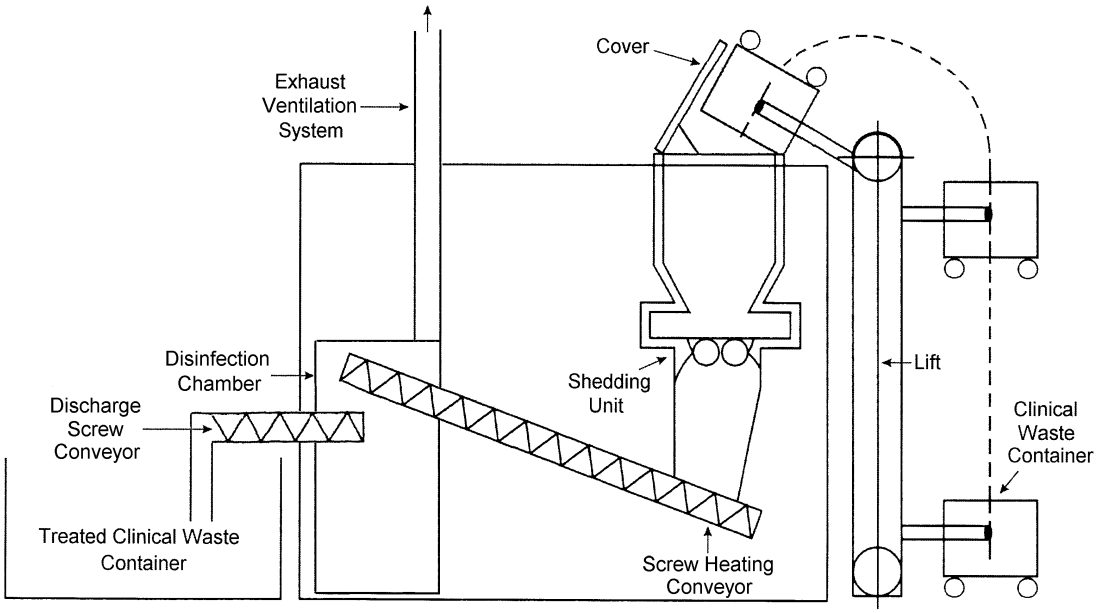
4.3.5 Advantages and Disadvantages of Dry Thermal Treatment Systems

The advantages are:

a) The capital investment costs and possibly the running costs are lower than incineration.

b) The treated waste, if the process has been properly carried out, may be disposed of into landfill sites or to Waste-to-Energy plants subject to the approval of the Regulators.

c) The treatment process does not involve the use of hazardous chemicals.



Schematic Diagram of a Dry Thermal Disinfection System

The disadvantages are:

a) Shredding or milling of clinical waste is necessary prior to treatment. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care is required in the removal of the untreated waste should that be necessary and also in the handling of the equipment which will have become contaminated.

b) Disinfection efficiency depends on operational conditions. A system must be present to ensure achieving adequate disinfection, as the treated, untreated or partially treated waste looks the same. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.

c) Dry thermal treatment heats the clinical waste to 100°-131°C. Vapour will be formed during this heating process. Chemicals such as residual amount of pharmaceuticals, disinfectants and cytotoxic drugs unavoidably associated with clinical wastes would be vaporised and escape into the environment. Mercury, if present in the clinical waste, would also be vaporised at this temperature due to its high volatility. There is also a possibility of production of offensive odours. Hence, air emissions may need to be properly controlled.

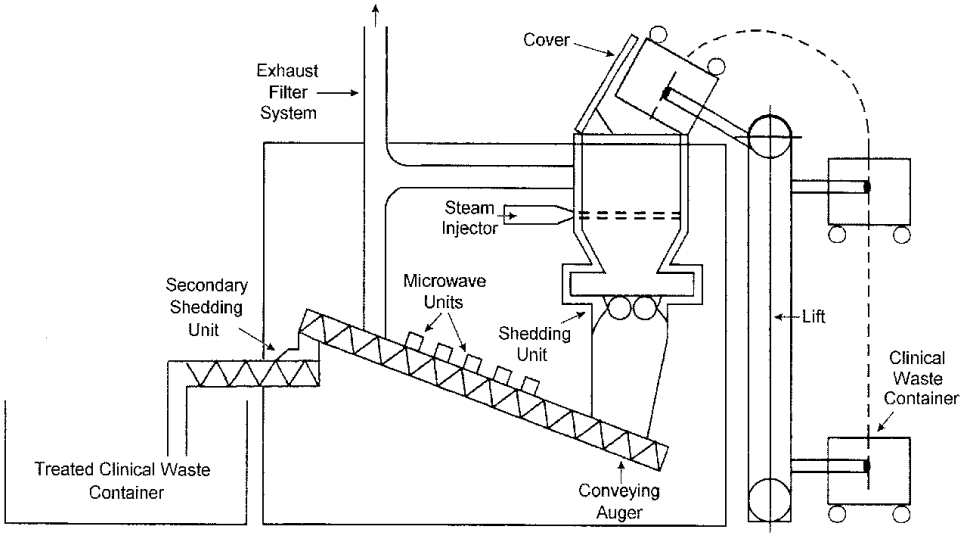
d) The system is unsuitable for:
   i. human and animal tissue and recognisable body parts
   ii. pharmaceuticals

iii. chemicals
iv. cytotoxic drugs

4.3.6 Electromagnetic Wave (Microwave and Radio wave) Disinfection Systems

Microwaves are short, high frequency electromagnetic waves which are generated in electron tubes, with built-in resonators, special oscillators or solid-state devices to control the frequency. Most micro-organisms are destroyed by the action of microwaves at a frequency of about 2450 MHz and a wavelength of 12.24 cm. Microwave thermal treatment systems for clinical waste operate by agitating the water molecules in or on the surface of the waste materials causing them to vibrate and the vibration produces heat. In a microwave treatment unit a loading device transfers the wastes into a shredder, where it is reduced to small pieces. Steam is then added to the waste, which is then transferred to the irradiation chamber. The chamber is equipped with a series of microwave generators. The waste is then irradiated for about 20 minutes. The microwaves heat the moisture contained within the wastes to the point (usually about 95^{o}C) that the clinical waste contained therein is disinfected. Once irradiated, the waste is then compacted inside a container for final disposal to either a landfill site or a municipal Waste-to-Energy plant.

The efficacy of microwave disinfection should be checked routinely by microbiological tests. The microwave process is used in several countries (e.g. USA) and is becoming increasingly popular. However, relatively high costs coupled with potential operation and maintenance problems mean that it is not yet recommended for use in developing countries (WHO, 1999a). Microwave irradiation equipment with a capacity of 250 kg/hour (600 tonnes/year, assume operating at 8 hr/day x 300 days/year), including loading device, shredder, steam humidification tank, irradiation chamber, and microwave generators, plus a waste compactor, may cost about US$ 0.5 million.



Schematic Diagram of a Microwave Disinfection System

A proprietary system of treatment in use in the USA is known as the Electro-thermal Deactivation (ETD) process. The system includes a system of pre-grinding the waste and then passes the waste through a field of high-intensity low-frequency radio waves oscillating at a frequency of 10 mega-hertz to heat the waste. It is claimed that the pathogens in the waste are killed at atmospheric pressure and at temperatures as low as 90°C and that they can penetrate deeper than higher frequency waves like microwaves.

4.3.7 Advantages and Disadvantages of Electromagnetic Wave Disinfection Systems

The advantages are:

a) The capital investment costs and possibly the running costs are lower than incineration.

b) If the process has been properly carried out, the treated waste may be disposed of into landfill sites or to Waste-to-Energy incinerators subject to the approval of the Regulators.

c) The treatment process does not involve the use of hazardous chemicals.

The disadvantages are:

a) Exposure to electromagnetic wave radiation is dangerous especially when high energy or high intensity of radiations involved. It is known that microwave radiation can heat body tissue the same way it heats other materials. The lens of the eye is particularly sensitive and exposure to high levels of microwaves can cause cataracts. Likewise, the testes are very sensitive to changes in temperature. Accidental exposure to microwave can cause sterility. It can also cause burns, and damages to the nervous system. There is also a possibility of danger from long-term exposure to low-level microwaves. A continuous electromagnetic wave leakage monitoring system and programme must therefore be implemented.

b) Shredding or milling of clinical waste is necessary prior to treatment to ensure better penetration of steam into the waste. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care is required in the removal of the untreated waste and also in the handling of the equipment which will have become contaminated.

c) Disinfection efficiency depends on operational conditions. A system must be present to ensure achieving adequate disinfection before disposal as the treated, untreated or partially treated waste looks the same. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.

d) Electromagnetic wave treatment, like autoclave treatment, heats the clinical waste but to 95°C-100°C only. Vapour will still be formed during this heating process. Chemicals such as residual amount of pharmaceuticals, disinfectants and cytotoxic drugs unavoidably associated with clinical wastes would be vaporised and escape into the environment. There is also a possibility of offensive odours. Hence, air emissions may need to be properly controlled. Microwave treatment also requires the waste to be wet and this may need to be supplemented with a steam supply. Liquid emissions may be formed and need to be controlled, despite the amount of liquid may be less than that of autoclave treatment.

e) Relatively high costs coupled with potential operation and maintenance problems mean that the system is not yet recommended for use in developing countries (WHO, 1999a).

f) It has been reported that the efficiency of the microwave system will decrease if the liquid content exceeds 10%, if the metal content of the waste is greater than 1% or if metal pieces larger than 0.2 kg are present (Brunner, 1996).

g) The system is unsuitable for:
   i. pharmaceuticals
   ii. human and animal tissue and body parts
   iii. chemicals
   iv. cytotoxic drugs

4.4 THERMAL TREATMENT (INCINERATION AND PYROLYSIS/ GASIFICATION)

Incineration

4.4.1 Incineration is the traditional method of treating clinical waste. The technology has been developed for over a century and the environmental impacts on the environment have been extensively studied. Improvements in incineration technology and pollution abatement equipment can minimize the environmental impact of incineration of clinical waste. Modern state-of-the-art clinical waste incinerators can meet the most stringent environmental standards.

Pyrolysis

4.4.2 Pyrolysis is the process of chemical decomposition of organic materials by heat (up to 2500^{o}C) in the absence of oxygen. This process is commonly used in the manufacture of charcoal or coke for many years. Pyrolysis results in a gas stream containing primarily hydrogen, methane, carbon monoxide, carbon dioxide, and various other gases and volatile organic compounds and inert ash, depending on the characteristics of the material being pyrolyzed. These gases are then incinerated in a secondary chamber at a very high temperature. Metals and ceramics are not reduced in size but are disinfected by the very

high temperature of the treatment unit. All residues are collected in a receptacle and emptied as needed. An air-cleaning unit is still required to remove unacceptable air pollutants, such as dioxins and heavy metals, from the effluent gas stream. This system can be applied to clinical waste. An example is the plant in the Netherlands at Dordrecht operated by Zavin.

Gasification

4.4.3 Gasification is a process similar to pyrolysis but where the materials to be treated have a high carbon content and are heated to temperatures as high as 1300^{o}C with limited amounts of oxygen. Energy rich gases are produced. These gases are then incinerated in a secondary chamber at a very high temperature. The waste materials are decomposed and sterilised in the process and the gases that are produced are treated by passing a series of scrubbers and filters to remove the pollutants (e.g. dioxins, furans etc.) and either are burnt to produce energy or used to pre heat the waste.

4.4.4 Advantages and Disadvantages of Incineration and Pyrolysis/ Gasification

The advantages are:

a) They can significantly reduce the volume and weight of clinical waste;
b) They can destroy all infectious micro-organisms most effectively;
c) They burn all types of clinical waste to ash and make them unrecognisable;
d) Shredding of clinical waste is not required;
e) They can completely destroy residual amounts of cytotoxic drugs, pharmaceuticals and toxic chemicals in the clinical waste and hence does not require stringent segregation of clinical waste for separate treatment;
f) They do not produce VOCs since the latter will be burnt out during incineration;
g) Heat recovery is possible; and
h) The environmental impacts have been extensively investigated and made known so that proper abatements can be carried out.

The disadvantages are:

a) Incineration of PVC-containing clinical waste may produce air emission with dioxins and furans if proper air pollution control equipment is not installed;
b) Incineration of clinical waste contaminated with mercury and other heavy metals may produce air emissions with such heavy metals if proper air pollution control equipment is not installed;
c) Capital cost may be higher than some other alternative technologies; and
d) There is considerable public concern and objection due to the perceived risk even though pollution abatement equipment can effectively remove air pollutants.

4.5 NOVEL TREATMENT TECHNOLOGIES

4.5.1 In this section two novel technologies (Plasma-based system and irradiation) for treating clinical waste are described and the advantages and disadvantages are identified.

Plasma Based Systems

4.5.2 Dr. Irving Langmuir, an American chemist and physicist, first applied the word "plasma" to ionised gas in 1929. Plasma consists of a collection of free-moving electrons and ions from atoms that have lost electrons. Energy is needed to strip electrons from atoms to make plasma. The energy can be of various origins: thermal, electrical, or light (ultraviolet light or intense visible light from a laser). With insufficient sustaining power, plasmas recombine into neutral gas. Plasma can be accelerated and steered by electric and magnetic fields, which allows it to be controlled and applied. It also provides many practical uses.

High-temperature plasmas in arc furnaces can convert, in principle, any combination of materials to a vitrified or glassy substance with separation of molten metal. Substantial recycling is made possible with such furnaces and the highly stable, non-leaching, vitrified material can be used in landfills with essentially no environmental impact. The temperatures reached in a plasma arc furnace are considerably more than that required to disinfect the waste. For example the plasma torch process uses an electric arc to attain temperatures as high as 10,000^{o}C to destroy waste. One of the major disadvantages of this novel technology is its extremely high capital and operating cost. Some plasma systems claim that there is no emission problem. However, an earlier USEPA report "Retech, Inc., Plasma Centrifugal Furnace – Applications Analysis Report" indicated that there were emissions from the plasma treatment process (USEPA, 1992). The particulate emission exceeded the Resource Conservation Recovery Act (RCRA) limits and the report concluded that a more efficient air scrubbing system was required. High NOx concentration in the stack gas was also noted.

Irradiation

4.5.3 A treatment system has been developed based on electron beams, which have the ability to destroy micro-organisms and sterilise a wide variety of materials. The electron beam generator is similar to those used for cancer therapy equipment in the hospitals and for sterilisation of foods and pharmaceuticals in the industry. Electrons from the beam interact with the electrons in the molecular structure of the target material, depositing energy and breaking the chemical bonds of organic compounds and fragmenting micro-organisms. While a material is being irradiated, it is never in contact with any radioactive materials, and the electrons used to treat the clinical waste would not make it radioactive.

Other systems may make use of ionising radiation from radioisotopes to treat clinical waste. All types of irradiation systems require extensive shielding to

protect the workers.

4.5.4 Advantages and Disadvantages of the Novel Technologies

The advantages are:

a) Provided that the process has been properly carried out, the waste treated by irradiation may be disposed of into landfill sites or Waste-to-Energy plants subject to the approval of the Regulators.

b) Novel technologies such as plasma-based systems can significantly reduce the volume and weight of clinical waste. Similar to incineration, plasma-based systems can kill all micro-organisms, make clinical waste unrecognisable, can completely destroy residual amounts of cytotoxic drugs, pharmaceuticals and toxic chemicals in the clinical waste and hence does not require stringent segregation of clinical waste for separate treatment, and can destroy VOCs.

The disadvantages are:

a) There is insufficient information to assess the cost due to the fact that there are very few plants in use for the treatment of clinical waste but the capital investment costs and operational costs are likely to be about the same as or higher than incineration. One of the major disadvantages of irradiation system is its extremely high capital and operating costs.

b) Where the ionising radiation comes from radioisotopes there is the problem of disposing of any radioactive waste created during the process.

c) The biggest disadvantage of novel technologies is that they are most likely to be marketed as novel techniques by small entrepreneurial companies specially designed for the customer and therefore limited proven track record is available from the prototypes. This will certainly mean that they will be constantly modified whilst in operation. Experience in this area has meant that the facility is either out of use for periods of time or in some cases has failed completely. Selecting novel prototype technologies particularly where it will be the only facility in Hong Kong is not something to be considered lightly as clinical waste is in constant production and very reliable facilities must be provided for its treatment and disposal.

d) Shredding or milling may be necessary prior to treatment by irradiation. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste considerable care is required in the removal of the untreated waste should that be necessary and also in the handling of the equipment which will have become contaminated.

e) Disinfection efficiency in the case of irradiation will depend upon operational conditions.

f) Irradiation cannot destroy the residual amounts of cytotoxic drugs, pharmaceuticals and toxic chemicals in the clinical waste.

g) Air and liquid emissions, which may be generated, need to be properly controlled.

4.6 SUMMARY

4.6.1 The advantages and disadvantages of the various alternative and novel treatment technologies have been identified in this chapter. They have been summarised in Table D of Chapter 5.

4.6.2 In brief, clinical waste treatment technologies should be able to:

a) Adequately disinfect or sterilize infectious materials in the clinical waste to reduce its microbiological hazard so that no further special treatment is required for subsequent disposal;

b) Destroy the sharps in clinical waste to minimize its physical hazard (and more importantly to prevent reuse/recycling of disposable syringes in the underground market);

c) Render clinical waste un-recognizable and un-offensive; and

d) Achieve significant volume reduction.

4.6.3 Any clinical waste treatment technologies to be selected for use should be capable of fulfilling the above functions in an environmentally sound, safe and cost-effective manner. To achieve these, the treatment system should:

a) Possess automatic controls and built-in failsafe mechanisms;

b) Have proper monitoring and recording systems;

c) Possess system to ensure waste cannot bypass the treatment process; and

d) Prevent creating other occupational and safety problems in the first place.

4.6.4 The alternative technologies have the following advantages:

a) The capital investment costs and possibly the running costs are lower than incineration;

b) If the process has been properly carried out, the treated waste may be disposed of into landfill sites or to Waste-to-Energy incinerators subject to the approval of the Regulators;

c) They do not produce dioxins and furans; and

d) They attract less public concern.

4.6.5 It should be noted that alterative technologies (autoclave, microwave and chemical treatment) have the following limitations:

a) They are not able to significantly reduce the volume and weight of clinical waste;

b) They may not be able to destroy all infectious micro-organisms at all times and the process of disinfection or sterilization depends greatly on the skills of the operators;

c) They cannot make clinical waste unrecognisable, unless they are equipped with shredders or grinders which are not only problematic but also create airborne pathogen hazard to the operators of the treatment facility and maintenance staff (WHO, 1999a);

d) They cannot destroy residual amounts of cytotoxic drugs, pharmaceuticals and toxic chemicals present in the clinical waste and hence require more stringent segregation of clinical waste to allow for separate treatment (WHO, 1999a; Table B);

e) They may require addition of chemical disinfectants which may be hazardous to human and other living things;

f) They generate toxic and carcinogenic VOCs and other toxic heavy metals in the vapour during the heating process. The VOCs and toxic heavy metals cannot be destroyed at low temperature. Some may also generate bad odour. All these may create occupational and safety hazards and must be properly controlled;

g) Heat recovery is not possible; and

h) Environmental impacts have not been extensively investigated or made known.

CHAPTER 5 COMPARISON OF DIFFERENT TECHNOLOGIES

This chapter compares the different technologies for treating clinical waste from the following aspects:

- Costs and financial implications
- Health, safety and environmental impacts
- Efficacies
- Reliability and ease of maintenance
- Handling of residues and further treatment requirements prior to final disposal
- Space requirements
- Public perception of risk

5.1 COSTS AND FINANCIAL IMPLICATIONS

5.1.1 The "polluter pays principle" should be applied when dealing with waste produced at healthcare facilities and all of the costs be applied to the function including segregation, storage, collection, purchase of equipment and labour costs as well as the treatment and disposal costs.

5.1.2 In the WHO publication "Safe Management of Wastes from Clinical Activities", an example was given for the disposal costs per tonne of different technologies in Switzerland. In general, the cost of incineration with high standards of treatment and pollution control is comparable to wet thermal disinfection while that of chemical disinfection is about half. The capital costs of providing a new alternative technology facility are generally less than that for a new incineration plant. However the operational costs are comparable for a wet disinfection system.

5.1.3 However, when assessing the costs of purchasing and operating a new treatment plant various points need to be taken into account and an annual average disposal cost arrived at (Table A). It should be noted that:

a) The cost quoted by a supplier of a treatment facility usually only includes the cost of the package equipment rather than all the costs as shown in Table A.
b) For some alternative and novel technologies, the life cycle cost may not be known as some of them are only newly developed.
c) A number of factors affect the total costs of disposal of clinical waste particularly where all of the waste types cannot be dealt with in the same facility and some waste has to be separately collected and disposed of by incineration. For example, pharmaceutical, cytotoxic and chemical wastes, and body parts cannot be destroyed by alternative treatment technologies (WHO 1998) (Table B).

Hence, careful assessment of the total costs should always be made.

TABLE A Cost Evaluation

CAPITAL COSTS	**Site costs**	Land purchase, Infrastructure, Utilities
	Consultancy Fees	Environmental Assessment, Engineering, Architectural design.
	Construction Costs	Building, Storage, Offices, Treatment Plant.
	Finance	Interest, Taxes, Accountancy Fees.
OPERATION COSTS	**Finance**	Interest, Taxes, Accountancy Fees.
	Pre-processing	Compaction, Containers, On site transport, Human resources, Chemicals, Training, Maintenance, Protective clothing.
	Off- Site Transport	Vehicles, Weighing, Maintenance, Human Resources, Protective clothing, Disposal Costs.
	Processing costs	Human resources, Utilities, Electricity, Water, Repairs and Maintenance, Consumables e.g. filters and chemicals, Training, Regulator compliance, Disposal of waste products and wastewater.
	Administration costs	Records, Insurance, Licences.

Source of information: Torgam Developments.

TABLE B Treatment of Various Types of Clinical Waste by Various Methods

Systems	**Infectious Waste**	**Anatomic Waste**	**Sharps**	**Pharma-ceutical Waste**	**Cytotoxic Waste**	**Chemical Waste**
Two-chamber, rotory kiln (CWTC Incinerator)	Yes	Yes	Yes	Yes	Yes	Yes
Single chamber incinerator	Yes	Yes	Yes	**No**	**No**	**No**
Pyrolytical incinerator	Yes	Yes	Yes	**Small amount only**	**No (yes for modern ones)**	**Small amount only**
Chemical disinfection	Yes	**No**	Yes	**No**	**No**	**No**
Wet thermal treatment	Yes	**No**	Yes	**No**	**No**	**No**
Microwave irradiation	Yes	**No**	Yes	**No**	**No**	**No**
Sanitary landfill	Yes	**No**	**No**	**Small quantities**	**No**	**No**

Based upon: WHO Teachers Guide (1998)

5.2 HEALTH, SAFETY AND ENVIRONMENTAL IMPACTS

5.2.1 Emissions from incineration and the potential impacts on the health and environment have been extensively studied (US EPA, 1991). On the other hand, whilst there was a rapid development of non-burnt alternative technologies to treat clinical waste in other countries, e.g. USA, there was a lack of proper attention to the potential health and safety impacts of such technologies.

5.2.2 A preliminary study carried out by Cole et al. (1993) for USEPA indicated that there were emissions of microorganisms from specific points in the microwave and mechanical/ chemical units. The study suggested that any technology which allowed access to the chamber during the shredding and grinding of untreated clinical waste, or where a phase of operation in the treatment process remained open to the environment would have the greatest potential of generating microbial aerosols. Microbial aerosols will invariably be generated if clinical waste is shredded or ground before treatment. Very good control must be in place to prevent escape of the aerosols from the shredder into the surrounding environment.

5.2.3 In November 1997, a Report was published by the USA National Institutes of Occupational Safety and Health (NIOSH) -"Control of Aerosol (Biological and Non-biological) and Chemical Exposures and Safety Hazards in Medical Waste Treatment Facilities" in which it is stated that " *Concern for medical waste treatment workers came from the unique character of the waste material and varying treatment technologies. Medical waste contains numerous chemicals that are themselves hazardous to worker health, and the Medical Waste Treatment technologies have the potential to generate others.* " The NIOSH Report also pointed out that little work had been carried out to assess the emissions from the alternative technology facilities apart from a study carried out for the USEPA on biological emissions conducted by Research Triangle Institute (Cole et al, 1993). Before this work there had been no research carried our specifically on the identification and assessment of hazardous exposures to the workers in the clinical waste alternative technology facilities.

5.2.4 The NIOSH report studied in detail four different technologies at four different sites:

a) Off-site steam autoclave
b) Off-site microwave
c) On-site prototype pyrolysis plant
d) Off-site mechanical/chemical treatment facility

and showed that the workers at clinical waste treatment facilities using alternative technologies are subjected on a daily basis to many types of health and safety hazards:

a) blood borne pathogens (e.g. AIDS, hepatitis B virus etc.)
b) other infectious agents
c) exposure to hazardous drugs, chemicals and aerosols
d) non-ionising radioactivity (microwave etc.)
e) noise (arising from shredding and compacting etc.)

f) heat stress
g) ergonomics
h) wounds from handling sharps and medical instruments

and exposure could be by the following routes:

a) skin
b) mucous membranes
c) inhalation
d) ingestion

5.2.5 Safety hazards and risks of injury were identified as:

a) lifting
b) moving
c) slips
d) falls
e) machine guarding
f) electrical problems

5.2.6 The safety hazards which are faced by workers on-site such as:

a) wet floors
b) untidy working conditions
c) hazards from electrical equipment
d) obstructions
e) ergonomic considerations
f) protective clothing - it's design and application
g) worker's hygiene
h) blood splashing

are identified in the report and are very similar to those found in industrial or hospital situations everywhere.

5.2.7 The three main areas of concern where information was not readily available were also identified as:

- The emission of volatile organic compounds (VOCs)
- Gaseous and particulate emissions
- The hazards from irradiation

Risk due to Toxic Volatile Organic Compounds in Air Emission

5.2.8 It is stated in the NIOSH Report that "*Volatile organic compounds are expected to be components of medical waste and may be formed and emitted during the treatment processes*." Emissions of gaseous and particulate contaminants from medical waste treatment technologies have not been well characterised. Thus, data were not available for selecting target chemicals to be monitored at the waste facilities.

5.2.9 The report indicated that there were a wide range of VOCs found in the facilities and only 29 VOCs which exceeded 0.05 mg/m^3 were reported. In the Summary of the Report, it stated that "*several VOCs were observed in each facility (i.e. the autoclave, microwave, chemical treatment and pyrolytic*

facilities), but no Occupational Safety and Health Administration (OSHA) Permitted Exposure Levels (PEL's) or American Conference of Governmental and Industrial Hygienists (ACGIH) Threshold Limit Values (TLV's) were exceeded". Results showed that whilst VOC concentration of individual chemical was acceptable within the facilities, the findings did highlight the total VOC concentrations could be high (e.g. 3 – 3.5 mg/m^3 in the autoclave facility and 1.5 – 6.5 mg/m^3 in the microwave facility). The findings also highlighted the variety of compounds that can be found in clinical waste and day-to-day variations in composition. For example, the formaldehyde concentration of an autoclave facility was found to be in the range of 0.08 - 0.18 mg, as compared to the ACGIH TLV of 0.37mg/m^3 (ceiling limit) and the OSHO PEL of 0.94 mg/m^3. Since all of the tests were carried out inside the building where the facility was located, it is not known what the levels were outside the building.

5.2.10 However, the exposure limits quoted are for single chemicals only. The health effect of a mixture is a more complex issue and it can be entirely different from those of individual components. In some cases, the individual chemical may act on the same organ or tissue or by similar toxicological mechanisms and their effects are 'additive'. In other cases, the overall effect is much greater than the sum of the individual effects and the effects are 'synergistic'. There are also 'potentiation' cases when one component has an effect but the second component does not but enhance the effect of the former one in a mixed exposure (American Conference of Industrial Hygienists, 1998; UK Health &Safety Executive, 1999; HK Labour Department, 1998).

Risk of Infection due to Micro-organisms in Aerosols

5.2.11 The risk of infection in using alternative and novel technologies is not well understood. The 1997 NIOSH report indicated that the risk of infection is difficult to estimate even when using very good data for exposure and documented seroconversion rates. Neither good exposure data nor documented seroconversion rates for clinical waste treatment workers were available. For this analysis, seroconversion rates for healthcare workers were used to represent the rate for clinical waste treatment workers. This was recognised to be an overestimate because most infectious organisms die off outside the ideal conditions of a host and the farther removed in time the organism is from contact with the host the lower the chance for causing infection. For waste, the temperature, humidity, and nutrient conditions are not optimal, so viability and, hence, infectivity will decline with time. Therefore, because clinical waste workers are not exposed to infectious agents immediately after they leave the host, clinical waste treatment facility workers are expected to have a lower seroconversion rate than healthcare workers. However, the NIOSH Report highlighted that:

a) The risk of infection not only extends to the workers themselves, but to their family and close associates outside the workplace.
b) This risk of disease transmission may be through the occupational acquisition of infection by the workers and the transmission of disease through normal modes to their families and friends.
c) This transmission may occur because the worker may take home

infectious agents on his clothes if personal protective equipment and clothing are not provided or not used as recommended.

d) This had happened in other occupations.

e) Increased caution is required if any of the secondary exposure involves immuno-compromised individuals (children, elderly, or HIV-infected).

Irradiation Hazards

5.2.12 The NIOSH report indicated that there was an incident involving a leakage of microwave close to the shredder of one of the microwave units. The levels much exceeded 10mW/cm^2 (the maximum limit set by the Occupational Safety & Health Association) and pegged the survey meter off-scale. Two microwave meters were used on site; however, both of them were out of calibration and one of them had lead batteries. The leak was readily reduced once the operator was told of the situation. The microwave radiation exposure would be controlled by regular maintenance with operating equipment. This finding points out that, in addition to regular checks of the treatment equipment, all testing equipment must be regularly checked, calibrated as needed, and maintained. Failing that, the operators may not easily notice the leakage from the microwave system until mishaps occur.

Other Hazards and Incidents

5.2.13 Further to the publication of the NIOSH report in 1997, there was a recent outbreak of suspected occupational-related tuberculosis (TB) among employees at a clinical waste treatment facility in USA (NIOSH, 1998). Three employees acquired active TB. It was shown that each of the 3 patients had a different drug susceptibility pattern, thus eliminating person-to-person transmission between these 3 employees. One of the cases was infected with a strain of tuberculosis bacteria (Mtb) identical to the strain identified in a person treated at a facility that sent waste to the clinical waste treatment facility. Furthermore, one of them was found to be multiple-drug resistant.

5.2.14 A detail evaluation of health hazard of an alternative treatment facility was conducted by the NIOSH of the Centres for Disease Control (CDC). The facility started operating in 1992 and was permitted to treat sharps, infectious waste and small amounts of human tissues using radio frequency wave (RF). The following waste types were not accepted: chemotherapeutic waste, chemicals and radioactive waste. The facility consisted of 13,500 square feet area. Approximately 2300 lb/hr (i.e. about 1000 kg/hr) of clinical waste was treated.

5.2.15 The alternative treatment facility used a primary shredder to shred the waste to 4-8" diameter and a secondary shredder to less than 3/8" diameter in a containment room. The shredded waste was then compacted to a density of 25 pounds per cubic foot in a press room. Water was sprayed onto the shredded waste to ensure 10 to 15% moisture. The shredding and compacting processes were carried out in an enclosed area which was under negative pressure. Exhaust air was filtered by a series of filter to ensure sterility when discharged

to the surrounding environment. The moistened waste was then heat-treated at 95^0C using RF.

5.2.16 CDC identified several factors in the alternative treatment facility that could result in employee exposures to aerosolised bacteria (including Mtb) and other bloodborne pathogens (e.g. hepatitis B, hepatitis C, human immunodeficiency virus etc):

a) Shredding and compacting of infectious waste created the potential for aerosolization of the products contained in the waste prior to heat treatment;
b) Deficiencies in the design of the process which resulted in the clogging of the process line, and a ventilation system which was unable to ensure that the in-feed chute (for feeding clinical waste to the treatment facility) would remain under negative pressure when such clogs occurred. When clog occurred, a situation called "blowback" frequently occurred, i.e. the air from the containment room would blow back out of the in-feed chute.
c) Direct contact of the workers with the waste (including exposures to needles, sharps, blood, human tissues etc.) during repair and maintenance of the equipment such as shredders;
d) Exhaust air from the RF treatment unit was originally exhausted outdoors. However, due to odour complaints from the local community, the company had to change the process to recirculate the odorous exhaust air from the treatment unit back into the containment room.
e) The process required all the employees to use airline respirators working in the containment room. The inadequacy of the respirators was noted since NIOSH investigators still detected odour in the containment area while using the company-supplied airline respirators.

5.2.17 The CDC also identified potential fire hazard of the alternative treatment facility. They noted that after prolonged use, carbon would accumulate on the surface of the RF oven ("cooking vessel"). They observed that a vessel actually "arc' and caught fire while being removed by a fork-lift.

5.2.18 The CDC further noted that the process required homogeneous treatment of waste at 95^oC for a fixed period of time to ensure inactivation of infectious micro-organisms. However, they observed that the temperature probing techniques employed would not accurately measure the temperature and that the employees informed the NIOSH that waste not reaching 95^oC was occasionally disposed of without being re-processed.

5.2.19 A draft WHO publication (WHO, 1999c) reported that 13 other workers also showed evidence of being exposed to tuberculosis in the RF facility but were not symptomatic. It also reported that tuberculosis has not been reported at other USA plants where sealed containers of clinical wastes were processed directly without opening and/recycling the containers.

5.2.20 On 4 Oct 2000, the CDC further reported the use of advanced molecular biotechnology to identify the DNA fingerprints of the Mtb bacteria and confirmed that processing clinical waste in the alternative clinical waste treatment facility resulted in the transmission of Mtb to at least 1 facility worker (Johnson et. al., 2000).

Discussion

5.2.21 Sufficient independent work has not been carried out on all of the alternative technologies such that all the inherent problems have been identified with certainty. This is particularly the case with respect to the emissions both within the building containing the systems or externally, and the effects on the health and safety of the workers or the general public. The scientists who have carried out the work in this field have called for the additional study to be carried out. There is also a need for comprehensive operator training, preventive maintenance systems and regular inspections to prevent, for example, the leakage that occurred around one of the microwave units and other environmental and safety hazards mentioned above.

5.3 EFFICACY

5.3.1 The introduction of the alternative technologies for the treatment of clinical waste caused concern amongst the environmental and public health agencies in a number of States in the USA. As a result, the representatives of about 15 States in the USA organised a series of meetings between 1992 and 1994 to discuss the issues and arrived at a set of standard approaches to the regulation of the alternative clinical waste treatment systems. One of the main concerns is the efficacy of the technologies to kill the wide range of micro-organisms in a complicated matrix in the clinical waste. Questions were also asked about the effects of the new systems on the occupational health and safety of workers, the environment and the effects on the general public. The technical and administrative procedures for permitting and reviewing the new technologies were the principal aims of this group as well as the formulation of a set of standards. In 1994 the group became known as the State and Territorial Association on Alternative Treatment Technologies (STAATT). The first official document produced by the organisation was published in 1994 and was the Technical Assistance Manual State Regulatory Oversight of Medical Waste Treatment Technologies.

5.3.2 This guidance document describes the consensus of the participants on the following topics:

a) Recommendations as to the levels of microbial inactivation for use in the evaluation of treatment systems;
b) Establishment of specific pathogen surrogates for efficacy testing of technologies;
c) Development of enumeration formulae for the quantification of efficacy test results;
d) Defining specific evaluation procedures for generators:
    i. Commercial facilities

ii. Healthcare facilities
iii. Research and development facilities
iv. Private practitioner facilities

f) Devising specific criteria and requirements for:
i. Waste residue disposal
ii. Operator training
iii. Challenge loads

g) Development of testing protocols for:
i. State permitting/licensing of treatment systems
ii. Site permitting
iii. User verification and challenge testing by different types of use

5.3.3 Since its publication, this guidance document has become widely accepted as the standard reference document on the subject in the USA and in a number of other countries. One particular standard defines the levels of microbial inactivation required for clinical waste treatment (See Table C). The minimum requirement for alternative treatment technologies recommended by STAATT is Level III. The various alternative treatment technologies should be able to achieve Level III provided that the equipment is operated properly.

TABLE C STAATT Standard for Microbiological Inactivation

Level I	Inactivation of vegetative bacteria, fungi and lipophilic viruses at a 6 $\log_{10}$ reduction or greater.
Level II	Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites and mycobacteria at a 6 $\log_{10}$ reduction or greater.
Level III	Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites and mycobacteria at a 6 $\log_{10}$ reduction or greater; and inactivation of *B. stearothermophilus* or *B. subtilis* spores at a 4 $\log_{10}$ reduction or greater.
Level IV	Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites and mycobacteria and *B. stearothermophilus* spores at a 6 $\log_{10}$ reduction or greater.

5.3.4 Since the publication of the STAATT document in 1994, new technologies have been introduced to the clinical waste market. These were addressed in the 1998 meeting of the STAATT and the existing recommendations were revised to take account of the recent technological advances. The revised edition (STAATT II) is due to be published in the near future.

5.3.5 However, up to the moment, there are no national standards for all the countries studied in this report. For example, even in USA where the treatment of clinical waste by alternative technologies has been debated for over ten years, a national standard for clinical waste treatment has yet to be realised.

5.3.6 A private company, the Underwriters Laboratories, Inc. in USA (UL), after consulting with representatives of the STAATT which has developed the guidance document for evaluating alternative technologies, is preparing a draft Standard (UL2334) with a view to seeking recognition of this Standard as an American National Standard through the Accredited Organisation Method of the American National Standards Institute. A Technical Committee has been set up to address various issues of emerging technologies. The Committee has established 7 Working Groups to assist in organising and developing various requirements. These Groups are as follows:

a) Efficacy Work Group
b) Equipment / Facility Protection Work Group
c) Input / Output Work Group
d) Maintenance Work Group
e) Regulatory Acceptance Work Group
f) Worker Safety Work Group
g) Production Control Work Group

5.3.7 The Standard is intended to determine whether individual equipment or system provides for sufficient microbial inactivation and reduction of the risk of injury to persons and damage to property incident to their use. To date, the Standards Development Technical Committee has met five times in 1999 and 2000. However the Standard is still in the draft stage.

5.3.8 Furthermore, the UK Environment Agency and Scotland EPA are still considering recommendations from consultants on whether the operation of clinical waste treatment facilities in the UK should achieve the Level III criteria and that in certain situations, [e.g. from hospital wards with known pathogens such as multiple drug-resistant *Staphylococcus aureus*] waste should be treated in accordance with Level IV (UK NHS, 1998). This may be particularly relevant to the HK situation as it has been reported that *Staphylococcus aureus* resistant to most known antibiotics in the world has already been isolated in hospitals in HK (SCMP, 1999).

5.3.9 In respect of thermal treatment systems for disinfection of clinical waste, the UK Environment Agency and Scotland EPA are also still considering whether it is appropriate to specify a minimum temperature to ensure adequate killing of the micro-organisms (UK NHS, 1998).

5.3.10 The STAATT II meeting also reckoned that operation of alternative technologies require mandated operator training because the efficacy of treatment and safety will depend on the operator skills. The proposed "ASME Standard for the Qualification and Certification of Medical Waste Incinerator Operators (Sept 1992)" has been reviewed for its potential applicability as a guideline for developing required elements for operator training. The guideline has yet to be prepared and approved by the relevant authorities.

Discussion

5.3.11 The criteria for efficacy testing for the alternative clinical waste treatment technologies have taken ten years to develop and this has been an

iterative process, which will continue until all of the problems which have been identified are overcome. This issue applies to all of the alternative and novel technologies where disinfection of the waste is the main objective and there is a need to demonstrate that the treated waste is disinfected to an acceptable scientifically based standard.

5.4 RELIABILITY AND EASE OF MAINTENANCE

5.4.1 Autoclave has been used by hospitals for many years for sterilizing surgical equipments and laboratory cultures. There should be less maintenance problem of the equipment itself. However, shredders may pose considerable operational and maintenance problems as metallic and other hard objects may lead to blockage and damage of the shredders. Independent information on the reliability of other alternative technologies and their ease of maintenance is not readily available and this is one area that requires further study. This is particular true for the novel treatment technologies.

5.4.2 On the other hand, incineration has a long history. In 1877, the first municipal waste incinerator in the world was opened in Manchester England following earlier trials of the system in Nottingham. High pressure steam was first generated from waste in Lancashire in September 1899; this ultimately led local councils to generate electricity to power trams, light their towns, pump water or sewage and, later, recharge electric vehicles. In 1914, there were 338 municipal incinerators in towns and cities throughout the United Kingdom. There were 295 with boilers to recover heat of which 77 also generated electricity. From the 1930s onwards incineration of municipal waste developed throughout the world. The recovery of heat from the combustion of clinical waste is well understood and is now practised throughout Europe. For example, the "state-of-the-art" pyrolytical incinerator facility in the Netherlands illustrates that, with proper engineering design, pyrolysis and gasification can be used for the successful treatment and disposal of clinical waste with environmental benefit. This long history and experience has demonstrated the reliability of the incineration technology.

5.5 THE HANDLING OF RESIDUES AND FURTHER TREATMENT REQUIREMENTS PRIOR TO FINAL DISPOSAL

5.5.1 One of the factors relevant to the treatment of clinical waste by most alternative technologies (wet thermal treatment, chemical treatment and microwave) is that the waste after treatment is wet. This may require the treated waste to be dried or contained in leak-proof containers prior to delivery to a landfill site or Waste-to-Energy plant.

5.5.2 Another problem arises when the waste is not rendered unrecognisable by the treatment system before it is transported to the landfill site. There is likely to be very strong public reaction if the media or the general public see the residuals irrespective of whether the residuals have been disinfected (see section 5.6 on public perception of risk). This is because it is not possible to

determine visually whether the residuals have been disinfected. Whereas if the waste has been treated by incineration, gasification, pyrolysis or plasma technology, the clinical waste will be converted into ash and rendered unrecognisable. It will be obvious to the casual observer that the clinical waste has been heat-treated and thus rendered sterile.

5.5.3 As clinical waste treated by alternative technologies (autoclave, microwave and chemical treatment) would still contain residual amounts of wide arrays of chemicals, pharmaceuticals and cytotoxic drugs and produce bad odour, the treated clinical waste should be properly labelled, packaged, transported and disposed (Ontario EPA, 1994). For incineration, gasification, pyrolysis or plasma-based technology, the amount of residue is greatly reduced. However, it may be necessary to further treat the ash by solidification to reduce its metal leaching properties.

5.6 SPACE REQUIREMENTS

Space for treatment equipment

5.6.1 The space required for an autoclave with a treatment capacity of 600 tonnes per year is as follows: the autoclave itself measures 2 m in diameter by 5 m in length. The space required to site and operate the plant, the shredder or grinder and other ancillary equipment is approximately 100 square metres and a further 100 square metres to store the wheeled containers (transit skips) for holding untreated and treated clinical waste.

5.6.2 The space requirement for an autoclave, microwave or chemical treatment plant would be very similar except in the case of a chemical treatment plant, approximately 25 square metres would be required for safe storage of the chemicals.

Ancillary space

5.6.3 The Clinical Waste Control Scheme for Hong Kong proposes that all the clinical waste from all the hospitals and clinics will be treated by the CWTC. The population of HK is 7 million at the moment and 8 million in 10 years time. If there is to be a central facility or several regional facilities in HK, the clinical waste will need to be transported to the facility contained in rigid transit skips in accordance with the United Nations recommendations. The number of skips used by the hospitals, clinics and collectors will be very significant. Facilities will be also required to clean and disinfect the skips automatically either on site or at other premises. The management of the skips will be a significant factor in the use of space since they have to be stored both at the hospitals and at the treatment facility before and after treatment together with a supply of spare skips in case of damage.

5.6.4 To handle the clinical waste in bulk in a cost-effective manner and reduce manual handling, it is necessary to provide equipment for loading the skips and feeding the waste into the treatment compartments automatically.

Considerable space should also be provided.

5.6.5 A site of around 200 square metres for the treatment plant together with ancillary space for holding and disinfecting skips may be difficult to find in the hospitals or clinics in Hong Kong where space is at a premium. The space required for other alternative technology plants, the ancillary equipment and the storage area for the filled containers awaiting processing is unlikely to be less than the 200 square metres shown above and could be more. Equally it is unlikely to be much less than that required for an incineration plant with the same throughput. This is certainly the case if the facilities are to be sited in a hospital. Access to the facility would also be a big problem if a regional treatment facility is located within a hospital setting in HK.

5.7 PUBLIC PERCEPTION OF RISK

5.7.1 *Risks from clinical waste*

The EC Priority Waste Stream Project Management team investigated the risks from clinical wastes and arrived at a view that is shown below. In general, risks can be divided into 2 groups, perceived risk and actual risk:

Perceived risk
A risk, whether real or not, which the public or health or environmental professionals, believe may result from clinical waste or its disposal, apart from any scientific validation of the risk.

Emotional risk
An emotional risk is a perceived risk. Commonly, where the level of risk is increased due to the emotional response of individuals to a prevailing situation which has offended their sensibilities or ethics.

Actual risk
Risk which is known to exist and for which a probability can be measured or inferred.

Risk of infection
An actual risk presented by pathogenic micro-organisms, exposure to which could result in an infection.

Toxic risk
An actual risk presented by any substance (drugs or not), exposure to which could provoke anatomical or functional harm.

Physical risk
An actual risk is one of accidental bodily damage or laceration that may or may not lead to subsequent infection.

5.7.2 Most people react when faced with waste from the treatment of human beings. Their disgust or repulsion, as when in contact with most types of waste, is related to their personal sensibility and ethics, and to the collective imagination; the experience has social and cultural connotations. People close

enough to see, smell and touch the waste are likely to be more deeply affected. This psycho-emotional threat would be independent of any scientific validation or refutation of risk. The sense of threat might continue to exist, therefore, even when the hazard is shown not to exist.

Health workers' perceptions may be due to the difficulty of making a logical scientific analysis of the risk. This lack of knowledge nevertheless means that people tend to see all clinical waste as health risk. The logic of the deeply felt risk thus tends to increase the quantities of risk unless some scientific check is imposed.

5.7.3 If the people not working in healthcare sector still perceive a serious risk from clinical waste, it may be explained thus:

- the probable consequence of some diseases is death (AIDS);
- the non-expert is not in control of the risk (micro-organisms which carry infections are invisible);
- waste is an intuitively plausible link in the chain of infection;
- non-experts cannot distinguish between the basic and sensational information; and
- identifying who or what is "responsible" for the risk (person, institution, or industry) is difficult.

5.7.4 ***Risks from the treatment and disposal of clinical waste***

Perceived risks are also related to the ways in which clinical waste may be processed:

- **Landfill** is seen as hazardous to the environment, particularly to health, fauna and flora, and groundwater. Unregulated landfilling is seen as more hazardous than regulated landfilling. Landfilled clinical waste is also seen as providing a culture medium for pathogenic micro-organisms.
- **Composting** is seen as hazardous to health and the environment, on the supposition that compost might be contaminated by pathogenic micro-organisms from the waste.
- **Alternative treatment technologies.** These were not considered in the EC Project risk assessment but health workers perceive them as a risk by being source of Volatile Organic Compounds and other toxic substances through air emissions when sited in hospitals. The general public will also have the same perception of risk similar to those when dealing with clinical waste at any facility.
- **Incineration on hospital sites.** People in the neighbourhood of hospitals tend to see the hospital incinerator as a hazard to their health and environment.
- **Centralised incineration.** People also, however, tend to assume that big technology entails big risk. Centralised incinerators are much larger than on site incinerators and so perceptions of greater risk are naturally attached to them. The perception is aggravated when the central incinerator processes clinical waste rather than household waste.

5.7.5 The gap between non-experts and experts lies in the comprehensiveness of their conception of risk. To experts, risk is a calculated value derived from observed mortality or morbidity; for non-experts the calculated value is altered by their judgement of, or outrage over, a publicised event or controversy.

5.7.6 A perceived risk may still be a real risk. The preponderance of needle stick accidents do not result in a hepatitis B infection, but some do. Nevertheless the hazards most feared by non-professionals do not necessarily pose the greatest risk. Subjectivity and emotion affect the perception of risk from clinical waste.

5.7.7 Industry has identified over 20 "outrage" factors in the non-expert perception of events. They include:

- **Free will**. A voluntary risk is more acceptable than an imposed risk: e.g. mountaineering.
- **Control**. Someone who imagines he controls the outcome is more tolerant of risk: e.g. driving *vs.* flying.
- **Fairness.** The public may expect, or accept, that people facing greater risk will get greater benefits: e.g. the x-factor in military pay.

Discussion

5.7.9 The perception of risks associated with the treatment and disposal of waste particularly clinical waste is heightened in the minds of the general public as shown in the extracts from the EC Priority Waste Streams Project Report. The NIMBY (not in my back yard) syndrome is well understood by waste management professionals and it is only by being transparent in all dealings with the public can this syndrome be overcome. There are particular problems in dealing with incineration plant mainly due to the gap between the professionals and the general public. To experts, risk is a calculated value derived from observed mortality or morbidity; for non-experts the calculated value is altered by their judgement of, or outrage over, a publicised event or controversy. The publication of outdated or erroneous data, which can be given a spin by some parties, can affect the perception of the general public and this should be taken into account when dealing with any proposal to install and operate any new facility. The general public is not the only stakeholder that perceive risk and object to a clinical waste treatment facility, the clinical professionals and other workers also perceive risks to their health and well-being associated with the siting of alternative technologies within the hospitals if they know that VOCs may be released in the hospital environment. This is heightened by the fact that they do not have sufficient information to make a logical evaluation of the risk.

5.8 SUMMARY

5.8.1 The disposal of untreated clinical waste in landfill is an option only where the authorities genuinely lack the means or where the level of waste management is still in a very early stage of development and even then proper

control has to be undertaken. In the European Union (EU) it is illegal to place untreated clinical waste into landfill sites.

5.8.2 Incineration of clinical waste has a long history. Over this time, data and information have been collated, analysed and evaluated. The proposed EU Directive on waste incineration comes directly out of this long-standing and well-documented dependence on incineration. Similarly, the scientific testing protocols have undergone significant developments to match the exacting emissions and environmental standards. Incineration still remains the most effective means of disposing of all clinical waste.

5.8.3 In comparison, alternative and novel technologies for the treatment of clinical waste are still in the development stage notwithstanding their rapid emergence over the past 20 years. In summary, it should be noted that:

a). The efficacies of killing microorganisms by alternative technologies, unlike high temperature incineration, depend very much on operational conditions and nature of clinical waste. Details protocols to assess such efficacies have to be developed. However, the protocols have only been operating for the past ten years and these too, like the technologies they were set up to regulate, are still in the development stage. Furthermore, there are no international standards for efficacy testing or emission standards for the alternative and novel treatment technologies at the moment. The STAATT which is the best available standard for efficacy testing is still under development.

b) Researchers studying the alternative technologies have discovered that there is a scarcity of independent research into their effects upon the environment and human health.

c) The limited research that has been carried out indicates that there are a variety of VOC's and other chemicals emitted during the process and the amounts and types vary on a day-by-day basis. Hundreds of chemicals are used in the hospitals and clinics. These include pharmaceuticals, cytotoxic drugs, disinfectants, bacteriological sprays, ointments, sterilising agents etc. Tens of thousands of other chemicals and pharmaceuticals are also being tested in pre-clinical and clinical research laboratories associated with hospitals and universities. Whilst expired chemicals should be separately collected as chemical waste, such chemicals may still be present in small/residual amounts in the used syringes, 'empty' ampoules, swabs or soiled dressings, animal beddings etc.

d) The inability of destroying or removing such chemical contaminants by alternative technologies should be considered. For any communal treatment facility, it would have to handle waste arising from various sources which may comprise ampoules and syringes contaminated with pharmaceuticals, chemicals, cytotoxic drugs, and disinfectants, and infectious or chemically- contaminated animal carcasses and beddings arising from medical research, in addition to human tissues and

amputated organs, soiled dressings contaminated with blood and other body fluids, sharps, infectious agents, microbiological cultures etc. Since it is improper and not practicable for the operators of treatment facilities to inspect every bag of clinical waste and confirm the absence of pharmaceuticals, chemicals or broken thermometers before treatment by alternative technology, toxic vapour will be given off during autoclave or microwave treatment if the hazardous materials are improperly segregated and find their way into the clinical waste stream. On the other hand, disposal of clinical waste by high temperature incineration may provide for a fail-safe solution.

e). Whilst the limited tests carried out by NIOSH (NIOSH, 1997) inside the selected treatment facilities indicated that the discharges were within the threshold limit values of that country,

- no tests had been recorded outside such facilities (as evaluating the environmental impacts of such facilities is not under the purview of NIOSH); and
- the cumulative impact of the wide arrays of residual chemicals on health and safety is not known.

f) With respect to the protection of the environment and harm to human health, sufficient independent work has not yet been carried out to develop protocols for this. For example, the Environment Agency for England and Wales has yet to consult its proposal for the control of the alternative and novel technologies. The recent CDC's report of occupational acquired tuberculosis of 3 workers (including one worker with multiple drug resistant) in an alternative treatment facility in USA (NIOSH, 1998; WHO, 1999c; Johnson et. al., 2000), where alternative technologies are developed and used more than any other countries, indicated that worker's health should not be overlooked in adopting a particular technology. The risk of occupational acquired infections in clinical waste disposal facility is more real than the perceived risk of dioxin formed during clinical waste incineration.

g). Novel technologies have presently neither the track record nor the regulatory framework to be considered as a serious contender at this stage.

5.8.4 A broad comparison of the various treatment technologies is presented in Table D.

TABLE D BROAD COMPARISONS OF DIFFERENT TECHNOLOGIES OF CLINICAL WASTE TREATMENT

COMPARISON CRITERIA	AUTOCLAVE/WET THERMAL TREATMENT	ELECTROMAGNETIC WAVE (MICROWAVE AND RADIOWAVE)	CHEMICAL DISINFECTION	HIGH TEMPERATURE INCINERATION
Destruction of infectious microorganisms				
• Efficacy	• Good - can achieve Level III destruction of infectious microorganisms	• Good - can achieve Level III destruction of infectious microorganisms	• Good - can achieve Level III destruction of infectious microorganisms	• Very Good - fully destroy infectious microorganisms
• Factors affecting efficacy	• Temperature and pressure • Improper packaging may affect steam penetration; 'cold' spot may happen. Shredding required to improve efficacy • Length of treatment cycle • Incomplete air removal from chamber may affect steam sterilization • Size of waste load	• Microwave source strength • Duration of microwave exposure • Extent of waste mixture • Moisture content of waste • Shredding for improving efficacy • Reported that microwave efficiency will decrease if liquid content of waste > 10%, metal content > 1% or metal pieces > 0.2 kg	• Chemical concentration • Temperature • pH • Contact time with chemical • Adequate mixing with chemicals is essential. Shredding is therefore important • Disinfectants may be interfered by organic components of waste	• Adequate mixing • Moisture content of waste • Filling of combustion chamber • Residence time
Destruction of sharps	• Cannot destroy sharps			• Incineration destroys all sharps and make waste unrecognizable
Destruction of body parts	• Not suitable to treat body parts due to cultural practice			• Incineration destroys all body parts and make waste unrecognizable
Destruction of residual amounts of cytotoxic drugs and pharmaceuticals	• Cannot destroy residual amounts of cytotoxic drugs and pharmaceuticals in clinical waste			• Incineration can destroy all residual amounts of cytotoxic drugs and chemicals in clinical waste
Impacts on the Environment	• May generate toxic volatile organic compounds, carcinogenic formaldehyde, mercury vapour and other un-characterized air emissions • Generate objectionable and foul odour • Generate wastewater from condensate. Wastewater may be regarded as chemical waste and treated as such • Treated waste may still contain residual amounts of chemicals, pharmaceuticals, mercury and cytotoxic drugs which may need proper handling.	• May generate toxic volatile organic compounds, carcinogenic formaldehyde, mercury vapour and other un-characterized air emissions • Small amount of wastewater may be produced from condensate. Wastewater may be regarded as chemical waste and treated as such • Treated waste may still contain residual amounts of chemicals, pharmaceuticals, mercury and cytotoxic drugs which may need proper handling.	• May generate toxic volatile organic compounds, carcinogenic formaldehyde, mercury vapour and other un-characterized air emissions • Disinfectants may react with residual chemicals to produce unknown chemicals • Very large amount of wastewater will be generated. Wastewater may be regarded as chemical waste and treated as such • Treated waste may still contain residual amounts of chemicals, pharmaceuticals, mercury and cytotoxic drugs which may need proper handling.	• Toxic volatile organic compounds will be incinerated. However, dioxins and mercury vapour may be formed • All air pollutants should be removed by appropriate pollution abatement equipment
Handling of waste treatment residues	• Treated wastes should be landfilled or incinerated in MSW Incinerator • Treated wastes which may be contaminated with residual amounts of chemicals, pharmaceuticals and cytotoxic drugs should be properly disposed			• Bottom ash should be disposed of in sanitary landfill

COMPARISON CRITERIA	AUTOCLAVE/WET THERMAL TREATMENT	ELECTROMAGNETIC WAVE (MICROWAVE AND RADIOWAVE)	CHEMICAL DISINFECTION	HIGH TEMPERATURE INCINERATION
Volume reduction of treated waste	• Cannot significantly reduce volume of waste unless shredder or compactor is used			• Incineration reduces volume of waste without shredding
Weight reduction of treated waste	• Cannot reduce weight of waste. Weight may be increased due to addition of water/steam or chemicals			• Incineration reduces weight of waste by more than 80%, depending on the content of combustible materials.
Operational safety and health issues	• Shredding of bags of clinical waste for better penetration of steam may lead to production of microbial aerosols and need proper control • Maintenance of shredders contaminated by clinical waste may pose occupational safety and health risks • Autoclaves working under high pressure need to be carefully control as required under the Boiler and Pressure Vessel Ordinance	• Shredding of bags of clinical waste for even heating of waste may lead to production of microbial aerosols and need proper control • Maintenance of shredders contaminated by clinical waste may pose occupational safety and health risks • Microwave and radiowave that cannot be detected by human senses, can pose significant health risk if leakage occurs. Leakage has to be monitored continuously in the workplace	• Shredding of bags of clinical waste for exposure of waste to chemicals may lead to production of microbial aerosols and need proper control • Maintenance of shredders contaminated by clinical waste may pose occupational safety and health risks • Many disinfectants are hazardous or toxic and need proper storage and careful handling	• No shredder is required and hence does not have microbial aerosol problem created by the use of shredders • Fire hazard should be properly controlled
Reliability and ease of maintenance	• Hard objects in waste may pose problems to shredder. • Other comparative information not available			• Technology well known and developed for over a hundred years • No shredder problem
Capital cost of facility	• Relatively lower	• Relatively higher	• Relatively higher but may be lower than modern incinerator	• Relatively higher
Waste treatment costs	• Relatively lower	• Relatively higher	• Relatively higher	• Relatively higher
Space requirements • Equipment	• Same for both autoclave and electromagnetic wave facilities		• Slightly more than autoclave and electromagnetic wave facilities due to the need for storage of chemicals	• More than others due to presence of air pollution abatement equipment
• Ancillary	• Same for all facilities as they all need waste storage areas, storage areas of transit skips for all hospitals and clinics, area for cleaning and disinfecting skips, areas for safety equipment, reception area for waste collecting vehicles and facility to weigh vehicles and skips, cold storage area for holding human organs, general ventilation and odour control facilities etc			
Public perception	• Unlikely attract attention from public and green groups due to lack of information on documented health risk studies • Hospital workers may disagree with the siting in hospitals			• Public perception of risk always lead to objection from the local residents and green groups
Further treatment requirements prior to final disposal	• Shredding and compacting/baling prior to delivery to landfill • Waste should be dried or transported in watertight vehicle/container before delivery to landfill			• Shredding and compacting/baling of waste not required before delivery to landfill
Others	• Autoclave is a traditional method for treating microbiological cultures in clinical laboratories • Medical institutions are familiar with this method		• Some facilities require patented disinfectants which may be expensive and not flexible in the use of other chemicals	• There is potential to recover heat. • Can treat all clinical waste types without stringent segregation of waste within hospitals and clinics

CHAPTER 6 REVIEW OF INTERNATIONAL PRACTICES

6.1 EUROPE

Background

6.1.1 Nearly all environmental legislations for the countries within the European Union (EU) is decided by the EU and implemented in local legislation after a Directive is passed by the EU. "Towards Sustainability" is the European Community Programme of policy and action in relation to the environment and sustainable development (is better known as The Fifth EC Environmental Action Programme). The general approach and strategy of the Fifth Environmental Action Programme which was approved by the Council and the Representatives of the Governments of the Member States on February 1 1993, differs from previous programmes as its title 'Towards Sustainability' implies, the programme sets longer term objectives and focuses on a more global approach.

6.1.2 One of the key precepts of the Action Programme is the sharing of responsibility, which requires dialogue and action by all partners in society. The Action Programme, as far as waste management is concerned, means putting into practice the Commission of the European Communities' "European Community Strategy on Waste Management" which was approved by the Council, of what is now, the European Union (EU) in September 1989.

6.1.3 One of the methods devised to implement the strategy was to select certain priority waste streams one of which was for Health Care Waste (HCW) and to apply the hierarchy or "ladder principle" for dealing with the waste. Top priority is to prevent waste being produced and the order of priority is shown below; dumping of untreated HCW is of course unacceptable and does not appear on the list.

1) Prevent
2) Re-use
3) Recycle
4) Incinerate (with heat recovery)
5) Incinerate
6) Landfill

6.1.4 In order to implement the Strategy for Waste Management (particularly for the Priority Waste Streams), which takes into account of the hierarchy approach, it is necessary for the Commission of the European Communities (CEC) to seek environmentally acceptable solutions. This was carried out in the case of the Priority Waste Streams with the groups and organisations that directly influence the production and consumption patterns ahead of the waste production stage in order that results can be achieved in the short term and behaviour patterns changed in the long term.

6.1.5 This approach depends upon thorough discussion taking place at EU level with the parties most affected by a particular priority waste stream. Independent consultants take part in the project to ensure that the strategic discussion is properly monitored and a consensus arrived at.

6.1.6 When properly carried out, this approach is likely to ensure maximum participation and lead to everyone fulfilling their responsibilities in achieving "sustainable development" in accordance with the CEC Waste Strategy. The HCW Priority Waste Stream Project Group was a representative group of manufacturers, producers, users, waste managers, environmental protection and recycling groups together with representatives of the Member States and with the support of the Commission and Consultants. In addition a reference network was established enabling all interested parties to participate. The HCW reference network had almost 300 members from 25 countries both within and outside of the EU. The HCW Project Group first met in June l992 and completed a programme of work leading to a strategy and implementation programme, which could be develop into EU legislation. In the case of HCW, the work of priority Waste Stream Project has not been turned into legislation and the work is now out of date. Nevertheless the information contained therein has been very useful both nationally and internationally and has made a significant contribution to the database, which for this waste stream is generally accepted as being small and unfocussed. Four Directives are particularly important as far as the countries in the EU are concerned. They are:

- The Framework Directive on Waste
- The Landfill Directive
- The Hazardous Waste Directive
- The proposed Waste Incineration Directive

6.1.7 The Framework Directive has been in force and amended a number of times since 1975. The Landfill Directive, which is in the process of being implemented in the countries in the EU specifically, excludes the landfilling of hospital or other clinical wastes arising from clinical or veterinary establishments which are infectious. (Infectious is as defined in the Hazardous Waste Directive.) All Directives are mandatory on all Member States of the EU and they have to implement through their own legislation within the time scale set by the Directive. The exclusion of infectious waste is one of many stringent requirements for landfill, which also includes a programme for reducing the amount of municipal biodegradable waste going to landfill to 35% of the 1995 amount. The proposed Waste Incineration Directive is to prevent, or where that is not possible to reduce as far as possible, the environmental impacts of emissions into air, soil, surface water and groundwater and the resulting risks to human health from the incineration and co-incineration of waste. Stringent operational conditions and technical requirements are set out as are emission limit values for waste incineration. When implemented this Directive will have a considerable effect on the way in which HCW is dealt with in the EU in the future (see 6.1.18). No timetable for the adoption of the Directive has yet been drawn up.

Germany

6.1.8 Germany has an estimated population of just over eighty million. Germany is highly urbanised, with about 85 per cent of the people living in communities of at least 2,000 people. The principal city is Berlin the capital of Germany with a population of about three and a half million.

6.1.9 In 1984 there were 554 on-site hospital incineration plants. By 1987 this had declined to 218 and at the moment there is there is only one hospital (Heidelberg) with a hospital waste incinerator and this one may be closed at the end of this year. Except for the hazardous waste incineration plants, there is only one off-site commercial incinerator in Kiel and two separate treatment units in Augsburg and Bielefeld in combination with a municipal waste incineration plant. Non-infectious clinical waste (German definition) from patient care is normally burned in all of the about sixty municipal waste incineration plants in Germany. Microwave and wet thermal treatment systems are in use in Germany but the exact numbers are not known. However the number in use is decreasing due to over capacity of the regional hazardous waste incinerators. The cost per tonne of incinerating clinical waste has been structured so that it is attractive to use these hazardous waste incinerators for clinical waste. For details of the situation in Germany see Table E.

TABLE E **Overview of Plants for the Thermal Treatment of Infectious Waste, Human Organ Waste and Body Parts From Hospitals and Other Healthcare Establishments in Germany** (Date: 08/2000)

Incineration plants for infectious waste or plants with special incineration chambers/ units for the incineration of infectious waste	**Hazardous waste incineration plants burning infectious waste together with other hazardous waste**	**Special plants for the disinfection of infectious waste**
Augsburg Treated waste in 1999: 1,373 tonnes Bielefeld Treated waste in 1999: 1,516 tonnes Kiel-Wellsee Treated waste in 1999: 527 tonnes Heidelberg Treated waste in 1999: 400 tonnes (treatment capacity: 2000 t/year)	Bergkamen, Biebesheim am Rhein, Burghausen, Frankfurt am Main, Hamburg, Herten, Krefeld, Leverkusen, Ludwigshafen , Marburg, Schwedt/Oder, Wesseling, Dormagen, Schwarzheide , Baar-Ebenhausen, Schöneiche	Braunschweig, Zwönitz, Frießnitz Treatment capacity: approximately 800 – 1,000 t/year Leipzig Freittal Treated waste in 1999: 52 tonnes Münster Treatment capacity: approximately 130 t/year

France

6.1.10 France is a member of the European Union and has an estimated population of 58 million with over 9 million living in the metropolitan Area of Paris, over 1.2 million in Greater Marseilles, and over 1.2 million in Greater Lyon. The current situation in France with respect to clinical waste is that most clinical waste is incinerated:

Technologies	Number	Annual Tonnage of HCW
On-site hospital incinerator	1	Not known
Off-site incinerator	3	40,000
Municipal incinerator	19	90,000
Thermal treatment	20	22,800

Greece

6.1.11 Greece is a country of mostly small towns and villages. It has a population of just under 10.5 million. Much of the urban population is concentrated around Athens the largest and most important city as well as being the capital, with a population of 3 million. The other large urban area is Thessaloníki, with a population of nearly 400,000.

6.1.12 A recent survey (1999) gave the following results:

- According to the national planning of the Ministry of Environment, which is based on an older (1986) study, central clinical waste incinerators are to be built in the main Districts of Greece.
- A new clinical waste incinerator is now under construction by the Union of Municipalities of the Major Athens Area. It consists of two units (one as stand-by), each with a capacity of 15 tonnes/day. A second incinerator, for the District of Central Macedonia, in Thessaloniki, is in the design phase. It consists of two units (one as stand-by), each with a capacity of 7.5 tonnes/day.
- Flue gases will comply with the EU Guideline for toxic waste incineration.
- Only a few large hospitals in isolated areas will continue to operate the on-site hospital incinerators.
- The "Ministerial Decision on the Management of Hospital Waste in Greece" is still under preparation and is expected to be published before the end of this year.
- The total number of hospital beds in Greece is 58,000-60,000. In many older hospitals the incinerators are not operating any more.
- Five hospitals with about 2,500 beds each have an incineration plant that is still operating and five hospitals with about 2,000 beds have an incinerator under construction.
- There still exists a small (700 kg/day) central incineration unit in Athens, serving a small group of hospitals and operated by the Union of Municipalities of the Major Athens Area.
- At the moment most clinical waste is disposed of in landfill sites, together with the municipal waste.

Ireland

6.1.13 The island of Ireland is divided into Northern Ireland, a constituent part of the United Kingdom, and the Republic of Ireland. The island is divided into four historical provinces–Connaught, Leinster, Munster, and Ulster–and administrative units called counties. The Republic of Ireland consists of Connaught, Leinster, and Munster provinces, totalling 23 counties and, in the north, the 3 counties of Ulster form the Province of Northern Ireland. The responsibility of dealing with clinical waste management in the whole island for the two jurisdictions is that of the Joint Waste Management Board (JWMB). The population of Northern Ireland is 1.6 million and that of the Republic 3.5 million.

6.1.14 A solution for clinical waste management in Ireland has been accepted by the JWMB and will be provided by a private company Sterile Technologies Ireland Limited (STI). It depends on the provision of two alternative technology systems sited in the Republic and an incineration plant located on a hospital site in Northern Ireland which will be used for disposing the waste that cannot be treated by the alternative technology. One alternative technology plant has been erected in Dublin and the other plant will be located in Tipperary. The existing incineration plant will continue to operate and will be upgraded as necessary to meet the legislation. The alternative technology that will be used is the Chem-Clav process. The process consists of a two-stage shredding/ pulverising process with simultaneous introduction of a disinfectant sodium hypochlorite. This sanitises both the equipment and the clinical waste. The equipment next separates for re-circulation excess fluids from the solid waste using an auger press. The surface of the solid waste now has a coating of the chemical; it is then introduced into an encapsulated auger where under temperature-controlled conditions, multiple port injections of steam go directly onto the remaining waste resulting in its sterilisation. The residual waste, now sterile and unrecognisable, can either be sent to sanitary landfill or depending on circumstances, recycled. The resultant waste product is nearly dry and reduced in volume by 90%.

Netherlands

6.1.15 The Netherlands has a population of just over 15 million. The nation is heavily urbanised with some 90% of the population live in towns and cities. The Netherlands is a member state of the European Union. Incineration is the only method in use in the Netherlands and no alternative technology is being used for the disposal of clinical waste.

6.1.16 All clinical waste produced in the Netherlands is treated in the "state of the art" thermal treatment plant (pyrolytical incinerator) operated by the Company Zavin. The plant is sited together with a municipal Waste-to-Energy plant and a sludge incineration plant in the City of Dordrecht. The heat from all three plants is transferred to a common boiler plant and turbine for the production of electricity. The three plants are owned and managed by different companies.

6.1.17 The Zavin clinical waste incineration plant can process up to 9000 tonnes of waste per annum but at the moment it only handles 6000 tonnes from the Netherlands and imports 1000 tonnes. The plant is based upon the principle of pyrolysis and gasification in the primary chamber and secondary chamber respectively. The absence of oxygen prevents incineration with flames. After the gasification stage an afterburner degrades the gases further by means of controlled incineration of the gases. The addition of natural gas is hereby minimized. The waste is reduced to 19% by weight and less than 3% by volume after treatment. It is claimed that the residue does not contain any hazardous waste and can be disposed of to landfill as an inert material. A flue gas washer is fitted to ensure the air emission fully complies with the very high standards of air quality in the proposed EU Waste Incineration Directive. The chemical and physical composition of the slag is permanently monitored and is landfilled. The fly ash and flue gas treatment residues are landfilled in a special landfill for hazardous waste in the Rotterdam region.

United Kingdom

6.1.18 In the United Kingdom, clinical waste was traditionally treated at the hospitals by on-site incineration. This began to change in the late 1980's following the rapid closure of hundreds of outdated hospital incinerators, changes in the management of the National Health Service and the introduction into the market of companies with state-of-the-art incinerators. These changes resulted in the reduction of clinical waste incinerators from 700 to 37. Today, most clinical waste is treated by incineration in the 37 incinerators, some of which may be situated in the hospitals and most of which are operated by private sector companies commercially. All these plants comply with the current legislation but it is not known whether they all will be able to comply with the proposed new EU Waste Incineration Directive without extensive improvements. The main requirement that has to be met is to achieve a level of incineration that ensures that the slag and bottom ashes do not have a total organic carbon content of more than 3%. There will be some incinerators that will be able to be easily adapted to meet the new criteria; the exact number is however not known at present.

6.1.19 There are two plants in the UK using the dry system of alternative technology, together with one microwave system and one autoclave system. The autoclave is used for treating the waste prior to incineration in a municipal Waste-to-Energy incinerator. One other municipal Waste-to-Energy incinerator also receives clinical waste in a specially designed loading system discharging the waste directly into the furnace hopper rather than the main bunker. The Environment Agency has developed interim criteria for licensing the alternative technologies and also for permitting the treatment of the clinical waste at the municipal incineration plants and will shortly be going out to consultation on three documents as follows:

a) Advice on efficacy testing
b) Review of alternative technologies
c) The Agency's policy advisory document.

6.2 UNITED STATES OF AMERICA

6.2.1 The population of the USA is about 265 million and according to the US EPA First Interim Report to Congress the number of clinical waste producers from the various facilities are set out in Table F.

TABLE F USA Clinical Waste Producers

Type of Facility	Number
Hospitals	7100
Laboratories	4,300
Clinics	15,500
Physicians	180,000
Dentists	98,400
Veterinarians	38,000
Residential Care	12,700
Blood Banks	900
Funeral Premises	20,400
TOTAL	377,300

Source : USA EPA

6.2.2 In 1997 the US EPA estimated that there were 2400 hospital incinerators burning clinical waste on site, i.e. about half of the hospitals operated their own incinerators. In 1997 the US EPA issued for the first time stringent final air emission guidelines for use by States in devising their plans to reduce air pollution from existing clinical waste incinerators and to reduce air pollution from incinerators built after June 20 1996. The regulations also provided for small rural community hospitals to help reduce emissions in a way that is affordable, by setting a more relax air emission standards than those in cities. Table G sets out the number of Alternative Technology Units in use in the USA. Set out in Table H is a sample of 13 States indicating the current situation in each of those States with respect to clinical waste incineration:

TABLE G Number of Alternative Technology Units in the USA

TYPE	NUMBER OF FACILITIES
Autoclave	931
Chemical Treatment	173
Heat Steam Thermal Treatment	92
Electro-Thermal Radiation	5
Microwaves	254
Novel Technologies	61
TOTAL	1516

Source : Jane Rubenstein 1997, Data Source Environmental Industries Association.

TABLE H Survey Results on the use of Incineration for the disposal of Clinical Waste in the USA

State	Hospital On-Site Incinerators	Off Site Incine-rators	Status of State Plans	Comments
Alabama	34	1	Final Plan under Review	There will be a closure of all but one of the on-site incinerators when the EPA Emissions requirement comes into force on June 9th 2001
Florida	28	4	No submission	The 28 hospital incinerators are likely to close and the waste disposed of at the 4 off-site centralised incinerators
Georgia	62		Final Plan under Review	These all were permitted but it is not known how many are still in use
Michigan	43	1	Draft Plan Available	
New Jersey	15		Draft Plan Available	
New York State	13	1	State Plan Approved	
Ohio	23		Draft Plan Available	
Oregon		1	Negative Declaration	
Pennsyl-vania	40		Final Plan under Review	
South Carolina	2		No submission	
Vermont	0	0	Negative Declaration	All Clinical Waste is disposed of out of State
Virginia	3		Draft Plan Available	
Wisconsin	5		No submission	One to close shortly
Wyoming	4		Final Plan under Review	Compliance date for the EPA requirements 15.9.2000

Source:Compiled by Torgam Developments Ltd
(http://www.epa.gov/ttn/uatw/129/hmiwi/planstat.html)

6.2.3 From the survey it is clear that there are still many on-site hospital waste incinerators operating. The situation with respect to the State plans for Clinical Waste in October 1999 is shown in Table I. A draft plan is first submitted to the EPA and may be accepted or rejected. It is expected that as the State plans are implemented the number of hospital incinerators will decrease dramatically (estimated by the US EPA as between 50%-80% of the existing 2400) and be replaced by other larger modern incinerators and

alternative treatment facilities which will most probably be operated by private companies.

Table I USA Status of State Plans for Clinical Waste

	Draft Plan Available	Final Plan under Review	State Plan Approved	Negative Declaration (No incineration plants)	No Submission
No. of States	12	10	7	4	33

Source: USEPA Web Site

6.3 FAR EAST

Australia

6.3.1 The Commonwealth of Australia is made up of six states as follows: New South Wales (NSW), Queensland, South Australia, Tasmania, Victoria, and Western Australia and two territories, the Australian Capital Territory (ACT) and the Northern Territory. It has a population of approximately 18 million. Sydney has a population of over 3.7 million and also contains the world's largest area of suburbs. The other cities are: Melbourne over 3.1 million, Brisbane over 1.4 million, Perth over 1.2 million, Adelaide over 1 million, Hobart over 200,000, and Canberra, a population of 325,000.

6.3.2 The Australian and New Zealand Clinical Waste Management Industry Group (ANZCWMIG) was formed to develop and promote consistent standards for the management of Clinical and Related Wastes based on "best practice' for its members. Membership of the ANZCWMIG is from waste transporters/disposal operators, waste generators, tertiary institutions, clinical device manufacturers and other stakeholders. The ANZCWMIG has recently published a revised "Industry Code of Practice for the Management of Clinical and Related Wastes". The revised Code of Practice was launched at the Enviro 2000 Conference of the Waste Management Association of Australia in April 2000 (this conference was held in conjunction with three other conferences – Waste Water, Greenhouse Gas and Odour Control).

6.3.3 In developing the Code of Practice, the ANZCWMIG sought comments from a diverse range of stakeholders. They include government agencies, professional associations and individual waste generators. In addition, this Code of Practice has been written with due account of the National Health and Medical Research Council "National Guidelines for Waste Management in the Health Care Industry" and all State/Territory requirements.

6.3.4 The generally accepted title for this waste type is Clinical and Related Wastes (Related Wastes refer to wastes such as pharmaceutical/cytotoxic and radioactive wastes). However, due to the legislative structure of Australian

Commonwealth, State and Territory governments, each State/ Territory enacts laws pertaining to waste management – in this instance for Clinical and Related Wastes. Therefore, there are a number of State and Territory governments who name this waste differently. However, they all have given an indication to put into place the necessary actions to ensure that the amended titles to achieve consistency – thus the waste should be known as Clinical and Related Wastes.

6.3.5 The use of technologies other than incineration is relatively new within Australia but does appear to be growing. The EPA within each State/Territory licences the operation of the treatment technology and thus if one State has approved a technology, it then tends to be market forces determining the success of it in other States. The following is a brief summary of the current situation with regard to treatment technologies within Australia:

a) **Incineration**
There are seven high temperature incinerators in use in Australia. There is at least one incinerator in each of the five mainland States and there is one in use in the ACT.

b) **Autoclave**
Autoclave treatment has been approved for treating clinical waste, and is being used in Queensland (2 units) and NSW (1 unit).

c) **Chemical Treatment**
Grinding/Shredding and Treatment with sodium hypochlorite (bleach) has been approved in Victoria, NSW, Queensland and New Zealand. There is one unit in use in Victoria and two in New South Wales. Grinding/Shredding and Treatment with hydrogen peroxide and lime (known as Matrix) (See 4.2.1.5 (b)) has limited approval for use in Queensland as it is still in the experimental stage.

d) **Microwave**
Microwave Disinfection is approved for use in NSW where there is one system in use.

e) **Landfill**
Generally landfill of untreated clinical waste is not acceptable and is for final disposal only after treatment. However, there is some limited landfilling of untreated clinical waste in rural NSW and minimal amounts in remote areas of Australia.

6.3.6 Cytotoxic wastes, pharmaceutical drugs and all chemicals have to be separated from the clinical waste stream for separate disposal by incineration at a facility that is licensed by the relevant EPA; such facilities have to achieve 1100°C in the secondary chamber and has installed appropriate pollution control equipment. All incineration facilities except in ACT, are privately owned and operated. Private companies operate all of the alternative technology plants. Alternative technology treatment licences generally do not allow the treatment of pharmaceuticals; they have to be separated out by the

waste generator.

6.3.7 Due to the Australian Constitution, restriction on trade between the States/Territories is not allowed. Therefore, Clinical and Related Wastes can and does, pass States/Territory borders for treatment. However, a generator cannot send waste to another jurisdiction if that jurisdiction treats the waste at a lesser standard than the originating jurisdiction, thus preventing what is referred to as pollution havens.

Philippines

6.3.8 The Philippines has a population of over 65 million. The distribution, however, is uneven; large areas are virtually uninhabited, while others have a relatively high population density the population is about 50% urban. The population of the capital Manila and the metropolitan area surrounding it is nearly 8 million.

6.3.9 The Philippines installed several sets of microwave systems for clinical waste treatment in Manila during 1999. Private sector companies operate them at the moment.

Japan

6.3.10 Japan has a population of 128 million with over 78 % living in urban areas. Geographically it consists of 4 large islands and over 1000 smaller islands. Most clinical waste is being treated by some 360 incineration plants located throughout the country. A small amount is being treated by alternative treatment technologies (Japan Ministry of Health & Welfare, 2000).

TABLE J Number of Treatment Facilities for Clinical Waste in Japan

TREATMENT METHODS	NUMBER
Incineration	360
Pyrolysis	7
Autoclave	3
Dry Heat	6
Others	6
TOTAL	382

Taiwan

6.3.11 A total of 33 clinical waste incinerators, which are located either on-site or off-site throughout Taiwan, were approved for the incineration of clinical waste in 1998.

Malaysia

6.3.12 Malaysia has a population of 20 million with about half of the population living in urban areas. Three companies carry out all of the services within the hospitals and transport the waste for disposal at 8 regional incinerators and 7 on-site incinerators (Pillay et al., 1999). The incinerators use state-of-the-art technology and pollution control equipment. The regional incinerators vary in size from 200 to 500 kg /hr and the onsite incinerators vary in size from 20 to 50 kg/hr. Malaysia has a clinical waste control scheme in place.

Singapore

6.3.13 The Republic of Singapore has a population of 2.8 million. At present there are two private contractors licensed to collect and transport clinical waste from the hospitals and clinics and they both dispose of the waste at their high temperature clinical waste incinerators.

6.4 SUMMARY OBSERVATIONS

The review undertaken from a sample of countries in the Far East, Europe and North America indicates a number of important points, which are set out below:

- Incineration has been the main method of treating clinical waste in most industrialised nations (e.g. many European countries) over the years. It is still preferred as the proven and most effective means of disposal and is still widely used.
- The development of alternative technologies began in the United States probably in California mainly due to the introduction of more stringent air emission standards in that State. The use of the alternative technologies is likely to grow as the States develop their plans for tightening up control of air emissions from the hospital incinerators. However incineration will continue to play an useful role even when plans have been approved e.g. New York State.
- The introduction of alternative technologies into other industrialised countries is growing due to the increasing demand by the public for tightening up emission standards and the significant costs associated with the necessary improvements to the incineration plants.
- In cases where alternative technologies are adopted, the autoclave is usually the choice. The number of autoclaves being used is 2 to 3 times more than microwave facility (which is the second commonly used alternative method).
- In the low and middle income countries that are tackling their clinical waste problems for the first time they are likely to consider the use of the alternative technologies which are less sophisticated in operation and lower in capital costs.

CHAPTER 7 APPLICATION OF ALTERNATIVE TECHNOLOGIES: OPPORTUNITIES AND CONSTRAINTS

7.1 INTERNATIONAL BACKGROUND

7.1.1 The management of waste produced during clinical activities is a matter of only recent concern and did not emerge as an issue in its own right internationally until the 1970's. Most hospitals in developed countries had on-site hospital incinerators or boiler houses and were able to dispose of all their wastes without stringent segregation of wastes. Changes arising from social and industrial factors and the subsequent problems began to emerge from two separate and distinct causes:

- Firstly, there was a steep increase in the amount of single use plastic medical devices and equipment being introduced into the market.
- Secondly, the hospital incinerators were not designed to burn plastic waste and hence produced black smoke which attracted public concern and they were being subjected to stricter gas emission controls.

7.1.2 However the reason that it did become an international public issue was because of a number of incidents that occurred where clinical waste had been handled in a criminally irresponsible manner. These incidents were then widely reported by the media, which in turn gave rise to public concern. Instances of the mishandling of clinical waste are still being reported worldwide.

7.1.3 The general public perceives clinical waste, as being the waste stream creating the greatest risk to public health. This is further exacerbated by the adverse publicity that these incidents have caused. Therefore, although the amount of clinical waste generated is relatively small, the overall effect, if it is mishandled, is disproportionately greater.

The United Nations Conference On The Environment And Development (UNCED)

7.1.4 The UNCED in 1992 led to the adoption of Agenda 2l and the concept of "sustainable development". Sustainable development has been defined as "developments that meets the needs of the present without compromising the ability of future generations to meet their own needs". The application of sustainable development to waste management means amongst other things applying the hierarchy or "ladder principle" for dealing with waste: Finding management solutions that are as near as possible to the top of the hierarchy:

1) Prevent
2) Re-use
3) Recycle

4) Incinerate (with heat recovery)
5) Incinerate
6) Landfill

7.1.5 Three other principles - the "proximity principle" the "polluter pays principle" and the "precautionary principle"- also need to be taken into account. The proximity principle means disposing of the waste as near as possible to the point of production. The polluter pays principle means ensuring that the producer will meet all of the costs of managing the waste including the costs of regulation and control. The precautionary principle means that where risk is uncertain or unknown one must assume that the risk is significant and plan protection measures accordingly.

7.1.6 Applying the hierarchy principle to clinical waste has to be undertaken with care particularly as there may be a conflict between the effects on the environment and the protection of human health. The European Commission's Priority Wastes Stream Project on Health Care Waste considered this issue and concluded that human health must come first but every effort must be taken to reduce the risk to the environment.

7.2 LOW AND MIDDLE INCOME COUNTRIES

Over the last decade, low and middle-income countries have faced a particular problem when they have been taking on the task of developing their waste management strategies. They find that, because of its importance, the first waste stream that has to be tackled is that of clinical waste. In order to improve their arrangements they have sought assistance from the World Health Organisation (WHO), the International Solid Waste Association (ISWA) and other international organisations to plan suitable management systems and regulatory regimes. The WHO has responded to these requests for assistance by producing three important documents to assist countries to develop suitable clinical waste management systems and, together with ISWA, organises conferences and seminars to promulgate the best practices world-wide. The WHO recommends that "*The final choice of treatment systems should be made carefully, on the basis of various factors, many of which depend on local conditions*." This is the method that has been adopted in the assessment of the situation in Hong Kong and all of the points mentioned in the WHO recommendation have been taken account of in this report. The WHO also recommends that the standards for air emissions should follow those of the USA EPA and the European Union, which will also be followed by the Hong Kong Government.

7.3 HIGHER INCOME COUNTRIES

The problems facing higher income countries are different and relate to the increased awareness among the population at large of the environmental effects of waste production both in the use of valuable natural resources and the effects of the storage, transport and disposal of waste on the environment. When companies designed products in the past, they have completely neglected to consider how the product is to be disposed of when it has reached the end of its useful life. However companies are now beginning to take waste management into account and even carry out a lifecycle analysis of their products to demonstrate their compliance with the

principles of sustainable development. The most obvious are, for example, reducing the amount of packaging, using less materials in the product, manufacturing the products using environmentally acceptable materials and reducing the chemical burden.

7.4 THE SPECIAL ADMINISTRATIVE REGION OF HONG KONG

7.4.1 Our conclusions and advice on the scope for applying various clinical waste treatment technologies to Hong Kong and the operational precautions if such technologies are adopted are based upon the information and data obtained during our research and the information on the current situation in Hong Kong.

7.4.2 Landfilling of untreated clinical waste is not an environmentally sound disposal method and should only be used if there is no other option. The existing practice in Hong Kong should only be considered as an interim measure.

7.4.3 It has been demonstrated that none of the alternative technologies is capable of dealing with all types of clinical waste and incineration will still be necessary to deal with the wastes that cannot be treated by the alternative technologies.

7.4.4 The efficacy testing of the alternative technologies is still being developed and the standards whilst agreed amongst the professionals of STAATT in the USA have not yet received national or international approval. Equally, sufficient independent research has not been carried out into the environmental and safety risks associated with the alternative technologies such as the production of Volatile Organic Compounds and the problems associated with mercury and other heavy metals if the technologies are not fitted with air pollution abatement equipment. The recent discovery of occupational-acquired tuberculosis in one of the alternative treatment facilities in USA also points to the need of careful assessment of the technology to be used.

7.4.5 Incineration is a well-established and proven technology and is still widely used to dispose of clinical waste in industrialised countries. Incineration has the smallest amount of residue and this can be disposed of safely in sanitary landfill sites. There are clearly established EU Directives on emission levels for its regulation; and in the USA, emissions are regulated on a state-by-state basis and must be strictly adhered to. It is considered that the Hong Kong CWTC can meet these emission levels at which, according to the professional bodies responsible for their establishment, no health or environmental risk is or will be involved.

7.4.6 It is considered that transparency in the environmental monitoring of the incineration plant is essential to promote public confidence and allay the perceptions of risk associated with the incineration plant. It is noted that the Environmental Performance Data of the CWTC have been published in the Hong Kong EPD's website (http://www.info.gov.hk/epd) and this good practice

should be continued.

7.4.7 The various constraints of applying the clinical waste treatment technologies, taking into account the local factors have been summarized in Table K below.

TABLE K Constraints of Applying Alternative Treatment Technologies in HK

Local Factors Being Considered	ALTERNATIVE TECHNOLOGIES (autoclaves, microwaves, chemical treatment)	INCINERATION AT HK CWTC
Types of Clinical Waste	- Technologies will only handle part of the clinical waste produced (Table B)	- Proposal will handle all types of clinical waste produced in HK
Clinical Waste Management Practices	- More stringent segregation will be required for the waste not suitable for treatment by a particular technology. This may not be feasible in the already under-staffed hospitals in Hong Kong. - Waste producers may also be required to send different types of clinical waste to different places for treatment, e.g. human body parts to CWTC incinerator and other clinical waste types to a different disposal facility.	- No special segregation will be required. - There is no need to re-train all the healthcare workers on waste segregation practice.
Environmental Impacts	- The environmental impacts of individual technology have not been not fully evaluated. Work would need to be carried out on air emissions both within the building and outside the building. - Protocol for testing of efficacy of destroying infectious micro-organisms is still being developed and agreed.	- An Environmental Impact Assessment has already been carried out and all impacts have been identified and mitigated. - Dioxin emission level can be controlled within the most stringent limit by air pollution abatement equipment. - Incineration can completely destroy micro-organisms.
Control and Enforcement	- Enforcement protocol is yet to be developed in other countries, e.g. no policy yet devised in the Environment Agency in UK. - There are also no agreed International Standards.	- International Standards have already been set for reference (e.g. the European Union Directive on the Incineration of Waste and the USEPA Standards for gas emission controls). Air emission control systems are well proven.
The Clinical Waste Control Scheme	- Different treatment technologies would need to comply with different sets of operational requirements. The enforcement authority would need to assess individual technologies. This would take longer time and more resources to implement the control scheme. - If each hospital and clinics were to install their own facilities, the resource of implementing the control scheme (enforcement) would be quite significant.	- This would offer the fastest and most practical route to implement the proposed clinical waste control scheme. - As there will be only one disposal facility in HK, the cost of enforcement would be smaller than several facilities scattering around the territory.

Local Factors Being Considered	ALTERNATIVE TECHNOLOGIES (autoclaves, microwaves, chemical treatment)	INCINERATION AT HK CWTC
Siting Issues	- No other site has been approved yet. - Planning permission would be required and due to public perception, proposal to build a waste facility in any other region is likely to run into opposition by the local community due to NIMBY effect. - If located in a hospital, the proposal could be opposed by the hospital staff or their families residing within the hospital.	- Already in use as an operating plant and only requires modification of the plant. - Opposed by NGO's and the local residents due to the perception of risk.
Capital and Operational Costs	- Capital costs for the alternative and novel technologies vary widely. - A specification would need to be written and tenders would need to be sought to arrive at a true capital cost. As an indication (see para. 7.5.8) the basic capital cost of the equipment for a small scale pilot (500 tonne per annum) plant is in the order of HK $2m (N.B. this figure is only for package plant and its installation and commissioning of the equipment). Operational costs are likely to be slightly more than incineration.	- Modifications estimated to cost $HK 52 million. This cost includes the reception facilities for private waste collection vehicles, weighing facilities for waste collection vehicles and transit skips, facilities for washing and disinfecting all transit skips delivered to CWTC by waste collectors, safety facilities, cold storage for human body parts, supplying all transit skips for all hospitals in HK. - No land cost is incurred as no additional land is needed
Availability of Other Facilities	- Autoclaves being used in hospitals to sterilize surgical equipment and dressings cannot be used to treat clinical waste because VOCs and heavy metals emitted during autoclaving clinical waste will contaminate the inside wall of the autoclaves and contaminate the surgical equipment if the autoclave is subsequently used to sterilize them. - Some small autoclaves are being used for sterilization of small amounts of laboratory microbiological cultures and cannot handle large amount of other clinical wastes. They are also not provided with shredders. Other than these, there is no other facility.	- CWTC already in place and only minor modification will be required.
Time of implementation	- Implementation would depend on finding available sites for the facilities, carrying out feasibility study and environmental impact assessment, further consulting the public on the proposal, building all the associated structures and supplies, and installing the treatment facilities and training the staff for the new technology. - Requirements for training of workers to use alternative technology are yet to be developed and agreed by the US STAATT.	- No additional land or site will be required. The only time required will be for modification work. - Requirements for training operators of incinerators are well established and recognized.

7.4.8 All these point to the advantages of modifying the present incineration plant of CWTC for treating clinical waste. Hence, proceeding with the modification of the CWTC is the recommended medium-term option particularly due to the constraints of adopting alternative technology in HK:

a) The time that will be necessary to find, and seek approval for alternative sites would be lengthy;

b) The time that will be taken to develop alternative safe and environmentally acceptable systems and technology would be considerable;

c) Space in hospitals in Hong Kong is at a premium. The installation of an in-house Alternative Technology Unit with all of the ancillary equipment and waste storage capacity would be very difficult to achieve without disruption to the other services in the hospital;

d) It will always be difficult to obtain approval for new sites for the treatment and disposal of clinical waste due to the perceptions of risk (see para. 5.7);

e) Land in Hong Kong is always at a premium; and

f) The need to keep the present incineration facility fully operational to dispose of hazardous waste as well as disposing of those types of clinical waste that cannot be treated by the alternative technologies(see Table B).

7.4.9 As any facility, e.g. the CWTC, has a designated life-span, whilst it is recommended that the Hong Kong Government proceeds with the modification of CWTC, the Hong Kong Government should also carefully consider the following recommendations in the longer term:

a) Keep abreast of the independent research being carried out worldwide and carry out a watching brief on the acceptance internationally of standards for efficacy testing, environmental testings and licensing criteria of alternative technologies.

b) Keep abreast of developments in other novel technologies. Hong Kong should not be involved in any experimentation at this stage but rather the Government should hold a watching brief on the developments taking place worldwide.

c) After obtaining more information on a) and b), to consider installing at a suitable site an Alternative Treatment Facility. A study should be carried out to decide on the purchasing, installation and operation of one technology, paying particular attention to the ease of operation and maintenance and the operational costs.

d) Based on the findings of the Hospital Authority's report and the present report, it is suggested that an autoclave can be considered. The reasons are that:

i. the technology is well known in hospitals,

ii. the technology is comparatively simple and more well developed and the capital costs are likely to be less than other more complex technologies, and

iii. the number of autoclaves being used in USA is greater than the number of other facilities.

It is suggested that the Hong Kong Government should not have all their eggs in one basket. Evaluation of autoclave technology should begin with one installation in the near future. The capital cost for 500 tonne per annum equipment is in the order of HK $2m. This figure includes automatic loading and post-treatment shredding equipment. However, extra cost should be allowed for special air pollution control equipment. Likewise the capital cost given does not include the cost of land or civil engineering works that will be required.

7.4.10 It is recommended that in the medium term the Hong Kong Special Administrative Region should proceed with its proposed modification of the CWTC to treat clinical waste.

REFERENCES

NOTE This investigation has required extensive research and the total number of research documents referred to would be too numerous to include in this document. They are available for reference in hard copy and are retained by the author. The bibliography below are the most important sources of reference and the major internet sites that have been visited.

(1) Apple Daily: Worker Brain Stem Death – suspected release of chlorine from using bleaching solution (**蘋果日報**): **疑傾倒過量釋有毒氯氣 – 漂白水洗廁男子腦幹死亡**, 17 Aug 2000.

(2) American Conference of Governmental Industrial Hygienists (1998). TLVs and BEIs – Threshold Limit Values for chemical substances and physical agents Biological Exposure Indices. ISBN 1 882417 23 2.

(3) Australian and New Zealand Clinical Waste Management Industry Group (2000). Industry Code of Practice for the Management of Clinical and Related Wastes . (http://www.emiaa.org.au/Clinical%20Waste.pdf)

(4) British Medical Association (1995). Code of Practice for the Safe Use and Disposal of Sharps.

(5) Brunner, C.R. (1996). Medical Waste Disposal. Incinerator Consultants Incorporated. ISBN 0-9621774-1-5.

(6) California State Polytechnic University, Pomona (1995). Medical waste disposal program. (http://www.csuponomona.edu/~ehs/medwst.html)

(7) Cole, E.C. et al (1993). Guidance for Evaluating Medical Waste Treatment Technologies, Draft Report for USEPA. (http://www.epa.gov/epaoswer/other/medical/down2.htm)

(8) Commission of the European Union (1994). Analysis of priority waste stream, Healthcare waste priority waste stream - Information document. CEU, DG XI, Brussels, Belgium, unpublished.

(9) Encyclopaedia Brittanica. (http://www.brittanica.co.uk)

(10) Environment Agency, UK. (www.environment-agency.gov.uk)

(11) European Union Council Directive of 12 December 1991 on Hazardous Waste 91/689/EEC. (http://www.europa.eu.int/eurlex/en/lif/dat/1991/en_391L0689.html)

(12) European Union Council Directive of 18 March 1991 amending Directive 75/442/EEC on Waste (91/156/EEC) [the "Framework" Directive] (http://www.europa.eu.int/eur-lex/en/lif/dat/1991/en_391L0156.html)

(13) European Union Council Directive on Landfill 1999/31/EC. (http://www.europa.eu.int/eur-lex/en/lif/dat/1991/en_399L0031.html)

(14) European Union (2000) Amended Proposal for a European Parliament and Council Directive on Incineration of Waste. (http://www.europa.eu.int/eur-lex/en/com/pdf/1999/en_599PC0330.pdf)

(15) Garner & Favero (1985). Guideline for Handwashing and Hospital Environmental Control. Atlanta, GA: US DHHS, PHS, Centres for Disease Control, 1985. (http://aepo-xdv-www.epo.cdc.gov/wonder/prevguid/p000412/entire.htm)

(16) Green, A.E.S. (1992). Medical waste incineration and pollution prevention. Van Nostrand Reinhold, New York.

(17) Hong Kong Government, Labour Department (1998). A reference note on occupational exposure limits for chemical substances in the work environment, Occupational Safety and Health Branch.

(18) INSCITE, Ltd. (1999). *Alternative treatment technology: autoclaving for clinical waste*. Prepared for the Hospital Authority, Hong Kong.
(19) Japan Ministry of Health and Welfare (2000). Report by the project team for the treatment of waste discharged from medical institution. [日本厚生省産業廃棄物對策室 (2000) 醫療機關ガらの廢棄物の處理にかかるプロジエクトチーム報告].
(20) Juniper (1999). Pyrolysis and gasification of waste: a world-wide technology" Volume 1 and 2, 1999 Shepherds Mill Uley UK. (http://www.jumiper.co.uk/gasification)
(21) Johnson, K.R. et al (2000). Transmission of Mycobacterium tuberculosis from medical waste, J. American Medical Association, 284, 1683-1688. (http://jama.ama-assn.org/issues/v284n13/abs/joc00379.html)
(22) London Waste Regulation Authority (1994). Guidelines for the Segregation, Handling Transport and Disposal of Clinical Waste, Second Edition, London 1994.
(23) Marshall, B.M. et al (1999). Release of bacteria during the purge cycles of steam-jacketed sterilisers. Br. J. Biomed. Sci : 56, 247-252.
(24) National Health and Medical Research Council (1999). National Guidelines for waste management in the health industry, Canberra, Australia. (http://www.health.gov.au:80/nhmrc/publicat/eh-home.htm).
(25) Ontario EPA (1994). Guideline C-4 - The Management of Biomedical Waste in Ontario. (http://www.ene.gov.on.ca/envision/gp/)
(26) Oslen, R.W. (1995). A comparison between the emissions of a 1993 permitted medical waste incinerator and a steam decontamination device. Air & Waste Management Association Report No. 95-TA50.56.
(27) Pillay, M.S., Tan, H, Aziz, A.N.A & Siru D (1999). Clinical Waste Management - The Malaysia Experience. Presented in the Medical Waste Seminar Program organized by the Institute of Environmental & Water Resources Management of the *Universiti Teknologi Malaysia* and the United States- Asia Environmental Partnership (USAEP).
(28) Price Brian (1990,1993). Hazardous Waste Management, Volume 1 1990 ISBN 1-85334-137-1 and Volume 2 1993 ISBN 1-85334-203-3, Financial Times, London.
(29) South China Morning Post (1999). First SAR case of drug-resistant infection brings warning on abuse. 22 Feb 1999. (Also, "Woman's death raises spectre of supergerm in HK, at http://seattletimes.nwsource.com/news/health-science/html98/germ_1000222.html; "港首見超級細菌奪一女命", Oriental Daily, 22 Feb 1999).
(30) Sterile Technology Industries Chem-Clav process. (http://www.stichemclav.com)
(31) Taiwan Environmental Protection Agency. 和地球一起 - 生生不息 - 醫療廢棄物管理簡介.
(32) Taiwan Environment Newsletter (1997). All Infectious Medical Waste to be Incinerated, June 1997. (http://sd.erl.itri.org.tw/envrtw/newsletter_12/news12.htm).
(33) Townend, W.K. and Pruess A (1998). Teachers Guide - Management of wastes from healthcare activities, Geneva, Switzerland, WHO. (http://www.who.int/environmental_information/Information_resources/worddocs/HCteachguid/health_care_wastes_teacher.htm)
(34) Turnberg, W.L. (1996). Biohazardous Waste – Risk Assessment, Policy and Management. John Wiley & Sons, NY. ISBN 0-471-59421-0.

(35) UK Health and Safety Executive and the Environment Agency (1999). Safe Disposal of Clinical Waste. ISBN 0 7176 2492 7.

(36) UK Health and Safety Executive (1999). Occupational Exposure Limits 1999. EH40/99. ISBN 0 7176 1660 6.

(37) UK National Health Service (1998). Clinical waste disposal/treatment technologies (alternatives to incineration), Health Technical Memorandum 2075 ISBN 0-11-322159-2.

(38) US Environmental Protection Agency. State of the Art Assessment of Medical Waste Thermal Treatment. Final Draft prepared by the Energy & Environmental Research (EER) (EPA-90/6). (http://www.epa.gov/epaoswer/other/medical/index.htm)

(39) US Environmental Protection Agency (1992). Retech Inc., Plasma Centrifugal Furnace – Applications Analysis Report by Risk Reduction Engineering Laboratory. EPA/540/A5-91/007. (http://www.epa.gov/ORD/SITE/reports/0049.html)

(40) Underwriters Laboratories Ltd (2000). Proposed Standard for Safety for Alternative Treatment Technologies for the Disposal of Medical Waste - UL 2334. (http://www.ul.com/eph/medwaste.htm)

(41) US National Institute for Occupational Safety and Health (1997). Control of Aerosol (Biological and Nonbiological) and Chemical Exposures and Safety Hazards in Medical Waste Treatment Facilities, Final Report, November 1997.

(42) US National Institute for Occupational Safety and Health (1998). NIOSH Health Hazard Evaluation Report – HETA 98-0027-2709 Stericycle, Inc., Mortin. Washington, Oct 1998.

(43) US National Institute for Occupational Safety and Health (NIOSH) (1999). Preventing Needlestick Injuries in Health Care Settings. DHHS (NIOSH) Publication No. 2000-108, Cincinnati, USA. (http://www.cdc.gov/noish/homepage.html)

(44) US National Institute for Occupational Safety and Health (2000). NIOSH Alert: Preventing worker injuries and deaths from explosions in industrial ethylene oxide sterilization facilities (April 2000). (http://www.cdc.gov/noish/2000119.html)

(45) USA State and Territorial Association on Alternative Treatment Technologies (STAATT) (1996). Technical Assistance Manual State Regulatory Oversight of Medical Waste Treatment Technologies, April 1996. (http://www.epa.gov/epaoswer/other/medical/down3.htm)

(46) World Health Organization (1999a). Safe Management of wastes from health-care activities. Geneva, Switzerland, WHO. ISBN 92 4 154525. (http://www.who.int/water_sanitation_health/Environmental_sanit/MHCWHanbook.htm)

(47) World Health Organization (1994). Managing medical wastes in developing countries. Geneva, Switzerland, WHO (WHO/PEP/RUD/94.1).

(48) World Health Organisation (1999b). Guidelines for the safe disposal of unwanted pharmaceuticals in and after emergencies. Geneva, Switzerland, WHO.

(49) World Health Organisation (1999c). Occupational and environmental health issues of solid waste management: special emphasis on developing countries. Levine.

(50) Zavin Company (2000). Professionals in infectious waste. Dordrecht, Netherlands. (http://www.zavin.nl/Engels/Ewelcome.htm)

ANNEX A

Curricula Vitae of the Author and Assistant Authors

William King TOWNEND OBE. MPhil. F Inst WM. FIM.

Background, Vocational and Managerial Experience

His basic discipline is environmental health. Over the past 34 years he has been employed in an executive capacity in the waste management industry and during that period he has been able obtain in depth experience of all aspects of the industry both as an operator and regulator. In 1986 following the abolition of the Greater London Council (GLC) he participated at a senior management level in the creation and development of a new organisation, the London Waste Regulation Authority (LWRA), which was dedicated to environmental protection and recognised both nationally and internationally as a "centre of excellence". When the LWRA was subsumed into the Environment Agency in April 1996, he was appointed the Senior Adviser in the Head Office Waste Management and Regulation Policy Group until he retired in February 1998. He is now an international environmental adviser and consultant and Non - Executive Chairman of Torgam Developments Ltd, an operational and consulting company specialising in healthcare waste management which he joined in August 1999.

He has obtained very wide ranging experience of the political and policy making processes at local, national and international level and has actively participated at all levels in policy development.

In April 1973 he was appointed an Officer by the GLC and for 8 years until it was abolished in 1986; he managed the Operations Division of the Waste Management Branch. The Division consisted of a large multidisciplinary team of managers, engineers, scientists, supervisors and administrators which together with the operative staff numbered over 500 with an annual budget of £110 million (2000 equivalent).

He was responsible for the operation of over 60 sites including the largest municipal Waste-to-Energy incineration plant in the U.K. at Edmonton. His responsibilities also covered the operation, completion and subsequent restoration of a number of large landfill sites. He was responsible for a complex network of transfer stations using road, rail and river transport. These services were provided by a wide range of direct labour and private sector organisations with short term and long term contracts which he was actively engaged in specifying, negotiating and managing.

Over the past 15 years, he has worked very closely with most Government Departments particularly the Departments of the Environment, Health, Trade and Industry, Agriculture Fisheries and Food, Transport, Home Office and also with most of the enforcement agencies. He also has had close working relationships with other international enforcement agencies and with the officials of DGXI of the European Commission.

He holds a Master of Philosophy Degree in Biology and is an Associate Reader at Brunel University. His other appointments include: -

- Joint Deputy Chairman of the Waste Management Industry Training and Advisory Board
- Member of the International Criminal Police Organisation (Interpol) Working Party on Environmental Crime and led the UK Delegation to the Conference in November 1997.
- He was the founder Chairman of the Interpol Environmental Crime Group (UK)

Experience in Healthcare Waste Management

The considerable national and international experience the author has obtained in Healthcare Waste Management is set out below:

- Chaired the London Waste Regulation Authority Clinical Waste Enquiry in London (CWEL) during 1987 to 1989 and produced Guidelines for clinical waste management being launched by the Government and adopted nationally. They remain the Environment Agency's policy document. Following on from that assignment he became the Chairman of the peer group that produced the last draft of the Governments Waste Management Paper No 25 commissioned by the Department of the Environment.
- As Head of Waste Management Operations in the GLC he was responsible for the commissioning and operation of the Edmonton Clinical Waste Incinerator.
- Adviser to the UK Audit Commission and assisted in the production of their appraisal of clinical waste management in the UK.
- He has acted as consultant and Adviser to the World Health Organisation (WHO) and other international aid agencies and has been involved in Healthcare waste assignments in Hungary (Two), Palestine, Jordan, Argentina, Portugal and Chile.
- Acted as the WHO representative on the European Commission's Priority Waste Stream Project on Health Care Waste.
- In 1996 he was instrumental in forming the International Solid Waste Association's (ISWA) Working Group on Health Care Waste and becoming it's Founder and current Chairman of the Working Group.
- Since 1979 he has produced 25 publications on healthcare waste management and presenting 15 of them at seminars or conferences.
- Joint author of the WHO Publication "Teacher's Guide - Management of wastes from health-care activities", Geneva 1998.

Details of PROFESSOR JOHN D. DONALDSON BSc; PhD; FRSC, C. Chem; FRSA
Centre for Environmental Research, Brunel University, Uxbridge, United Kingdom

Qualifications:

B. Sc University of Aberdeen
PhD University of Aberdeen
D.Sc. University of London

Professional Qualifications.:

Fellow of the Royal Society of Chemistry
Chartered Chemist
Fellow of the Royal Society of Arts

Experience:

John Donaldson is currently Professor in the Centre for Environmental Research in the Department of Materials Engineering at Brunel University. He has extensive experience in the management of both fundamental and industrial based research projects. His recent research has been concerned with problems of interest to industry and includes both fundamental and applied studies of environmental science topics. More than 100 research workers working under his supervision have obtained doctorate degrees and he has published over 200 papers in the scientific literature.

Professor Donaldson is Director of the Hopeman Associates Limited and has acted as a consultant and adviser to a large number of companies in the chemical, agricultural, food, water treatment, mineral treatment, heat exchanger, paint and electronics industries. He is currently advisor to the Bureau Internationale-do la Recuperation et du Recyclage on Technical Working Group issues related to the Basel Convention. Professor Donaldson has also advised legal, insurance and investment companies on environmental issues. He is currently Deputy Chairman of the Waste Management Industry Training and Advisory Board and a member of the Institution of Electrical Engineers Energy and the Environment Committee. Prior to moving to Brunel University in 1990 Professor Donaldson was for ten years Professor of Industrial Chemistry and Director of the Industrial and Biological Chemistry Research Centre at The City University in London. Professor Donaldson was the foundation appointee to the Chair of Industrial Chemistry and successfully carried out the dual tasks of setting up a research centre and forging three-way links between the University, the chemical and related industries in the City of London.

Details of Dr SUE GRIMES BSc; PhD; MBA; MRSC, C.Chem.; Dip. MRS
Centre for Environmental Research, Brunel University, Uxbridge, United Kingdom

Qualifications:

BSc University of London
PhD The City University, London
MBA The City University, London

Professional Qualifications:

Member of the Royal Society of Chemistry
Chartered Chemist
Diploma of the Market Research Society

Experience:

Sue Grimes' qualifications of a first class honours degree and a doctorate in Chemistry combined with an MBA, bringing a unique combination of skills to her environmental science research and consultancy work. She is currently head of the Centre for Environmental Research at Brunel University, Director of the Masters courses in Environmental Pollution Science, Environmental Science with Legislation & Management, Environmental Science with Occupational Health and Environmental Management. She has represented academia nationally on The Royal Society of Chemistry's working party for the accreditation of environmental auditors, verifiers and assessors.

Sue is an experienced research supervisor of academic and industrial-based projects in inorganic, industrial and environmental chemistry. She has built up a research group at Brunel which carries out studies on fundamental aspects of environmental sciences. The group which already consists of three post-doctoral workers and more than twenty researchers has attracted considerable support from industry. She has published about 100 papers in the scientific literature. Dr Grimes has acted for fifteen years as a consultant to water treatment companies and has carried out research for, or advised other organisations in the automobile, chemical, effluent treatment, food, heat exchanger, hydro-metallurgical, metal recovery, paints, petroleum and textile industries. She has been a senior managing consultant in projects involving contaminated land, effluent treatment and control, water treatment, control of atmospheric emissions, environmental impact audits and environmental legislative compliance. She is also Technical Editor for SCI's Journal of Chemical Technology and Biotechnology. Prior to moving to Brunel University in 1990, Dr Grimes was a lecturer in chemistry at The City University. In her capacity as Tutor to a Masters degree in Industrial and Administrative Sciences she initiated and directed research projects in both industrial chemistry and technical management. The topics of the management studies included services marketing in technical industries, management of environmental problems in technical industries, managing creativity and research management.