INVESTIGATIONS ON COMMON TREATMENT TECHNOLOGIES FOR SOME BIOMEDICAL WASTES

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CERTIFICATE

Certified that the work embodied in this thesis entitled **"INVESTIGATIONS ON COMMON TREATMENT TECHNOLOGIES FOR SOME BIOMEDICAL WASTES"** which is being submitted by Mr. Surjit Singh Katoch, in fulfillment of requirements for the award of the degree of Doctor of Philosophy in Department of Chemical Engineering of Thapar University, Patiala -147004, India, is a record of candidate's own work carried out by him under our supervision and guidance. The matter presented in this thesis has not been submitted in part or full for the award of any degree in any other University or Institute.

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It is to certify that Mr. Surjit Singh Katoch, a Ph.D. student of Thapar Institute Of Engineering & Technology (Deemed University), Patiala – 147 004, India, had been allowed to study and collect the data related to biomedical waste management practices from various health care facilities (HCFs) and centralized treatment facility (CTF) for academic purposes as per permission sought vide letter No.TI/SCB/SM/326 dated, September 27, 2003. The major health care facilities covered are IGMCH, KNH, DDUH, IH, and SS.

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Abstract

Biomedical waste is a specific category of waste that is potentially dangerous for spreading infectious diseases in man or animal and is considered as an extreme hazard. Some health care products and practices are harmful to humans and the environment. Infectious waste is produced from hospital and laboratories, physician offices, dental offices, clinics, research laboratories, surgery centers, nursing homes, veterinary offices, funeral homes, and setting where home health care is delivered. It can be the source of diseases like acquired immune deficiency syndrome (AIDS), hepatitis, tuberculosis, and other communicable diseases. Inadequate and inappropriate handling of health-care waste may have serious public health consequences and a significant impact on the environment. The increasing usage of highly developed medical devices; drugs and disposable products are a drain on natural resources as well as over burden on waste handling systems. Management plans are required to meet environmental, hygiene and regulatory obligations and to define reference waste products. The plan should incorporate a cradle-to-grave approach to infectious medical wastes, which includes the adoption of standard operating-procedures to address: the generation, segregation, containerization and storage, handling and transportation, treatment, and disposal.

This study investigated the influence of the operating parameters on the overall performance of the biomedical waste treatment technologies. Since it is not feasible to build treatment facility in every hospital and clinic, biomedical wastes must be transported to a central treatment facility (CTF), which may be located far away from the health care facilities. This gives rise to CTF location, capacity, problem of optimally planning and scheduling the collection of medical wastes from a disperse group of facilities. The reduction of hospital infectious waste, the control of polluting and toxic emissions, the avoidance of unnecessary disinfection procedures and disposables, and the implementation of energy and water saving technologies are practicable measures in hospital ecology. Biomedical waste, however, can be rendered safe and unobjectionable, aesthetically and environmentally, if health care facility managers implement the requirements and

recommendations of the several codes of practice and technical advice, which are simple and not much expensive.

The rate of biomedical waste generation depends strongly upon season of the year as well as distinctive specialty of health care facility. In the present study it was observed that the rate of waste generation in general health care facility is more in summer whereas in Gynaecology and Obstetrics hospital this rate is higher in winters. Therefore the proposed model can help in resource planning in a better way. The model enables waste managers to make long term strategies by comparing among several waste management options and waste treatment technologies throughout the year for a given bed occupancy. It can be used either at a regional or national level for the purpose of setting guidelines for biomedical waste treatment. It can also be used at local level with the purpose of choosing a more environmentally beneficial strategy. Identifying and improving one or more of the processes that make potential impacts can optimize the prevailing strategy.

The other benefits of the proposed model can be in reducing the quantity of biomedical waste, especially where waste has to be transported for incineration, by proper planning during peak season. Municipal Corporations, State Governments, and the Central Government need to plan and construct centralized facilities to recycle, treat, and dispose of biomedical waste. Based on the current available data on biomedical wastes, a preliminary plan for the spatial distribution of cross-district centralized treatment and disposal facilities should be presented.

*Key Words***:** Biomedical Waste; Infectious Hospital Waste; Regulated Medical Waste; Health Care Waste; Incineration; Treatment; Disposal; Modeling; Seasonal Variation.

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Abbreviations and Acronyms

APCD (S)	Air Pollution Control Devices (Systems)
APCR	Air Pollution Control Residue
BIS	Bureau of Indian Standards
BPEO	Best Practicable Environmental Option
CD	Cytotoxic Drug
CDC	Center for Disease Control
CMC	Contaminated Material Containers
CPCB	Central Pollution Control Board
dscm	dry standard cubic meter
EA	Environment Agency
EG	Emissions Guidelines
EP	Extraction Procedure
EWC	European Waste Catalogue
FML	Flexible Membrane Liner
Gy	Grays (1Gy = 100 rads)
HAP	Hazardous Air Pollutant
HMWI	Hospital Medical Waste Incinerator
IBA	Incineration Bottom Ash
I-TEF	International Toxicity Equivalent Factor
I-TEQ	International Toxic Equivalent
LOD	Limit of Detection
MACT	Maximum Achievable Control Technology
MoEF	Ministry of Environment and Forests
Nm^3	Normalized (standard) cubic meter; the volume a gas occupies at atmospheric pressure (1013 mb) and 273.15K (0 ^oC)
NSI	Needle Stick Injury
NSPS	New Source Performance Standards
N-TEQ	Toxic equivalent using the Nordic scheme (Commonly used in the Scandinavian countries)
OSHA	Occupational Safety and Health Administration
PAHs	Polycyclic Aromatic Hydrocarbons

PCBs	Polychlorinated Biphenyls
PCDDs	Polychlorinated Dibenzo-p-Dioxins
PCDFs	Polychlorinated Dibenzofurans
PCNs	Polychlorinated Naphthalenes
ppmdv	Parts per milliom, dry basis, by volume
Rm^3	Reference cubic meter: gas volume measured at 25 ^oC and 1atm
Sm^3	Gas volume in dry cubic meters at STP and 11% O_2
SOP	Standard Operating Procedures
SSADM	Structured Systems Analysis Design Method
STAATT	State and Territorial Association on Alternative Treatment Technologies
SWAP	Strategic Waste Achievement Programme
TCLP	Toxicity Characteristic Leaching Procedure
TCSA	Toxic Substances Control Act
TPR	Thermal Process Residue
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
WAEPA	Western Australian Environmental Protection Authority
WHO	World Health Organization

1. INTRODUCTION

1.1. Biomedical Waste Generation and Characteristics

Wastes produced from hospital and laboratories, physician and dental clinics, research laboratories, surgery centers, nursing homes, veterinary practices, funeral homes, and personal home health care come in the category of biomedical waste. These biomedical wastes are capable of spreading infectious diseases in man or animal and are considered as an extreme hazard. It can be the source of diseases like acquired immune deficiency syndrome (AIDS), hepatitis, tuberculosis, and other communicable diseases. Due to the fact that higher risk to community is associated with these wastes, environmental scientists, media persons and social activists have paid considerable attention. However, still the biomedical waste is poorly defined and there is inconsistency in the terminology used to define infectious waste. The terms infectious, pathological, biomedical, biohazardous, toxic, and medically hazardous have all been used to describe infectious waste. Regulatory agencies, hospitals, and research laboratories have differing perspectives and objectives that influence their views. Bhadram (2002) studied that biomedical waste has been a growing concern ever since the Environmental Protection Act, 1986 (Government of India), redefined it as hazardous waste. The disposal of hospital waste can be very hazardous particularly when it is mixed with municipal solid waste.

The situation of increasing usage of highly developed medical devices; drugs and disposable products, it is a major task for hospital epidemiologists to maintain high standards of hygiene while reducing environmental pollution, reducing consumption of limited natural resources, and minimizing costs. The reduction of hospital waste, the control of polluting and toxic emissions, the avoidance of unnecessary disinfection procedures and disposables, and the implementation of energy and water saving technologies are practicable measures in hospital ecology. To realize a sustainable development within hospitals, it is necessary that the need to maintain a balance between effective infection control and a good ecological environment is recognized and supported by health-care workers and the hospital management (Daschner and Dettenkofer, 1997).

The potential microbiological risks associated with health care waste are still unfamiliar to health workers, and the assessment requires expert advice. Public health is compromised due to lack of accountability in the handling of some hospital and veterinary wastes; specifically body fluid contaminated equipment and containers as well as microbiological materials. The most important to protect public health is a manifest system of cradle-to-grave accountability for an infectious portion of a hospital's waste. The waste produced in the course of health-care activities carries a higher potential for infection and injury than any other type of waste. Inadequate and inappropriate handling of health-care waste may have serious public health consequences and a significant impact on the environment (Pruss et al., 1999). For proper handling of waste generated, it is equally important to predict the amount of waste generation beforehand. Unfortunately, there is virtually no any mathematical model or correlation available that can predict waste generation rate throughout the year. In the present work an attempt has been made to develop a model to correlate seasonal variation in generation rate of a particular category (yellow bag). Before developing the model a detailed survey of existing norms and trends were also studied.

Categorization and segregation of biomedical waste are very important, as severity of the risk associated in handling them is different for each type of wastes. Personnel involved in the treatment of medical waste are exposed to infectious agents through several routes including skin penetration, skin contact, or by the aerogenic route. Medical waste contains variety of human pathogens including bacteria, fungi, viruses, and parasitic organisms as well as microbial toxins. Needle sticks, cuts, falls, strains, sprains, burns, electrical, mechanical, and chemical injuries are additional potential consequences of medical waste treatment. Additional hazards include radioactive, hazardous, and cytotoxic waste exposures (Cole et al., 1993).

The risk is further aggravated due to improper handling and disposal of waste. El-Hamouz (2002) reported that medical waste generated in West Bank hospitals and medical centers is collected in plastic bags and then dumped together with other domestic waste without any separation. This malpractice usually leads to air pollution and the danger of spreading viruses and bacteria widely.

Results of a survey made in Taiwan (Chou et al., 1999) indicated that most animal hospitals did not classify infectious and non-infectious wastes properly. Animal hospitals in Taiwan generally do not have their own effluent outlets, and more than 80% of the wastewater does not meet the applicable standards. One quarter of the wastewater samples can be classified as highly toxic. More fecal coliforms were found in animal hospital wastewater than in general medical waste. The risk of dissemination of waterborne diseases cannot be excluded. Although the total pollution due to animal hospital waste is minute, the toxic and pathogenic characteristics of the waste can be harmful to the environment and to the public health.

If segregated properly, the amount of potentially dangerous waste is quite low. Biomedical waste (infectious waste/ regulated medical waste) is estimated to be 15 percent or less of overall waste stream. However, as shown in Table 1.1, its composition and characteristics varies considerably.

Table 1.1. Typical Composition and Characteristics of Infectious Waste.

Particulars	Percent
Composition:	
Celluloid Material (paper & Cloth)	50-70%
Plastics	20-60%
Glassware	10-20%
Fluids	1-10%
Typical Characteristics:	
Moisture	8.5-17% by weight
Incombustibles	8% by weight
Heating Value	7,500 BTU/lb

Source: HCWH (2001).

Each country has its own set of regulations defining and setting standards for the handling, treatment and disposal of regulated medical wastes. Further each health care institution may refine those definitions and standards depending on the nature of the facility, types of procedures, patients, and other site-specific conditions. Compounding the problem of classification is a confusing mix of medical waste categories based on type (e.g., microbiologic, pathologic, etc.), based on origin (e.g., isolation waste, surgery waste, laboratory waste, dialysis waste, etc.), and based on physical characteristics (e.g., soft

wastes, hard metals, glass, plastics, liquid, etc.). Many regulatory definitions of regulated medical waste are based on ten broad categories defined in a 1986 USEPA guide on infectious waste.

1.2. Waste Management Plan

Biomedical waste management strategies include planning and organization; characterization of waste and losses; development of waste minimization options; technical, regulatory, and economic feasibility; implementation; monitoring and optimization; continued and ongoing evaluation of reaching a zero generation status. Implementing effective biomedical waste management programmes require multisectoral cooperation and interaction at all levels. Establishment of a national policy and a legal framework, training of personnel, and raising public awareness are essential elements of successful health care waste management. Management of health care waste should thus be put into a systematic, multifaceted framework, and should become an integral feature of health care services. Each hospital is required to develop a waste management plan that provides for a thorough segregation and treatment of waste. The main aims of biomedical waste management are:

- minimizing risk for personnel, general public and environment
- minimizing the amounts of waste being generated
- segregation and separation of wastes
- designation of deposit areas in the wards
- establishment of safe routes for the transportation of the waste
- establishment of a safe and proper area for the temporary storage
- proper waste treatment and disposal

Correct identification and quantification of biomedical waste is of paramount importance in order to have a cost effective waste disposal system. Above all, segregation is the key to effective biomedical waste management. It ensures that correct disposal routes are taken. Segregation should be carried out under the supervision of the waste producer and as close as possible to the point of generation. Segregation must therefore take place at source, that is, in the ward, at the bedside, in the theatre, in the laboratory, in the delivery room, etc.,

and must be carried out by the person generating the waste, for example the nurse, the doctor or the specialist, in order to secure the waste immediately and to avoid dangerous secondary sorting.

According to the "polluter pays" principle, each health care establishment are financially liable for safe management of any waste it generates. The costs of separate collection, appropriate packaging, and on-site handling are internal to the establishment and paid as labour and supplies costs; the costs of off-site transport, treatment, and final disposal are external and paid to the contractors who provide the service. The costs of construction, operation, and maintenance of systems for managing biomedical waste can represent a significant part of the overall budget of a hospital or health care establishment. Funds may come from the private sector or from one or more levels of government. For government owned health care establishments, the government may use general revenues to pay the cost of the waste management system.

Over the past few years privatization has been increasingly adopted in a number of countries (including India) as an alternative method of financing various types of public works, including health care waste management. Under such an arrangement a private entity finances, designs, builds, owns, and operates the treatment facilities and sells its collection and disposal services to government and private health care establishments. It may be a desirable option, particularly for treatment methods other than incineration. The following are probably among the main reasons for considering privatization:

- inability of hospitals to raise the needed capital
- expected greater efficiency in the private sector because of fewer constraints than in the public sector (e.g., greater flexibility in purchasing and personnel policies, allowing for more rapid adaptation to changing needs)
- transfer of responsibility for proper operation and maintenance to an organization with more resources for minimizing risk.

A disadvantage of privatization is the potential loss of overall control by the responsible public agency. The feasibility of cooperation between local health care establishments needs be explored as another means of minimizing costs.

1.3. Systems and Standards for Treatment

Several types of treatment and disposal processes have been applied to biomedical waste. However, incineration has been identified as the best option for the disposal of infectious hospital waste in many areas. Treatment of regulated medical waste by US hospitals is most commonly accomplished by incineration (range = 64%-93% by type of waste). About one-third of US hospitals steam sterilize their microbiological waste, and about one-fourth pour liquid blood down a drain connected to a sanitary sewer. Nonregulated medical waste is discarded via a sanitary landfill. Presumably the reason for excluding medical waste from landfills has been concern that pathogenic microorganisms might persist in and move through landfilled solid waste, become part of the leachate produced, enter the surrounding environment (i.e., ground and nearby surface waters), and result in human exposure and disease through ingestion of leachate contaminated waters (Rutala and Mayhall, 1992). Hospital waste incineration has been the main method for disposing of a wide range of materials, including combustible materials such as polyvinyl chloride plastics, papers and discarded items of equipment that constitute biomedical waste, because it can significantly reduce the volume of waste material and can also destroy organic matter (Lee et al., 2003a,b).

The main disadvantage of medical waste incineration is the emission of pollutants to the atmosphere, some of them extremely toxic. Pollutants are usually emitted either in condensed (particulate matter) or in gaseous phases. Many organic and metallic compounds have known effects on human health and environment (Alvim-Ferraz et al., 2000, Alvim-Ferraz and Afonso, 2003a,b). UNEP (2005), explained standard method to safely and reliably destroy viruses, bacteria, and pathogens the infectious hospital waste, often treated by incineration or pyrolysis. Further, due to its origin and its composition, medical waste can contain toxic chemicals, e.g., heavy metals or precursors, which may form dioxins and furans. However, it has also been shown that incineration of medical waste in small and poorly controlled incinerators was a major source of PCDD/PCDF. According to Chen et al. (2003) the inventories of potential emissions of polycyclic aromatic hydrocarbons (PAHs) performed in a lot of countries in the recent past have shown that combustion is a major contributor to the environmental concentrations of these

toxic pollutants. Up to now, the emissions of PAHs have become one of the most controversial issues related with different incinerators.

Steam autoclave treatment has been used for sterilizing medical instruments in hospitals and the treatment of waste in laboratories for many years, thus the validation of autoclaving for sterilizing medical equipment is well documented. Medical waste may contain many of the same pathogens as those associated with used medical equipment and supplies, however, medical waste may contain a much higher concentration of organisms in a more complex matrix. These differences make it necessary to have a unique test method specifically for the assessment of steam autoclaving as an effective medical waste treatment technology. The factors that affect the efficacy of steam autoclave treatment of medical waste are those affecting the internal waste load temperature, steam penetration of the waste, and the duration of treatment. Steam autoclaves operate most effectively when the temperature measured at the center of the waste load approaches 121 ^{o}C and there is adequate steam penetration of the waste load under pressure. Steam autoclave treatment does not normally include a destruction step in the treatment cycle. The solid wastes remain recognizable after treatment, although they may be adequately treated to inactivate all types of microorganisms, including bacterial spores (Cole et al., 1993).

1.4. Processing and Disposal of Treated waste

The main goal of incinerators is to develop a sustainable waste management by reducing volume of nonavoidable and nonrecyclable medical waste to be disposed, and to decrease its post depositional reactivity due to its organic matter inventory. Priority pollutants are trace metals enriched in medical waste products. Since combustion will not destroy inorganic compounds present in healthcare waste, such as metals, it is possible that such compounds may end up in bottom ash at harmful concentrations. While some general information is available from recently published work, the behaviour of the metals in the bottom ash of medical waste incinerators is yet to be understood. Although the bottom ash can be utilized for recovery from the conventional incinerators based on the grate system, a major portion of these residues are still landfilled (Racho and Jindal, 2004).

In Japan, reported Shimaoka and Hanashima (1996), landfilling or ocean dumping of fly ash is prohibited. To avoid the possibility of causing damage to environment and human health, fly ash must be subjected to intermediate treatment to be stabilized and made insoluble and non-unhygienic. Four methods can be used for the fly ash intermediate treatment; (1) cement solidification, (2) treatment by chemicals, (3) acid and other solvents and (4) melting and solidification.

1.5. Common Treatment Facility – Case Study

In exercise of the powers conferred by sections 6, 8 and 25 of the Environment (Protection) Act, 1986; Ministry of Environment and Forests, Government of India has notified "Biomedical Waste (Management and Handling) Rules, 1998" which came into force on July 27, 1998 (MoEF, 1998). These rules apply to all persons who generate, collect, receive, store, transport, treat, dispose, or handle biomedical waste in any form. It shall be the duty of every occupier of an institution generating biomedical waste which includes a hospital, nursing home, clinic, dispensary, veterinary institution, animal house, pathological laboratory, blood bank by whatever name called to take all steps to ensure that such waste is handled without any adverse effect to human health and the environment. The amendments of Principal Rules have further been notified on March 06, 2000; June 02, 2000 and September 17, 2003. Thus the rules emphasized the treatment and disposal of biomedical waste in compliance with standards prescribed therein. Under normal circumstances biomedical waste generated is not allowed to be mixed with other waste and stored beyond a period of 48 hours. If for any reason it becomes necessary to store the waste beyond such period, the authorized person must take permission of the prescribed authority and take measures to ensure that the waste does not adversely affect human health and the environment.

Every occupier of an institution is required to set up in accordance with the time schedule prescribed in the rules, requisite biomedical waste treatment facilities like incinerator, autoclave, microwave system for the treatment of waste, or ensure requisite treatment of waste at a common waste treatment facility or any other waste treatment facility. All types of health care institutions were required to set up treatment facility by December 31, 2002.

Selection of appropriate waste treatment technology is most crucial in laying down a system of proper waste disposal in a health care institution. One of the options which is most common in India for the treatment of health care waste is the incinerator. There is growing interest in alternative technologies for treatment of biomedical waste due to concerns of air pollution from biomedical waste incineration. Therefore, some of the advanced technologies alternative to incineration such as microwave, hydroclave, pyrolysis, ozonation, alkaline hydrolysis etc., is being critically examined for economical and safe handling. Common treatment facilities are necessary because it is not feasible for smaller health care establishments to set up a complete treatment and disposal system due to lack of space, trained manpower, minimum scale of operation and scale of economy. The main reasons for improper management of the biomedical waste are financial and technological constraints and difficulty in monitoring of scattered health care facilities. The central treatment facilities would be providing advantage of economies of scale, state-of-art technologies, air control devices and ease of monitoring the functioning of waste management facilities.

In compliance to Biomedical Waste (Management and Handling) Rules, Municipal Corporation Shimla established a centralized treatment facility for incineration of infectious hospital waste during the month of August 2002. Incineration is commonly used method to be quite safe means of neutralization of infected wastes from hospitals provided that it is carried out under appropriate thermal conditions so that it does not lead to contamination of the environment by toxic chemical compounds, which are produced in reactions of secondary synthesis which takes place during high temperature processes.

There are around 100 clinics and health care facilities in the limits of Municipal Corporation, Shimla. In the present study only five major health care facilities viz., Indira Gandhi Medical College & Hospital (IGMCH), Kamala Nehru Hospital (KNH), Deen Dayal Upadhyay Hospital (DDUH), Indus Hospital (IH), and Shimla Sanatorium (SS) are considered. Biomedical waste generation data at major health care facilities of Shimla town, under present study, have been collected for two consecutive years (2003 & 2004).

Thereafter preliminary trends for amount of infectious waste collected in colour coded bags from IGMCH, KNH, DDUH, IH, and SS were analyzed. Finally, results of the mathematical model developed for the prediction of seasonal variation in the waste generation rate is integrated to compare the waste (yellow bags) incinerated at the common treatment facility available in Shimla town.

2. LITERATURE REVIEW

2.1. Occupational Hazard and Healthy Working Environment

There has been increasing concern among healthcare workers about the exposure to cytotoxic drugs during reconstitution, preparation, administration, and disposal of these drugs. The Health and Safety in Employment Act 1992, which came into force in New Zealand on 1st April, 1993, puts the primary responsibility on the employer to provide a safe and healthy work environment by identifying and effectively managing any hazards associated with the work. The only acceptable means of reducing operator exposure is by the use of a proper biological safety cabinet. Australian standard, AS 2567 – 1994 *Laminar flow cytotoxic drug safety cabinets*, together with its companion document, AS 2639 – 1994 *Laminar flow cytotoxic drug safety cabinets – Installation and use*, specifies means of providing both product and personnel protection in the preparation, manipulation and dispensing of cytotoxic drugs (OSHS, 1997).

During a three-year epidemiological study, spirometric lung function was tested once annually among residents from three communities surrounding a hazardous waste, biomedical, or municipal incinerator and among residents in three comparison communities. A total of 1,016 nonsmoking individuals, aged 8-80 years, participated during atleast 1 of the 3 years of the study; 358 individuals participated all 3 years. There was no difference in percent predicted forced vital capacity, forced expiratory volume in 1 sec, or forced expiratory flow rate over the middle of the forced vital capacity among members of the incinerator communities, compared with nonincinerator communities, and there were no significant differences in lung function within the 3 sets of communities. There was no evidence from this study that an association existed between residence in these 3 waste incinerator areas, which met state and federal emissions regulations, and average spirometric pulmonary function of nonsmoking community members (Hazucha et al., 2002).

The promotion and protection of the health of medical waste treatment workers and the control of biological, physical, and chemical hazards to which they are exposed can be achieved through proper training, supervision, and health surveillance. Appropriate biohazard training should be provided as required by Federal and State Occupational safety and Health Administration (OSHA), USA, regulations and/or recommendation by specific health agencies such as the National Institute of Health (NIH) and the Centers for Disease Control (CDC). Biohazard training for medical waste treatment personnel shall be consistent with training outlined in the OSHA final rule on Occupational Exposure to Bloodborne Pathogens (Cole et al., 1993).

Lee et al., (2003) have evaluated the hospital waste incinerator workers exposed to various pyrolysis products, by assessing urinary 1-hydroxypyrene glucuronide (1-OHPG), as an internal dose of PAH (Polycyclic Aromatic Hydrocarbons) exposure. Pre- and post-shift samples were collected from 28 hospital incinerator workers. Information on smoking habits and use of personal protective equipment were collected by means of a self-administered questionnaire. Their results suggest that the urinary 1-OHPG levels in hospital waste incinerator workers may be modified by the GSTM1 genotype, but these findings remain to be confirmed in future studies involving larger sample sizes. Anglim et al., (1995) investigated the cause of an outbreak of needle stick injuries (NSIs) in hospital employees of a 700-bed university hospital. Employee health department records were reviewed of workers suffering sticks from needles piercing fiberboard contaminated materials containers (CMCs). A laboratory evaluation of needle puncture resistance properties of the CMCs was performed using a testing apparatus. The cost of a hospital waste disposal program using fiberboard CMCs was compared with the cost of a program using rigid plastic (polypropylene) boxes. During 40 months of surveillance in 1986 and from 1989 to 1991, only one NSI had occurred from the needle piercing a CMC. During 9 months in 1993, 13 NSIs occurred due to needles piercing CMCs. No clinical illness resulted from the NSIs. The outbreak was halted by a temporary change to plastic (polypropylene) boxes for sharp disposal until receipt of a box with a newly designed solid fiberboard liner. A program for infectious waste disposal using fiberboard CMCs can be safe and cost-effective if appropriate standards for puncture resistance are met.

2.2. Legislative, Regulatory, and Policy Aspects

Lawmakers have enacted a variety of laws and regulations to ensure disposal of certain potentially infectious or otherwise objectionable waste. In the United States, over the last decade, the improper disposal of solid waste has manifested itself in the passage of a series of Federal and state level control statutes of unprecedented scope and impact. At the Federal level, the statutes include three major environmental laws and three major amendments. The three major laws are: (1) the Resource Conservation and Recovery Act (RCRA) of 1976; (2) the Toxic Substances Control Act (TCSA) of 1976; and (3) the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980. CERCLA is also known as Superfund. The three amendments are: (1) the Hazardous and Solid Waste Act (HSWA) of 1984; (2) the Superfund Amendments and Reauthorization Act (SARA) of 1986; and (3) the Medical Waste Tracking Act (MWTA) of 1988 (Lee and Huffman, 1991). Nakamura et al., (1992) used the passage and implementation of the Medical Waste Tracking Act of 1988 (MWTA) to explore the implications of health and environment policies that are formulated in the context of events defined politically as a crisis. Building on Kingdon's (1984) 'garbage can' model of policy initiation, they assessed the linkage between a policy environment that provides strong but short-lived support for the enactment of a policy and its subsequent implementation. Among the implications of less-than-impressive substantive results of the MWTA is the lesson that while a crisis can tilt the political balance in favour of regulatory legislation; it cannot as readily produce the consensus required to sustain that regulation at the levels promised in the legislation

The Environmental Protection Agency (EPA) has recently demonstrated a keen interest in inspecting laboratories with respect to their management of hazardous waste. As a result of this initiative, EPA has taken enforcement actions at pharmaceutical and biotechnology companies and at a number of colleges and universities. Alleged violations point out what researchers and environmental professionals at these organizations have said for years. The prescriptive, one-size-fits-all hazardous waste regulations do not apply well to laboratory operations and activities. The article identifies several regulatory areas that are problematic for laboratories and discusses innovative national and state regulatory models now being

piloted (Balf, 2001). Chen (2000) explored industrial treatment in light of current successes in the treatment of medical waste. The proper intermediate treatment for medical waste has exceeded 90%. The reasons and stages behind this achievement provide a possible model for improving treatment for other types of industrial waste. These reasons include: (1) subsidies by the competent industrial authority to public hospitals for the construction of medical waste treatment facilities, (2) authorization by the public properties law for public facilities to be run by private operators, (3) government technical assistance to help private contractors undertake such operations, (4) effective controls and auditing by the competent industrial authority, (5) full cooperation between health and environmental department, (6) full cooperation with government waste treatment policies by the medical sector.

Topsale (1990) presented overview for the Hospital Waste Incinerator (HWI) inspection manual prepared by the U.S. Environmental Protection Agency (EPA). The manual is to serve as a guideline to assist state, and local agency personnel in the safe inspection of HWIs, which are subject to Federal, State, and/or local air pollution control regulations. Hospital waste incineration in the EPA inspection manual refers to the combustion of all waste produced by hospital or hospital type (e.g., commercial) facilities. The manual addresses an inspector's legal authority, applicable regulations under the Clean Air Act, inspector responsibilities and liabilities, and general inspection procedures, including safety. Etter et al., (1990) found that within the past four years, public opinion has caused a flurry of legislative and federal level. The EPA, Office of Technology Assessment (OTA), and the Centre for Disease Control (CDC) have issued management guidelines. OSHA has proposed standards to reduce worker exposure to blood-borne pathogens. The EPA has promulgated regulations to implement the Medical Waste Tracking Act. The EPA has proposed rules for municipal waste combustors, under Section 111 of the Clean Air Act (CAA), which apply to medical combustors processing noninfectious wastes. The EPA is also developing new source performance standards solely for medical waste combustors.

The veterinary medical profession supports regulations that benefit public health. In 1988, US Congress passed the Medical Waste Tracking Act, a federal program that mandates

tracking certain regulated waste. Veterinarians modify AVMA's model plan to create an individualized practice plan in compliance with federal, state, and local laws and regulations. State and local veterinary medical organizations monitor state and local regulation to influence decisions that affect veterinarians and to keep their members informed of changing requirements. Veterinarians and veterinary medical organizations are constantly needed to remain involved so that regulations do not unfairly burden the veterinary profession (Brody, 1989).

2.3. Classification of biomedical waste

The Medical Waste Tracking Act (MWTA) of 1988, USA, defined medical waste as any solid waste, which is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals. Descriptions of specific classes of medical wastes are listed in Title 40 of the Code of Federal regulations (CFR) Part 259 and include Cultures and Stocks; Pathological Wastes; Human Blood and Blood Products; Used Sharps; Animal Waste; Isolation Wastes: Unused Sharps (Cole et al., 1993). The Health Services Advisory Committee (HSAC) of UK puts clinical waste into five categories: Group A, Group B, Group C, Group D, and Group E (EA, 2003). In India, MoEF, GoI (1998) has notified Bio-medical Waste (management & Handling) Rules -1998, which describes ten categories viz., Human Anatomical Waste; Animal Waste; Microbiology & Biotechnology Waste; Waste Sharps; Discarded Medicines and Cytotoxic Drugs; Solid Waste; Liquid Waste; Incineration Ash and Chemical Waste. Many regulatory definitions of regulated medical waste are based on ten broad categories defined in a 1986 EPA guide on infectious waste management. The ten categories are: Cultures and Stocks; Anatomical Wastes (or Human Pathological Wastes); Human Blood, Blood Products, and Other Bodily Fluids; Sharps; Animal Wastes; Isolation Wastes; Contaminated Medical Equipment; Surgery Wastes; Laboratory Wastes; and Dialysis Wastes (HCWH, 2001). The comparison of different categories of infectious medical waste and suggested treatment/disposal options is tabulated (Table 2.1):

Table 2.1. Categories of Infectious Medical Waste and Recommended Treatment/Disposal Options – HSAC, USEPA, and MoEF GoI.

Source/Type of Medical Waste	**HSAC**		**USEPA**		**MoEF GoI**	
	Infectious Waste	Treatment/ Disposal Methods	Infectious Waste	Treatment/ Disposal Methods	Infectious Waste	Treatment/ Disposal Methods
Microbiological (e.g., stocks and cultures of infectious agents)	Yes	S and I	Yes	S, I, TI, and C	Yes	S, I and TI
Blood and blood products (i.e., liquid blood and blood products)	Yes	S and I	Yes	S, I, SEW, and C	Yes	S, TI, and SEW
Pathological (e.g., tissue and organs)	Yes	I	Yes	I, SW, and CB	Yes	I and DB
Sharps (e.g., needles, blades)	Yes	S and I	Yes	S and I	Yes	SW, TI, and C
Communicable disease isolation	No	…	Yes	S and I	No	…
Contaminated animal carcasses, body parts, and bedding	Yes	S and I	Yes	I and SW (not bedding	Yes	I and DB
Contaminated laboratory wastes	Yes	…	Optional	If considered IW, use S or I	Yes	S, TI, and I
Surgery and autopsy wastes	No	…	Optional	If considered IW, use S or I	Yes	I and DB
Dialysis unit	No	…	Optional	If considered IW, use S or I	No	…
Contaminated equipment	No	…	Optional	If considered IW, use S, I, or GS	Yes	S and TI

Sources: Rutala et al., 1989; EA, 2003; and MoEF, GoI 1998

HSAC – Health Services Advisory Committee, UK; USEPA- US Environmental Protection Agency; MoEF, GoI – Ministry of Environment and Forests, Gazette of India; S - steam sterilization; I - incineration; TI - thermal inactivation; C - chemical disinfection for liquids only; SEW - sanitary sewer; SW - steam sterilization with incineration or grinding; CB - cremation or burial by mortician; DB - deep burial; IW - infectious waste; and GS - gas sterilization.

2.4. Generation and Segregation

The term medical waste, hospital wastes, and infectious wastes are often used interchangeably. The term ‘medical wastes’ refers to all types of wastes produced by a medical facility; ‘hospital wastes’ refers to all wastes produced by a hospital; and ‘infectious wastes’ refers to that portion of a medical or hospital waste that has the potential to transmit disease. Currently, most medical waste generators designate between 10 to 15% of it as infectious. Hershkowitz (1990) reported the 6,000 substandard, on-site medical waste incinerators in hospitals nationwide generate medical waste in the United States. Annually, hospitals generate from 500,000 to 3 million tons of waste. Small generators of waste (medical clinics, drug users) are responsible for medical waste on beaches, causing billions of dollars in lost revenue for business (Hall, 1989). Marrack (1988) assessed that chlorinated plastics (PVC) accounted for 9.4% of the weight of ‘red bag’, supposedly infectious, waste from two communities 150 and 98 bed hospitals. Rutala et al. (1989) studied that the United States hospitals generated a median of 6.93 kg of hospital waste per patient per day and infectious waste made up 15% of the total hospital waste. Most hospitals (>90%) considered blood, microbiology, sharps, communicable disease isolation, pathology, autopsy, and contaminated animal carcass waste as infectious. Other sources of hospital waste that were commonly (>80%) designated infectious were surgical, dialysis, and miscellaneous laboratory waste.

The hospital waste (HW) production is ranging from 0.5 to 3.0 kg/day/bed with mean value around 2.0 kg/day/bed. The HW fraction assimilable to solid municipal refuses (considering also the expired medicine) is considered around 50-60% of total amount. According to recent investigations, in Italy there would be around 420,000 hospital beds sharing out among 1,700 public and private clinical hospitals. Considering 80% as very conservative occupation factor, the daily HW production is about 670 tons (250,00 tons/y) (Tata and Beone, 1995). Alvim Ferraz et al., (2000) quantified the production of medical waste from a general hospital. A 3.8-kg/bed/day production of medical waste was estimated for 1998; its incineration is related with an ash production of 0.3-0.4 kg/bed/day. Mattoso and Schalch (2001) reported the evaluation of the current definition, classification and quantification of hospital waste being carried out by hospitals in different countries is

extremely important to avoid improper waste management practices. In this work, the waste management from a 400 bed Brazilian hospital that generates about 386 kg/day of hospital waste was studied. The generation rate of just over 1 kg/bed/day was considered small, although more than 50% of the waste from non-isolation wards, consisted of food waste. It was also interesting to note that the highest generation rate per patient per day was found in private rooms and the lowest rate in the public ones. Idris and Saed (2002) reported increasing concern with disposal of hospital waste, which has exploded recently. From the total composition of hospital wastes, 80% are comparable to domestic solid waste. The remaining 20% include radioactive wastes and pharmaceuticals, hazardous wastes, such as cytotoxic agents used in chemotherapy, chemical wastes, infectious wastes, contaminated sharps, anatomical wastes and pathological wastes.

Altin et al. (2003) did the study to evaluate the physical and elemental composition of waste in four hospitals in Sivas, Turkey. During the study period it was estimated that the daily waste generation rate of four hospitals was 985 kg/day, projected to be 1267 kg/day in 2015. Furthermore, analysis indicated that the moisture content of waste was 14.2%. The four hospital wastes consist of 92% combustible wastes and 8% noncombustible wastes by mass. The combustible wastes constitute paper (16%), textiles (10.2%), cardboard (4%), plastics (41.2%) and food waste (17%). Since the ratio of combustible waste is high, the incineration method has been suggested as a proper disposal method. Awad et al. (2004) carried out research for generated hazardous waste after selecting three hospitals in Irbid, Jordan; Princess Basma hospital (public), Princess Bade'ah hospital (teaching), and Ibn Al-Nafis hospital (private). The generation rates were determined (kilogram/patient/day or kilogram/bed/day) for the three hospitals. Statistical analysis was carried out to develop models for the prediction of the quantity of waste generated at each hospital (public, teaching, private). In these models number of patients, beds, and type of hospital were revealed to be significant factors on quantity of waste generated. Chitnis et al., (2005) studied that pathology, microbiology, blood bank and other diagnostic laboratories generate sizable amount of biomedical waste (BMW). The audit of the BMW is required for planning proper strategies. The audit in their laboratory revealed 8 kgs anatomical waste, 600 kgs microbiology waste, 220 kgs waste sharps, 15 kgs soiled waste,

111 kgs solid waste, 480 liters liquid waste along with 33000 litres per month liquid waste generated from labware washing and laboratory cleaning and 162 liters of chemical waste per month.

The decision to select an appropriate technology must encompass a strategic framework dealing with various aspects of medical waste management. The underlying elements of a strategic framework are waste minimization and segregation. Segregation of clinical waste at source is important from the point of view of both health and safety and waste management. Different components of the waste stream must be kept separate from each other. Specifically, potentially infectious waste, regular trash, hazardous waste, and low level radioactive waste must be segregated from each other. Staff training is essential to keep regulated medical waste and hazardous waste separated from each other. Minimizing or eliminating the generation of waste at the source should have a higher priority than recycling or reuse. Hagen et al. (2001) had conducted four infectious waste surveys between 1991 and 1999 that involved opening a total of 7364 bags of infectious waste. Dhahran Health Center was producing a total of 1163 kg of infectious waste per day before the first survey. This was reduced to 407 kg per day after implementation of a waste segregation program in 1991 (a reduction of 65%). Incineration operation was reduced from daily to 3 days per week, with a corresponding reduction in incinerator emissions. Infectious waste from inpatient, surgical, and obstetric areas was reduced by a total of 70% between 1991 and 1999, from 2.8 kg (6.1 lb) to 0.85 kg (1.9 lb) per patient per day. This is in the range of 2 to 4 lb per patient per day that is generally reported. However, regardless of the method of treatment and disposal, such surveys are valuable quality improvement tools because all health care facilities want to reduce disposal costs, identify high-value items mistakenly discarded, and improve safety.

2.5. Volume and Mass Reduction

Volume and mass reduction is another important factor since the facilities will have to pay by volume or mass for hauling the treated waste and disposing at a landfill. Diminishing landfill capacities could eventually drive up the cost of land disposal. High heat thermal technologies offer the highest levels of volume and mass reduction. Other technologies

may require an added shredder or compactor to reduce volume. The primary purpose of burning municipal solid wastes (MSW) and hospital solid wastes (HSW) is to reduce their volume, because the great difficulties encountered in acquiring sites for controlled and uncontrolled landfill waste disposal operations. Incineration of such materials reduces the original volume by 65-70%, and generates bottom ash and fly ash (Lombardi et al., 1998). Municipal solid waste incinerators (MSWI) reduce the volume of waste by about 90% and its mass by about 70%. Approximately 80% of incineration residue is bottom ash (Chimenos et al., 1999). MSWI and hospital medical waste incinerators (HMWI) can be operated as integrated waste management systems. They offer a reduction in both the mass (70%) and volume (about 90%) of waste subjected to final disposal as well the possibility of energy (Ibanez et al., 2000; Alvim-Ferraz and Afonso, 2003; Johansson and van Bavel, 2003; Shim et al., 2003).

Incineration can destroy or inactive infectious wastes, provides significant (>90%) mass and volume reduction of the waste, and render materials unusable (Batterman, 2004). Racho and Jindal (2004) presented the results of the investigations that were carried out to determine concentrations of some heavy metals in residual bottom ash from the medical waste incinerator in Ratchasima-Thonburi Hospital in the northeastern city of Nakhon Ratchasima in Thailand. The hospital has a capacity of 300 beds and generates about 60 kg of waste everyday. A pyrolysis type incinerator is used to burn the hospital waste about two to three times per week. The amount of waste incinerated on a single day ranged between 130-250 kg. Typically, the incinerator generated approximately 27 kg of bottom ash by processing about 180 kg of medical refuse.

2.6. Technology Options for Biomedical Waste Treatment

The environmental regulations actually mandate the treatment of infectious medical waste on a daily basis if it is stored at room temperature. A number of treatment methods are available. The final choice of suitable treatment method is made carefully, on the basis of various factors, many of which depend on local conditions including the amount and composition of waste generated, available space, regulatory approval, public acceptance,

cost, etc. However, incineration used to be the method of choice for most hazardous health-care wastes and is still widely used.

2.6.1. Incineration Technology

Incineration of waste is affordable and feasible only if the "heating value" of the waste reaches at least 2000 kcal/kg (8370 kJ/kg). The value for infectious waste, for instance, exceeds 4000 kcal/kg. The other characteristics that make waste suitable for incineration are content of combustible matter above 60%, content of non-combustible solids below 5%, content of non-combustible fines below 20%, and moisture content below 30%. All types of incinerator, if operated properly, eliminate pathogens from waste and reduce waste to ashes. However, certain types of health-care wastes, e.g., pharmaceutical or chemical wastes, require higher temperatures for complete destruction. Incinerators designed especially for treatment of health-care waste should operate at temperatures between 900 and 1200˚C (Pruss et al., 1999). Pandompatam et al. (1997) have successfully experimented a pilot-scale incinerator with a nominal capacity of 50 kg/h used to simulate PCDD (Polychlorinated Dibenzo-p-Dioxin) and PCDF (Polychlorinated Dibenzofurans) emissions from fuel processing NaCl contaminated bark. With 0.76 wt.% chlorine in the bark, about 50 and 100 ng/m^3 of total PCDD, and total PCDF were detected. The corresponding PCDD and PCDF values for the uncontaminated bark were 0.3 and 0.3 ng/m^3. The toxicity equivalent (TEQ) for the 0.76 wt. % salt contaminated bark combustion was 3 ng/m^3 as compared to the control value of 0.02 ng/m^3. The PCDD and PCDF homolologue distribution as well as the fractions of 2378- substituted PCDD and PCDF isomers in each group were examined. The data was found to agree well with the available field data from literature. It was found that although the 2378-sustituted isomers patterns in the case of bark combustion and hospital waste incineration follow the same trend, the patterns for the PCDD and PCDF homologue distributions in these two cases are different.

Biomedical waste incinerators in Ontario are available in a wide range of capacities. Ozvacic et al. (1990) reported testing and evaluation program carried out at Ontario in small, batch or semi-continuously fed two-chamber type incinerators. All these

incinerators are equipped with either afterburners or secondary stage burners to keep the combustion gas at 1000 ˚C for one half second. The Ontario Ministry of the Environment (MOE) has initiated an extensive testing and evaluation program to generate the needed emission data. Except for data generated in this program, there are no other air emission data for toxic pollutants from biomedical waste incinerators in Ontario. Nasserzadeh et al., (1995) reported that the use of incineration to dispose of clinical waste is increasing as clinical waste disposal regulations become more stringent. Every year in the UK more than one million tones of hospital wastes are generated. Most of this is potentially infectious and must be incinerated. Liberti et al., (1996) reported in their second paper in a two-part series more detailed data on the physicochemical characteristics of normal (NHW) and infectious (IHW) hospital waste determined experimentally in a large sanitary district that includes four hospitals, public and private, with 164 sanitary departments, 40 analytical laboratories and 2500 rehabilitation beds, near the town of Bari (Suthern Italy). In all cases, IHW was shown to be classified as "non-toxic" deserving 950˚C rather than 1200˚C incineration temperature according to Italian Legislation.

Waclawiak (2002) studied a cylindrical pyrolyzer used in hospital waste incineration and reported that crucial factors are length and width of the reactor in terms of optimization of gas yield. Both experimental and modeling studies of the pyrolysis process inside the unit were carried out. It was shown how velocity, pressure and density of gas change in the reactor. The reactor used was 1 m long and 24 cm in diameter, filled with municipal waste. Although widely used, incinerators pose serious environmental problem. Marrack (1988) established the hydrochloric acid; dioxins and furans generated during the burning of chlorinated plastic (PVC) in 'red bag' waste are important air pollutants. In this waste, PVC provides much of the organic chloride for the dioxins and furans generated. Their concentrations are least in flue gases from those plants with BACT design, flue gas clean up and management techniques – the most constrained incinerators. The many manually fed, small categorical red bag incinerators associated with hospitals have no flue gas clean up systems and represent minimally constrained incinerators. Their toxic stack emissions are considered a significant community health hazard. This problem leads to consider other non-incineration techniques.

2.6.2. Non-incineration Technology

Non-incineration treatment includes four basic processes: thermal, chemical, irradiative, and biological. The majority of non-incineration technologies employ the thermal and chemical processes. The main purpose of the treatment technology is to decontaminate waste by destroying pathogens. Facilities should make certain that the technology could meet state criteria for disinfection.

2.6.2.1. Autoclaving

Autoclaving is an efficient wet thermal disinfection process. Typically, autoclaves are used in hospitals for the sterilization of reusable medical equipment. They allow for the treatment of only limited quantities of waste and are therefore commonly used only for highly infectious waste, such as microbial cultures or sharps. Research has shown that effective inactivation of all vegetative microorganisms and most bacterial spores in a small amount of waste (about 5-8 kg) require a 60-minute cycle at 121˚C (minimum) and 1 bar (100kPa); this allows for full steam penetration of the waste material. About 99.9999% inactivation of microorganisms is achievable with autoclave sterilization (Pruss et al., 1999). Chitnis et al., (2005) audited biomedical waste in pathology, microbiology, blood bank and other diagnostic laboratories. Needle sharps are collected in puncture proof containers and needles autoclaved before sending to needle pit. All microbiology waste along with containers/plates/tubes is autoclaved before recycling/disposal. The discarded/infected blood units in blood bank need to be autoclaved before disposal since chemical treatments are difficult or inefficient.

Lauer et al. (1982) examined the temperature profile of infectious laboratory waste being autoclaved relative to the type of containers used in the process. A standardized waste load (1,750 ± 4 g) placed in the container was evaluated by using a direct readout thermocouple. The sensor of the thermocouple was placed within an unused and outdated agar plate, centrally located about 5 cm from the bottom of the container. The gravity displacement autoclave tested reached 121ºC within 3 minutes. Waste within a steel container (plus 1 liter of water) reached 108, 120, and 122ºC at 12, 30, and 50 minutes respectively. Without the addition of water, the corresponding temperatures were 60, 110, and 120ºC,

respectively. With steel, "autoclavable" plastic bags, and no additional water, the temperatures were 36, 71, and 105 ºC, respectively. When 1 liter of water was placed in the autoclavable bag, the temperatures were 98, 115, and 121ºC, respectively. Waste within a polypropylene container (dimensions similar to those of the steel container) with and without the addition of 1 liter of water, reached a maximum temperature of 108 ºC at 50 minutes. With a polypropylene container, autoclavable plastic bag, and 1 liter of water, the corresponding temperature was 99ºC. Without the addition of water, the temperature was 92ºC. The importance of container, moisture, and material in autoclaving was demonstrated.

Blood bank regulations and biomedical waste rules of India advocate disinfection of contaminated blood units. Incineration is not recommended due to polyvinyl chloride (PVC) content of blood bags. This study was designed to evaluate the efficacy of chemical disinfection of blood units deliberately contaminated with *Staphylococcus aureus* and *E.coli* with 1 and 6% hypochlorite, 10% formalin and 33% formaldehyde and autoclaving of blood units contaminated with the above mentioned vegetative forms and B. stearothermophilus spores. Only 33% formaldehyde could bring about 5 Log reduction of bacteria but it is highly irritating and toxic. Autoclaving at 15 lbs pressure for 2 hours uniformly inactivated the vegetative forms and B. stearothermophilus spores. Thus, autoclaving of PVC blood bags is a safer and reliable method compared to chemical disinfection (Chitnis et al., 2003).

2.6.2.2. Microwave Irradiation

Most microorganisms are destroyed by the action of microwaves of a frequency of about 2450 MHz and a wavelength of 12.24 cm. The microwaves rapidly heat the water contained within the waves and the infectious components are destroyed by heat conduction. In the USA, a routine bacteriological test using *Bacillus subtilis* is recommended to demonstrate a 99.99% reduction of viable spores (Pruss et al., 1999). Hoffman and Hanley (1994) assessed a clinical waste decontamination unit that used microwave-generated heat for operator safety and efficacy. Tests with loads artificially contaminated with aerosol-forming particles showed that no particles were detected outside

provided the seals and covers were correctly sealed. Thermometric measurement of a self-generated steam decontamination cycle was used to determine the parameters needed to ensure heat disinfection of the waste reception hopper, prior to entry for maintenance or repair. Bacterial and thermometric test pieces were passed through the machine within a full load of clinical waste. These test pieces, designed to represent a worst-case situation, were enclosed in aluminum foil to shield them from direct microwave energy. None of the 100 bacterial test pieces yielded growth on culture and all 100 thermal test pieces achieved temperatures in excess of 99 ˚C during their passage through the decontamination unit. It was concluded that this method might be used to render safe the bulk of ward generated clinical waste.

2.6.2.3. Chemical Methods

Chemical disinfection, used routinely in health care to kill microorganisms on medical equipment and on floors and walls, is now being extended to the treatment of health care waste. Chemicals are added to waste to kill or inactivate the pathogens it contains; this treatment usually results in disinfection rather than sterilization. Chemical disinfection is most suitable for treating liquid waste such as blood, urine, stools, or hospital sewage. Several self-contained waste treatment systems, based on chemical disinfection, have been developed specifically for health care waste and are available commercially. Barek et al. (1998) have tested three chemical methods viz. oxidation with sodium hypochlorite (NaClO, 5%) hydrogen peroxide (H_2O_2, 30%), and Fenton reagent ($FeCl_2.2H_2O$; 0.3 g in 10 ml H_2O_2, 30%), for the degradation of four anticancer drugs: Amsacrine, Azathioprine, asparaginase and Thiotepa. The efficiency of the degradation was monitored by high-performance liquid chromatography. In all cases where a high degree of degradation was achieved, the residues obtained were non mutagenic.

2.6.2.4. Plasma Pyrolysis

Plasma pyrolysis is a state-of-the-art technology for safe disposal of medical waste. It is an environment-friendly technology, which converts organic waste into commercially useful by-products. The intense heat generated by the plasma enables it to dispose all types of waste including municipal solid waste, biomedical waste and hazardous waste in a safe and

reliable manner. Medical waste is pyrolysed into CO, H_2, and hydrocarbons when it comes in contact with the plasma-arc. These gases are burned and produce a high temperature (around 1200˚C). In the plasma pyrolysis process, the hot gases are quenched from 500˚C to70˚C to avoid recombination reactions of gaseous molecules that inhibit the formation of dioxin and furans. The gas analysis results reveal that toxic gases found after the combustion are well within the limit of the Central Pollution Control board's emission standards. The plasma pyrolysis technology has been indigenously developed at the Facilitation Centre for Industrial Plasma Technologies, Institute for Plasma Research, Gandhinagar (Nema and Ganeshprasad, 2002). Inaba and Iwao (2000) reported that plasma treatment is being developed and tested for incinerator ash, low level radioactive wastes, industrial and biomedical wastes, etc., by industrial companies and municipalities world wide.

2.7. Selection of Suitable Treatment Technology

Certain treatment options may effectively reduce the infectious hazards of health care waste and prevent scavenging but, at the same time, give rise to other health and environmental hazards. Walker (1990) studied the current technology used to manage infectious and hazardous wastes in hospitals. Infectious waste is either incinerated or it is sterilized and landfilled (a few states permit landfilling without pretreatment). Most hospital based waste incinerators are adequate to dispose of syringe needles and body parts. Chlorinated plastics require state-of-art commercial incinerators that can remove the hydrochloric acid, dioxins, and furans from the stack gas. Chemotherapy waste is mostly gloves and gowns and if not properly sorted can represent a large volume. A potential problem is the discharge of small concentrations of formaldehyde into the sewer. Yufeng et al., (2003) reported that based on the conventional pyrolysis principle, a new apparatus has been developed for waste disposal in China. It is especially useful in China, as the waste is not sorted. The experiment shows that the concentration of dioxins meets the emission standard of 0.1 ng TEQ/Nm^3 by controlling the residence time and temperature. The expulsive solid weight is as low as 5-7% of the whole refuse. At the same time, a great deal of fire gas was generated at the treatment process. The final choice of treatment

system should be made carefully, on the basis of various factors, many of which depend on local conditions (Table 2.2):

Table 2.2. Factors to consider in selecting an Appropriate Treatment Technology.

World Health Organization (Pruss et al., 1999)	Health Care Without Harm (HCWH, 2001)
The final choice of treatment system should be made carefully, on the basis of various factors, many of which depend on local conditions: • disinfection efficiency • health and environmental considerations • volume and mass reduction • occupational health and safety considerations • quantity of wastes for treatment and disposal/capacity of the system • types of waste for treatment and disposal • infrastructure requirements • locally available treatment options and technologies • options available for final disposal • training requirements for operation of the method • operation and maintenance considerations • available space • location and surroundings of the treatment site and disposal facility • investment and operating costs • public acceptability • regulatory requirements	Determining the best technology or combination of technologies for a particular facility depends on many site-specific factors including the amount and composition of waste generated, available space, regulatory approval, public acceptance, and cost. Some key factors to consider are: • throughput capacity • types of waste treated • microbial inactivation efficacy • environmental emissions and waste residues • regulatory acceptance • space requirements • utility and other installation requirements • reduction of waste volume and mass • occupational safety and health • noise and odor • automation • reliability • level of commercialization • technology manufacturers/vender background • cost • community and staff acceptance

2.8. By-product/ Residue of Treatment

Residues (bottom ash, grate sifting, heat recovery ash, fly ash, and air pollution control residue) are generated at different points in process of waste incineration. Chemical analyses of solid waste residue, bottom ash, air pollution control residue and combined ash often been published. Lombardi et al. (1998) reported that a fly ash coming from a hospital solid wastes incineration plant was solidified/stabilized in cementitious matrices. Owing to

the high chloride, sulphate and alkali content and the low Si, Al and Fe values this fly ash cannot be used in the formulation of blended cement. The objectives of solidification stabilization treatment were therefore to reduce the leachability of the heavy metals present in this material so as to permit its disposal in a sanitary landfill requiring only a low degree of environmental protection. The mechanical properties and leaching behaviour of solidified products were investigated. Idris and Saed, (2002) mentioned the ash produced from a hospital waste incinerator was treated using a high temperature melting process at 1200˚C. The quality of the produced slag was characterized by X-ray diffraction (XRD), X-ray fluorescence (XRF), leaching tests and sequential chemical extraction of metals. The slag contained large amounts of SiO_2, CaO, Al_2O_3, Sn, Ni, Cu, Ba and B. XRD analysis revealed a moderate crystal structure for the melted slag and identified the main crystals as quartz (SiO_2), kaolinite [$Al_2Si_2O_5(OH)_4$], albite ($NaAlSi_3O_8$) and gibbsitc [$Al(OH)_3$]. The observed crystal structure assists in preventing the leaching of heavy metals from the slag. Furthermore, the leaching results found the produced slag to comply with disposal limits set by the USEPA. Melting was found to stabilize heavy metals in hospital waste successfully and therefore it can be an acceptable method for disposal.

Zandaryaa et al. (2001) carried out an experimental study of the selective non-catalytic reduction (SNCR) process to determine the efficiency of NO_x removal and NH_3 mass balance, the NO_x reducing reagent used. Experimental tests were conducted on a full-scale SNCR system installed in a hospital waste incineration plant. Anhydrous NH_3 was injected at the boiler entrance for NO_x removal. Ammonia was analyzed after each flue-gas treatment unit in order to establish its mass balance and NH_3 slip in the stack gas was monitored as well. The effective fraction of NH_3 for the thermal NO_x reduction was calculated from measured values of injected and residual NH_3. Results show that NO_x reduction efficiency in the range of 46.7-76.7% is possible at a NH_3/NO molar ratio of 0.9-1.5. No direct correlation was found between theNH_3/NO molar ratio and the NH_3 slip in the stack gas since the major part of residual NH_3 was converted into ammonium salts in the dry scrubbing reactor and subsequently collected in the fabric filter. Moreover, another fraction of NH_3 was dissolved in the scrubbing liquor.

2.8.1. Environmental Emissions

Incinerator emissions should comply with the national standards. Flue (exhaust) gases from incinerators contain fly ash (particulates), compound of heavy metals, dioxins, furans, thermally resistant organic compounds, etc., and gases such as oxides of nitrogen, sulfur, and carbon, and hydrogen halides. If flue gases are to be treated, this must be done in at least two different stages- "de-dusting", to remove most of the fly ash, followed by washing with alkaline substances to remove hydrogen halides and sulfur oxides. Wastewater from gas washing and quenching of ashes should undergo a chemical neutralization treatment before discharged into a sewer; the treatment includes neutralization of acids and flocculation and precipitation of insoluble salts. Sludges from wastewater treatment and from cooling of fly ash should be considered as hazardous waste. They may either be evacuated to a waste disposal facility for hazardous chemicals, or be treated on-site by drying followed by encapsulation in drums which are then filled up with cement mortar and may be disposed of in a landfill. The solid ashes in the incineration residue are far less hazardous than fly ash, and in the past have been reused in civil engineering works. Incineration produces between 25 and 30 kg of dust per tonne of waste (Pruss et al., 1999).

In August of 1997 the United States Environmental Protection Agency (USEPA) issued New Source Performance Standards (NSPS) and Emission Guidelines (EG) for medical/infectious waste incinerators in the United States. These new requirements will have considerable impact on the over 2300 hospital facilities operating an incinerator. Within the context of the new regulations, any equipment installed prior to February 27,1995 is categorized as an existing installation and any equipment installed after February 27, 1995 is categorized as a new installation. From a categorization stand point, facilities which process less than 200 lbs/h are considered to be small application. A facility which processes more than 200 lbs/h but less than 500 lbs/h of medical waste is considered to be a medium sized application. Those facilities which have equipment with design throughput capacities of greater than 500 lbs/h are considered to be large application and are thereby required to meet much more restrictive levels of emissions (Remmen, 1998). The characterization of the control technologies available to assure

compliance with the new requirements will follow the categories for the various installations included in Table 2.3.

Table 2.3. USEPA Emission limits under the 1997 "Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Hospital/Medical/Infectious Waste Incinerators"

Controlled Emission/ Pollutant	**Emission Limits**		
	Small (≤200 lbs/hr or 91kg/hr)	**Medium** (200-500 lbs/hr or 91-227kg/hr)	**Large** (≥500 lbs/hr or 227kg/hr)
Particulate Matter (PM), mg/dscm	69	34	34
Carbon Monoxide (CO), ppmv	40	40	40
Dioxins/Furans (PCDD/PCDF),			
ng/dscm total	125	25	25
ng/dscm TEQ	2.3	0.6	0.6
Hydrogen Chloride (HCl), ppmv	15 or 99% reduction	15 or 99% reduction	15 or 99% reduction
Sulfur Dioxide (SO_2), ppmv	55	55	55
Nitrogen Oxides (NO_x), ppmv	250	250	250
Lead (Pb), mg/dscm	1.2 or 70% reduction	0.07 or 98% reduction	0.07 or 98% reduction
Cadmium (Cd), mg/dscm	0.16 or 65% reduction	0.04 or 90% reduction	0.04 or 90% reduction
Mercury (Hg), mg/dscm	0.55 or 85% reduction	0.55 or 85% reduction	0.55 or 85% reduction
mg = milligrams, dscm = dry standard cubic meter, ppmv = parts per million by volume, ng = nanograms, TEQ = toxic equivalent In addition, new incinerators are subject to a 5% visible emission limit for fugitive emissions generated during ash handling and a 10% stack opacity limit.			

Sources: Remmen, 1998; Pruss et al., 1999; and HCWH, 2001

The stack gas samples from municipal solid waste incinerators (MSWIs), small size incinerators (SIs), a hospital waste incinerator (HWI) and an industrial waste incinerator (IWI) were collected and analysed for polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs). This study shows that PCDD/Fs emission is related to the age of incinerators, CO, and flue gas dust. The PCDD/Fs emission of the small size incinerators is considered as the major point source of PCDD/Fs emission in Korea (Oh et al., 1999). Murnyak and Guzewich (1982) quantified chloride/chlorine emissions from a hospital's medical waste incinerator in conjunction with a particulate emission stack test. Chlorine emissions averaged 100.5 mg/m^3 with a standard deviation of

72 mg/m^3 for five sample runs. It was estimated that the plastic content of the waste burned varied up to 30%. Since, in general, emission standards for chlorine from medical waste incinerators do not exist, a simple diffusion model technique is suggested to estimate a safe distance to locate a medical waste incinerator from occupied buildings. Lindner et al., (1990) detected dioxins and furans in emissions from eight medical waste incinerators tested in California. Total uncontrolled emissions ranged from 363 to 11,811 nanograms per dry standard cubic meter. The most effective of three wet scrubbers achieved an emissions control efficiency of 95 percent for total PCDD and PCDF. A baghouse was less than 30 percent efficient in removing PCDD and PCDF from the incinerator emissions.

Manscher et al. (1990) conducted an extensive series of dioxin measurements on Danish municipal and hospital solid waste incinerators during the last two years. The study was directed toward finding the total annual dioxin emissions from MSWI in Denmark, now estimated to be 3 kg of dioxins and furans. This sum is equivalent to 50 g of 2,3,7,8-TCDD according to the Nordic Equivalents. Measurements were carried out according to a statistical design followed a plan of pre-randomized sampling. This procedure allowed casual interpretation of the correlations found between the dioxin emissions and certain operating parameters. The statistical model obtained describes the emissions by variations between incinerators, by variation in time, and by changes in the load, the excess air and the HCl concentration in the flue gas. Nasserzadeh et al. (1995) carried out emission monitoring on the high temperature clinical waste incinerator plant with a burning capacity of 12 tonne/day (4MW) at Sheffield, UK. The emissions including the measurement of CO, CO_2, O_2, NO_x, SO_2, HCl/HF, volatile organic compounds, particulates, heavy metals and dioxins/furans in the flue gas. Scrubber liquor, filter cake and ash were also analyzed for heavy metals, dioxins/furans and unburnt carbon content. A computational fluid dynamic code (FLUENT) was employed to predict the three-dimensional reacting flows within the incinerator geometry. The objective of this modeling work was to investigate the influence of the design and operating parameters on overall performance of the incinerator. Experimental measurements of gas composition, temperature and velocities were compared with the model predictions. Modeling results correctly indicated trends and were invaluable for the interpretation of the incinerator performance data. As a result of the

test data and mathematical modeling of the whole process, suggestions for design improvements for the Sheffield clinical incinerator were made.

Shy et al. (1995) studied the residents of three communities having, respectively, a biomedical and a municipal incinerator, and a liquid hazardous waste-burning industrial furnace. The results were compared with three matched-comparison communities. They did not detect differences in concentrations of particulate matter among any of the three pairs of study communities. Average fine particulate (PM2.5) concentrations measured for 35 days varied across study communities from 16 to 32 $\mu g/m^3$. Within the same community, daily concentrations of fine particulates varied by as much as eightfold, from 10 to 80 $\mu g/m^3$, and were nearly identical within each pair of communities. Direct measurements of air quality and estimates based on a chemical mass balance receptor model showed that incinerator emissions did not have a major or even a modest impact on routinely monitored air pollutants. A one-time baseline descriptive survey (n=6963) did not reveal consistent community differences in the prevalence of chronic or acute respiratory symptoms between incinerator and comparison communities, nor did they see a difference in baseline lung function tests or in the average peak expiratory flow rate measured over a period of 35 days.

The concentrations of atmospheric pollutants associated with incineration were estimated using emission factors, comparing the effluents with and without control of atmospheric pollutants. The calculated concentrations were compared with the emission limits established by Portuguese legislation. The results indicate that, if there is no control of atmospheric pollutants, their concentrations exceed the established limits. This is observed even if correct operation and maintenance procedures are used. The emission concentrations of dioxins are higher than the Portuguese emission limit, which is particularly worrying due to the high toxicity of some of these compounds. The conclusions obtained clearly justify the great concern regarding air pollution associated with medical waste incinerators currently operating in Portugal (Alvim Ferraz et al., (2000) Levendis et al., (2001) carried out laboratory investigation on the emissions from batch combustion of representative infectious (red bag) medical waste components. Plastics and

cloth account for the majority of the red bag wastes by mass and, certainly, by volume. An electrically heated, horizontal muffle furnace was used for batch combustion of small quantities of shredded fuels (0.5-1.5g) at a gas temperature of ≈ 1000ºC. The residence time of the post combustion gases in the furnace was ≈ 1s. At the exit of the furnace, the following emissions were measured: CO, CO_2, No_x, particulates and polynuclear aromatic compounds (PACs). Nearly all of the mass of carbon of cotton gasified to CO and CO_2, while only small fractions of the carbon in latex were converted to CO_2 and CO (20% and 10% respectively). Yields of NO_x from batch combustion of latex and cotton accounted for 15% and 12% respectively. No SO_2 emissions were detected, indicating that during the fuel rich combustion of latex, its sulfur content was converted to other compounds (such as H_2S) or remained in the soot.

Wang et al. (2002) conducted laboratory experiments in a two-stage horizontal muffle furnace in order to monitor emissions from batch combustion of polystyrene (PS) and identify conditions that minimize them. PS is a dominant component of municipal and hospital streams. Bench-scale combustion of small samples (0.5g) of shredded Styrofoam cups was conducted in air, using an electrically heated horizontal muffle furnace, kept at T_{gas} = 1000˚C. Upon devolatilization, combustion of the polymer took place in a diffusion flame over the sample. The gaseous combustion products were mixed with additional air in a venture and were channeled to a secondary muffle furnace (afterburner) kept at T_{gas} = 900-1100˚C; residence time therein varied between 0.6 and 0.8 s. At the exits of the primary and the secondary furnace the emissions of CO, CO_2, O_2, NO_x, particulates as well as volatile and semi volatile hydrocarbons, such as polycyclic aromatic hydrocarbons (PAH), were monitored. Online analyzers, gravimetric techniques, and gas chromatography coupled to mass spectrometry (GC-MS) were used. Experiments were also conducted with a high-temperature barrier filter, placed just before the exit of the primary furnace to prevent the particulates from entering into the secondary furnace. Results demonstrated the beneficial effect of the afterburner in reducing PAH concentrations, including those of mutagenic species such as benzo(a)pyrene. Filtration drastically reduced soot emissions, by more than 90%. Limited soot formation in the afterburner was again observed with increasing temperatures.

El-Hamouz (2002) studied that medical waste has been separated from municipal waste in Nablus city only in the last three years and disposed of in a medical waste incinerator. A computer reaction program was written to simulate the combustion process taking place during medical waste incineration and to calculator the emission factor and the amount of pollutant emission gases from the medical waste incinerator. It has been found that the highest amount of pollutant emission gases was from burning plastic and glass medical waste. In addition, chlorinated hydrocarbons emissions, such as dioxins and furans, from the incineration process were also calculated using an existing model from the literature. It has been found that the dioxin/furans emissions increase with increasing HCl concentration and decreasing combustion temperature. This confirms the need to control these pollutants from the medical waste incinerator. Lee et al., (2002) conducted a study on two batch-type medical waste incinerators (MWIs), including the one with a mechanical grate (MG-MWI) and the other with a fixed grate (FG-MWI) for the disposal of general medical waste and special medical waste, respectively. Both incinerators shared the same air pollution control devices, which were installed in series, including one electrostatic precipitator (ESP) and wet scrubber (WSB). In this study, the GC/MS technique was used to analyze the concentrations of 21 PAH species contained in the stack flue gas, ESP fly ash, WSB effluent, and incinerating ash. Results show that total PAHs (i.e., the sum of 21 PAH species) in stack flue gas were dominated by LM-PAHs (i.e., two to three ringed PAHs), but in incinerating ash, ESP fly ash and WSB effluent it is found that they were dominated by MM-PAHs (i.e., four-ringed PAHs) and HM-PAHs (i.e., five to seven ringed PAHs) for both types of MWIs. The above results due to air pollution control devices used in both types of MWIs had much higher efficiencies on both MM-PAHs and HM-PAHs (>78%) than on LM-PAHs (<5%). The emission factors of total PAHs for MG-MWI (=252,000 g/kg-waste) were lower than FG-MWI (=856,000 g/kg-waste), which was probably due to more complete combustion involved in the combustion process of the former than the latter. Nevertheless, the above two emission factorswere found consistently higher than the above results warrant the need for seeking better technologies for disposing medical waste in future.

The Ame's Salmonella typhimurium (TA98) assay was used to determine the mutagenicity of stack fly ash from a medical/pathological waste incinerator. Stack fly ash was also collected from a boiler plant adjacent to the incinerator and ambient air particles (upwind and downwind of the incinerator and boiler facilities) were collected and bioassayed. Downwind particulate mutagenicity (revertants per cubic meter of air) was significantly greater than upwind particulate mutagenicity. Mutagenic emission rate estimates (revertants per kilogram waste feed) for the incinerator and boiler were less than estimates published for wood stoves, automobile gasoline engines, and residential furnaces. Incinerator stack fly ash and downwind ambient air particulate samples collected during incinerator auxiliary burner failure demonstrated significant increases in mutagenicity compared to samples collected during routine incinerator operation (Driver et al., 1990).
Polycyclic aromatic hydrocarbon (PAH) emissions were assessed from two batch type medical waste incinerators (MWIs), one with a mechanical grate and the other with a fixed grate, both operated by a medical center. Both MWIs shared the same air pollution control devices (APCDs), with an electrostatic precipitator and a wet scrubber installed in series. Results show that when APCDs were used, total PAHs and total benzo-[a]pyrene equivalent (total BaPeq) emission concentrations of both MWIs were reduced from 2220 to 1870 $\mu g/m^3$ and 50 to 12.4 $\mu g/m^3$, respectively. Industrial Source Complex Short Term model (ISCST) to estimate the ground level concentrations of the residential area and the traffic intersection located at the downwind side of the two MWIs. For the traffic intersection, it is found that both total PAHs and total BaPeq transported from MWIs to both studied area were not significant. For the residential artea, similar results were found when APCDs were used in MWIs. When APCDs were not included, they found that PAHs transported from MWIs accounted for <12%, but total BaPeq accounted for >90%, of the on-site measured concentrations. These results suggest that the use of proper APCDs during incineration would significantly reduce the carcinogenic potencies associated with PAH emissions from MWIs to the residential area (Lee et al., 2003).

A composite approach involving wind sector analyses, receptor modeling, and dispersion modeling has been developed to estimate the impact of a biomedical waste incinerator (BWI). This is presented using measurements of 12-h ambient air particulate matter and

acid gases from a versatile air pollutant sampler, with meteorological data obtained near the BWI as part of a larger short-term respiratory effects study. Monitoring was performed in the same time frame for three consecutive years, the first year being prior to installation of air pollution control devices (APCDs) at the BWI, the next year with the BWI having APCDs, and the final year with the BWI "mothballed". Use of integrated wind sector analyses and receptor/dispersion modeling provided evidence of reduced BWI impacts in addition to information about the nature of emission sources (Mukerjee et al., 1996). Walker and Cooper (1992) presented the results of an extensive literature survey and data analysis conducted to determine uncontrolled and controlled pollutant emission factors (mass pollutant emitted per mass waste incinerated) for medical waste incinerators (MWI). Pollutant emission factors were calculated separately by type of medical waste (red bag, general hospital, and pathological waste), and add-on air pollution control (APC) equipment (wet scrubber systems, or dry scrubber/Baghouse combinations). Pollutants for which emission factors were determined are particulate matter, carbon monoxide, hhydrogen chloride, sulfur dioxide, nitrogen oxides, various metals, dioxin/furans, and the selected volatile organic compounds (VOCs). In addition, the combustion gas produced per mass of waste incinerated was determined in order to compute expected pollutant concentrations in the exhaust gases based on the pollutant emission factors. Data from 40 MWIs burning various forms of medical waste and equipped with or without add-on air pollution control equipment were used to develop pollutant emission factors.

Air pollution control devices (APCDs) are not compulsory for medical waste incinerators (MWIs) in developing countries. In South Africa, combustion gases are usually vented directly to the atmosphere at temperatures greater than the formation temperature of dioxin. The possibility of dioxin formation outside the incinerator stack has been hypothesized. A plume model has been developed and tested in the wind tunnel with a scale model of an incinerator stack. The plume temperature and trajectory predictions of the plume model were verified within ±3% experimental accuracy. The formation models predict that the average polychlorinated dibenzodioxins/furans (PCDD/Fs) formed in the plume will exceed the stack emission regulations in South Africa of 0.2 ng/Nm^3 toxic equivalent quotient (TEQ) by between 2 and 40 times. The calculated concentration does

not include additional gaseous PCDD/F compounds that may be formed at high temperature post combustion zones through pyrosynthesis mechanisms (Brent and Rogers, 2002). Abad et al. (2003) presented results of a dioxin abatement programme undertaken in the municipal waste incineration plant of Montcada i Reixac (Bacelona, Spain) after the replacement of an obsolete air-cleaning device by a new flue gas treatment system. Preliminary results revealed levels between 44 and 111 ng I-TEQ/Nm^3 when the gas cleaning system consisted only of an old electrostatic precipitator (ESP). Decreased levels around 15 ng I-TEQ/Nm^3 were observed when the semi dry scrubber began to operate and the ESP was switched off. Again, remarkable dioxin removal was observed after the installation of the fabric filter and levels around 0.3-0.4 ng I-TEQ/Nm^3 were soon achieved. The results also demonstrated a significant change in the dioxin distribution present in the combustion-derived materials (Table 2.4).

Table 2.4. Comparative Emission Values before and after Air Pollution Control System (APCS) upgrading at MWI plant of Montcada i Reixac, Barcelona, Spain.

Parameter	Before	After
Emissions		
Operation (h/yr)	8000	8000
Flue gas (N m^3/h)	45000	45000
ng I-TEQ/N m^3	111.39	0.016
Annual PCDD/PCDF formation (g I-TEQ/yr)	40.1	0.006
Contribution (%)	65.15	0.347
Solid waste from gas treatment		
Production (Mg/yr)	1300	1300
PCDD/PCDF levels (ng I-TEQ/g)	16.3	1.07
Annual PCDD/PCDF formation (g I-TEQ/yr)	21.19	1.39
Contribution output (%)	34.43	83.83
Bottom ash		
Production (Mg/yr)	10500	10500
PCDD/PCDF levels (ng I-TEQ/g)	0.025	0.025
Annual PCDD/PCDF formation (g I-TEQ/yr)	0.26	0.25
Contribution output (%)	0.43	15.82
Total emitted PCDD/PCDF (g/yr)	61.55	1.66

Source: Abad et al. (2003)

2.8.2. Effluent Treatment

Hospital and communal wastewater differ with respect to their content of specific chemical substances like disinfectant or medicaments. The biodegradation of ifosfamide and cyclophosphamide was investigated by using the Closed Bottle Test (OECD 301 D). Both

the structural isomeric antineoplastics were not biodegraded at aconcentration of 5mg/L in the Closed Bottle test within 28 days. A prolongation of the test up to 57 days did not alter the result. Cyclophosphamide and ifosfamide were not found toxic against wastewater microorganisms. Further investigations about the elimination of ifosfamide and cyclophosphamide in the process of wastewater treatment are necessary to get more knowledge about the possible risk connected with these substances (Kuemmerer et al., 1996). Giuliani et al., (1996) evaluated the genotoxic potential of the wastewater of a hospital by the umuC test. Within 2 years over 800 native wastewater samples were analyzed. Genotoxic activity was found in 13% of the samples. The highest genotoxic activity occurred in the morning hours, but the genotoxic samples were detected also during the day and night. 96% of the genotoxic wastewater samples revealed a genotoxic potential without growth inhibition of test bacteria monitored as OD-600, in the same way as antineoplastic drugs like mitomycin C or cisplatin. 4% of the genotoxic wastewater samples showed combined cytotoxic and genotoxic activities as seen in control experiments using glutaraldehyde containing disinfectants and certain antibiotics.

The sludge from hospital waste treatment facilities is a potential source of infectious organisms. The average numbers of microorganisms in the sludge of hospital wastewater in Taiwan were as follows: total count $8.1x10^7$ cfu g^{-1} (dry weight of sludge), and $1.4x10^6$, $3.6x10^5$, $1.6x10^5$, $2.2x10^5$ and $5.5x10^4$ cfu g^{-1} (dry weight of sludge) for total coliforms, faecal coliforms, faecal streptococci, Pseudomonas aeruginosa and Salmonella spp., respectively. Salmonella spp. Were detected in 37% (10 of 27) of the sludges from hospital wastewaters. Therefore, the treatment of such sludge to reduce pathogenic microorganisms should be considered (Tsai et al., 1998). In the treatment of hospital waste sludge, which contains high concentrations of organic components, the amount of hypochlorite has a pseudo-first-order relationship to the formation of organic halides. Ethanol is a common and safe solvent that is used for the extraction of organic halides from sludge. However, the high partitioning coefficient of sludge for microorganism floc (or chlorinated microorganism floc) retards the extraction effectiveness of ethanol (Tsai et al., 1999). Tsai and Lin (1999) have reported that hypochlorite and chlorine dioxide were used to disinfect hospital wastewater sludge. Their abilities to inactivate pathogenic microorganisms were

compared. Reductions in indigenous coliform organisms and Pseudomonas aeruginosa were estimated. The results indicate that hypochlorite is a better disinfectant than chlorine dioxide for coliforms. Higher disinfection efficiency was obtained by treating a lower concentration of sludge. In addition, a higher agitation speed gave higher disinfection efficiency with hypochlorite. The disinfection efficiencies of both disinfectants were higher against settled sludge than against thickened sludge. Therefore, it is recommended that disinfection should be performed on settled sludge rather than in a thickening tank.

As is widely known, hospital wastewaters play a very important role in the increase and transmission of resistance in bacteria. A total of 52 transformation experiments were carried out using the $CaCl_2$ method. With R-plasmids which were isolated from hospital wastewater bacteria with plasmid-coded resistance to third generation cephalosporins. Transformations were realized in 10 of the experiments in which 3 antibiotics were detected (19.2%). In 4 of the experiments 2 antibiotics were detected (7.7%), and in 18 of the experiments 1 antibiotic (34.6%). No transformation was obtained 20 of the experiments (38.4%) (Dincer et al., 1996). The mutagenic and carcinogenic antineoplastic agent cyclophosphamide (CP) is released into sewers by cancer patient excretion. To assess the biological degrability of CP two standardized test systems, the Zahn-Wellens/EMPA test (OECD 302B) and a laboratory scale sewage treatment plant, were used. In both test systems the agent exhibited only poor degradability. To verify the expected occurrence of CP in hospital sewage, water samples were analyzed for CP with GC/MS after enrichment by solid-phase extraction. CP could be detected in concentrations ranging from 20 ng/L to 4.5 μg/L. The occurrence of the agent could also be proved in samples from the influent and the effluent of the communal sewage treatment plant into which the hospital's sewage water is used. Concentrations ranged from 7 to 143 ng/L. In an attempt to assess the contribution of CP to the genotoxicity assay, were investigated. However, no genotoxic effects of CP were found up to concentration of 1 g/L (Steger-Hartman et al., 1997).

Iodized X-ray contrast media (XRC) for medical applications are responsible for the high concentration of AOX (halogenated organic compounds adsorbable on activated carbon) in

hospital wastewater exceeding the legal German discharge limit. The refractory properties of these substances lead to an accumulation in the natural water body. The elimination of contrast media from hospital wastewater by photochemical oxidation with hydrogen peroxide was investigated. The mechanism and the kinetics of the degradation of XRC were examined. These experiments demonstrate that a complete removal of the organically bonded iodine and a partial mineralization is feasible. The influence of various operating parameters such as gas flowrate, H_2O_2 input, XRC concentration and kind of XRC were investigated. Experiments showed that a recycling of elemental iodine from the exhaust gas is technically and economically possible (Sprehe et al., 2001). Gerbase et al., (2004) experienced that radionuclides have long been employed for biomedical purposes, but the concept of management and control of radioactive waste is relatively recent. Procedures to control disposal of radioactive waste are therefore still not regulated in several countries. As a result, residual radioactive waste carelessly discharged may contaminate the water resources. This article describes the strategies adopted by the University Hospital of Geneva to manage the radioactive waste generated by medical procedures, and presents a longitudinal analysis of 15 years of radioisotope surveillance of the hospital's effluent. Applying the industrial ecosystem approach, an overview of the radioisotope chain, from production to discharge and recycling is presented graphically. It shows that the principles of industrial ecology can apply to the healthcare system and be in agreement with the current social, economical and environmental constraints.

Kiffmeyer et al. (1998) discussed a trace analytical procedure for the cytostatic drugs carmustine, chlorambucil, cisplatin, cyclophosphamide, cytarabine, etoposide, 5-fluorouracil, melphalan, methotrexate, and vinblastine was developed in order to evaluate the environmental hazards of these drugs in clinical wastewater and sewage treatment plants. The analysis was performed using solid phase extraction with subsequent HPLC separation and quantitative determination by gradient elution techniques with DAD and fluorescence detection. Detection limits after the clean up and enrichment procedure vary from 0.002 to 0.2 mg/L. A simulation of the degradation processes under conditions as close as possible to those in a real sewage plant showed that cisplatin and

cyclophosphamide are not biodegradable, but cytarabine and 5-fluorouracil are biodegradable in different magnitudes.

Maurya et al. (2002, 2003a, 2003b) have optimized a best-suited condition by considering the concentration of substrate, reaction time, amount of catalyst, oxidant and solvent for maximum transformation of phenol. All encapsulated complexes serve as catalyst for the decomposition of H_2O_2 and for the oxidation of phenol to a mixture of catechol and hydroquinone using H_2O_2 as an oxidant. However, selectivity towards the formation of catechol and hydroquinone vary from catalyst to catalyst. Rai et al. (2007) investigated in a laboratory scale the decolorization of a simulated dye waste containing three different triphenylmethane dyes using two-stage anaerobic high rate reactor. It has been shown that the influent dye concentration had little effect on overall COD and color removal.

2.9. Common Treatment Facility

A Common Biomedical Waste Treatment Facility (CBWTF) is a setup where biomedical waste, generated from a number of healthcare units, is imparted necessary treatment to reduce adverse effects that this waste may pose. The treated waste may finally be sent for disposal in a landfill or for recycling purposes. The Biomedical Waste (Management & Handling) Rules, 1998, gives an option to the biomedical waste generator that such waste can also be treated at the common biomedical waste treatment facility. The Second Amendment of the Rules in June 2000, further eased the bottlenecks in upbringing the CBWTF by making Local Authority responsible for providing suitable site within its jurisdiction. In an area, only one CBWTF may be allowed to cater up to 10,000 beds at the approved rate by the Prescribed Authority. A CBWTF shall not be allowed to cater healthcare units situated beyond a radius of 150 km. However, in an area where 10,000 beds are not available within a radius of 150 km, another CBWTF may be allowed to cater the healthcare units situated outside the said 150 km (CPCB, 2003). Chang (1995) has reported that rapid advances of medical activities in Taiwan have caused an environmental problem in managing the waste generated by hospitals or clinics. Government regulations, public concern and an increased commitment to a clean environment have also brought more attention to the handling problems of medical waste. A project to plan and manage

the first centralized incineration plant for infectious hospital waste has been carried out in Taiwan. Public concern against incineration was considered to be the most important criterion to address during establishment of the incinerator, as well as good operational performance.

2.10. Safe Disposal in Engineered Landfill/ Facility

Health care waste disposal is becoming a problem of increasing importance in almost all industrially advanced countries. Sanitary landfill has been accepted for disposal of clinical waste, except for the biological waste to be incinerated for ethical reasons and infectious waste contaminated by class 4 viruses, Yersinia pestisor Bacillus anthracis (Ponka et al., 1996). As by a recent Italian law a meaningful percentage of hospital waste (50 to 60%), corresponding to food residuals, plastics, paper, various organic materials, etc., could be landfilled as municipal refuses if preliminary submitted to a suitable sterilization treatment (Tata and Beone, 1995).

Refuse originated from consulting rooms of medical doctors of five different specializations were disposed of for more than six months in a model landfill. Another variants of the same experiment consisted of a mixture, made from refuse as above with municipal refuse (1:10), and of municipal refuse alone. Using estimation of either CO_2 and NH_3 evolution before and after disposal, continuous temperature measurement, organic matter and moisture contents, the mineralization process in the disposed refuse was followed. In model landfill, which was kept under aerobic conditions the results, indicated a low rate of mineralization in refuse from medical consulting rooms. The mixture containing municipal refuse and refuse from medical consulting rooms showed mineralization rate similar to that of municipal refuse alone. If the model landfills were kept nearly anaerobic almost no mineralization occurred in all kind of refuse disposed of (Filip and Frost, 1985). Refuse from medical consulting rooms, a mixture of those refuse with municipal refuse (1:10), and municipal refuse were disposed aerobically and roughly anaerobically for over six months in a model landfill. Survival, proliferation, and transportation of microorganisms were estimated at different periods of time. Concentrations of aerobic bacteria and hypomycetes decreased during the first weeks of

deposition but remained later unchanged. Concentrations of nonsporeforming indicator bacteria (*Escherichia coli, feacal streptococci*) decreased more strongly, and E.coli could not be found at latest after 23 weeks. In municipal refuse alone and mixed with refuse from medical consulting rooms, Pseudomonas aeruginosa proliferated temporarily. Leaching of microorganisms from the model landfill was observed in the whole course of the disposal period (Trost and Filip, 1985).

2.11. Developing a Long-term Strategy/ Further Research

There are no entirely satisfactory definitions of clinical waste; nor are there methods in general use that are safe and environmentally acceptable for the storage, transport and final disposal of the ever increasing volume of such waste that is generated by the health services. Hazardous, potentially infectious and aesthetically objectionable waste has been found on beaches and exposed on domestic refuse landfill sites, causing public disquiet about health hazards and environmental pollution. Landfill is officially discouraged, where not illegal, and many older type incinerators cannot now be used became their effluent pollutes the atmosphere. Modern and efficient incinerators are expensive and the parochial nature of health service management and accounting militates against their installation and use. Laboratory waste, however, can be rendered safe and unobjectionable, aesthetically and environmentally, if the requirements and recommendations of the several codes of practice and technical advice, which are simple and inexpensive, are implemented by laboratory and hospital managers (Collins, 1991)

In the management of medical wastes, a management plan should be established to ensure protection of public health and the environment. The plan should incorporate a cradle-to-grave approach to infectious medical wastes. This includes the adoption of standard operating procedures (SOPs) to address: the generation of wastes, segregation of wastes, containerization and storage of wastes, waste treatment, waste handling and transportation, waste disposal, and contingency planning (Meaney and Cheremisihoff, 1989). Liberti et al., (1994) have reported that a two-year R&D project dealing with the study, design, prototype plant development and operation of an integrated management system of infectious hospital wastes (IHW) was performed by CO.PR.AM., an Italian industrial

consortium. The project was concerned with the characterization, handling (collection, storage, transportation) and incineration of IHW produced by a large sanitary district (three hospitals, 191 different clinics, 40 laboratories, and a total of 2500 bedspaces) and permitted researchers to analyse in detail each major aspect of IHW disposal such as production handling and treatment in order to devise an optimal solution to their overall management.

The field of medical waste disposal is changing rapidly. Over the past decade, there has been increasing public health concern over health care's red bag waste. The health care industry must routinely contend with a complex set of regulations covering occupational safety, transportation and packing, medical waste disposal management, and now environmental regulations for medical waste incinerators. Boutacoff (2000) discussed the ability of hospitals and other health care facilities to maintain the quality of patient care with cost control. Partnerships with health care organizations, energy service providers, equipment vendors and industry associations were established as the way to optimize energy use and reduce costs (Zanoni, 1998). Shih and Lin (1999) have studied that most small to medium sized hospitals and clinics in Taiwan do not have on-site treatment facilities for their medical and infectious wastes and must rely on outside agencies for its collection and treatment. The problem of optimally planning and scheduling the collection of medical wastes from a disperse group of facilities is formulated as a periodic vehicle routing problem. Special attention is paid to the requirement that waste pickup be made on at least a weekly basis. A two-phased approach is used to solve the resulting optimization model. The first phase solves a standard vehicle routing problem to determine a set of individual routes for the collection vehicles. The second phase uses mixed integer programming to assign routes to particular days of the week.

In Helsinki, Finland, new guidelines have been adopted for the management of wastes from healthcare facilities. The purpose has been to rationalize waste management, reducing the amount of waste needing special treatment and lowering costs, while at the same time maintaining occupational safety and preventing environmental hazards (Ponka et al., 1996). There is currently no form of biological monitoring or health assessment technique

that is sensitive or specific enough to adequately predicts the effects of chronic long-term exposure to cytotoxic drugs (OSHS, 1997). Clark (1997) reviewed the present and future provision for clinical waste treatment and disposal in Scotland. Data was obtained using open structured interviews and a simple questionnaire. The results of the study indicate that the transition from central to local organization has been carried through largely without mishap. A single exception to this affects consortia who have yet to secure long term facilities for the treatment of their waste. External influences, particularly the acquisition of planning consents for new plant remains problematic for would be developers. The commissioning and regulation of new technologies would also appear to be ad hoc. Finally, if the proposed facilities are constructed and commissioned then the current situation of over capacity will be considerably exacerbated.

Dilly and Shanklin (2000) observed that U.S. Army medical treatment facilities (MTFs) would be challenged to reduce waste as the army internalizes an environmental ethic and privatizes solid waste management. A questionnaire was modified to survey solid waste management practices, participation in waste reduction and recycling programs, and solid waste management problems in 25 MTFs. Questionnaires were returned by 19 (76%) of the sites. Eighteen sites participated in waste reduction and recycling programs. Twelve used contractors to disinfect potentially infectious solid waste off site. Mean importance ratings of waste reduction and recycling were 2.00 and 1.83 (1= very important; 5 = very unimportant), respectively. Limited staffing was ranked as the most significant waste management problem followed by cost and regulatory compliance. More information on waste generation in MTFs is needed. The Army Medical Department should be presented as a model of environmental and natural resource stewardship for health care industry.

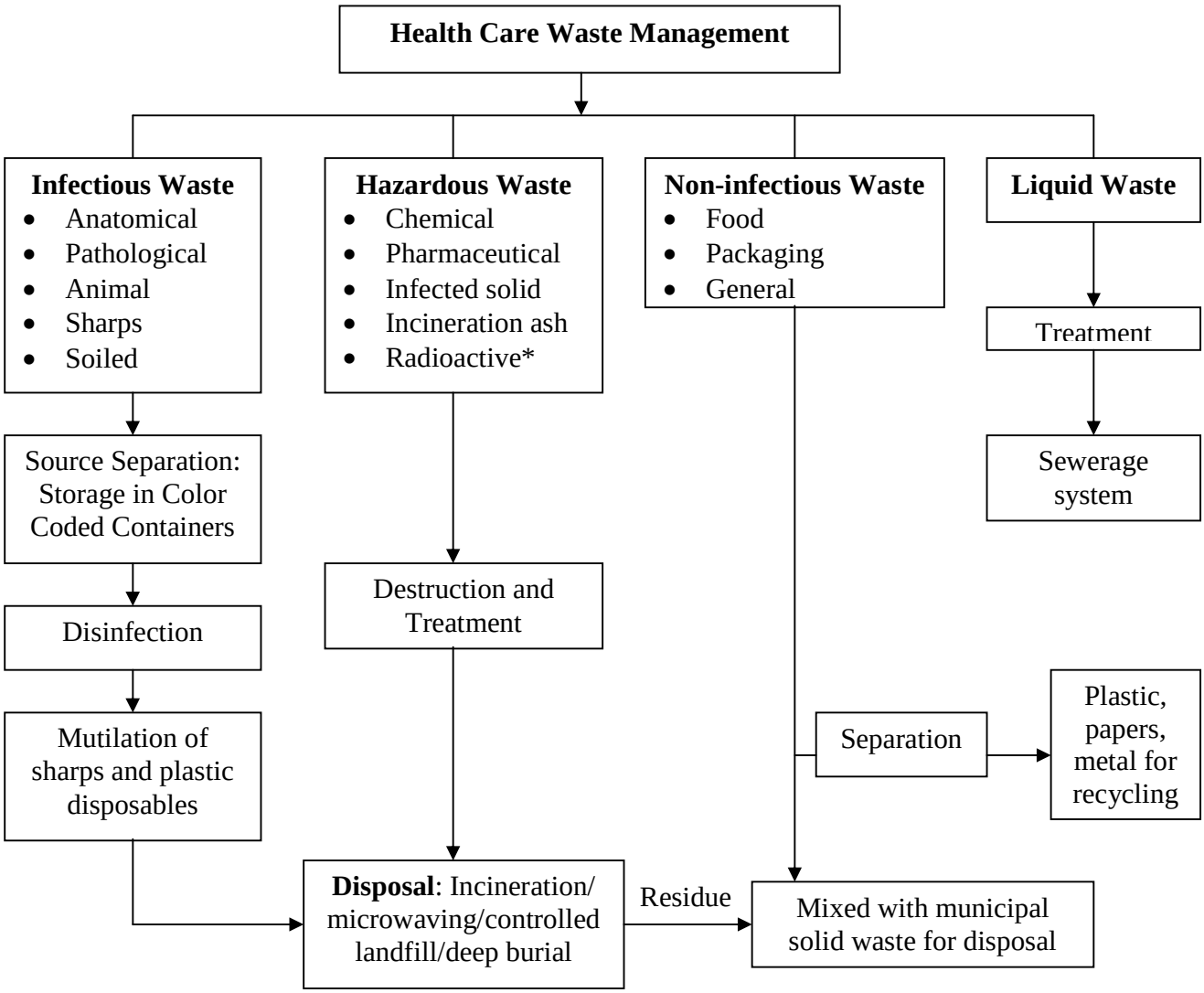
The treatment and disposal of hazardous wastes in China is summarized on the basis of the results of the Declaring and Registration Project initiated nationally in 1995. A principle framework for the sound management of hazardous wastes is proposed, which includes three levels of technical solutions. Large-scale enterprise are encouraged to recycle, to treat, and to dispose of wastes by means of constructing facilities, and to have their extra capacities available to the public for a reasonable fee. Municipal Governments, Provincial

Governments, and Central Government are to plan and construct centralized facilities to recycle, treat, and dispose of wastes. Centralized facilities at the municipal level will mainly focus on special wastes that are unsuitable to transport and store, such as hospital waste, and for the technical solution at this level, incineration and recycling are identified as the main approaches (Li et al., 2002). Chung and Lo (2003) have derived four criteria: environmental desirability, economic optimization, social acceptability and equity, and administrative diligence. These four criteria are then applied in the context of Hong Kong for the evaluation of management performance of construction and demolition waste, clinical waste and chemical waste. Their analysis showed that the management of three types of wastes has failed in almost all the sustainability criteria. The main causes for the unsatisfactory waste management performance in Hong Kong is closely related to the governance style of the government rather than some general causes such as a lack of technological know-how or financial constraints.

Biomedical waste management rules were formulated in response to the worldwide public concern over medical waste. The practice of separation into different types of waste in health care institutes should be evaluated more scientifically. Due to a lack of data from the Indian sub-continent, this study was initiated at a tertiary care hospital. Samples were collected from different waste at the hospital, at different time interval, for microbiological evaluation. The results reveal that the microbial flora isolated from infectious waste and general wastes from the hospital are similar. The samples from general waste in this study reveal many types of pathogens. The bacteria present in the waste initially was low in quantity, but they replicated rapidly over time so that significant numbers were detected 24 hours, due to environmental factors which were favorable for growth during this period. This study strongly suggests that waste should be removed from the hospital within 24 hours of its generation to prevent environmental contamination caused by any accidental spillage of waste. General waste generated in the hospital should be treated similar to infectious waste, as it can be equally hazardous (Saini et al., 2004).

Patil and Shekdar (2001) studied the health care waste management in India and analyzed the prevailing situation covering various issues like quantities and proportion of different

constituents of wastes, handling, treatment and disposal methods in compliance with Biomedical Waste (Management & Handling) Rules, 1998, as shown in Figure 2.1.



*Return to Supplier

Figure 2.1. Prescribed pathways for management of health-care wastes.
Source: Patil and Shekdar (2001).

Federal regulations that specifically address the disposal of pharmaceuticals exist only for those designated as controlled substances by the Drug Enforcement Administration (DEA). For all others, the generator must determine the best method of disposal to comply with existing environmental regulations. The variety of disposal methods results from not only the differing characteristics of pharmaceuticals, but also from generators' confusion

regarding proper disposal requirements. One of the largest sources of confusion in pharmaceutical disposal is whether the pharmaceutical is a hazardous or medical waste. Using proprietary databases of pharmaceuticals, companies can quickly identify which pharmaceuticals may be returned, which must be disposed, and what the appropriate disposal method is. Fig.2.2 outlines the decision making process for the disposal of discarded pharmaceuticals. When determining the proper final management practice, applicable state and local regulations should be identified prior to selecting the final disposition (Musson and Townsend, 1998).

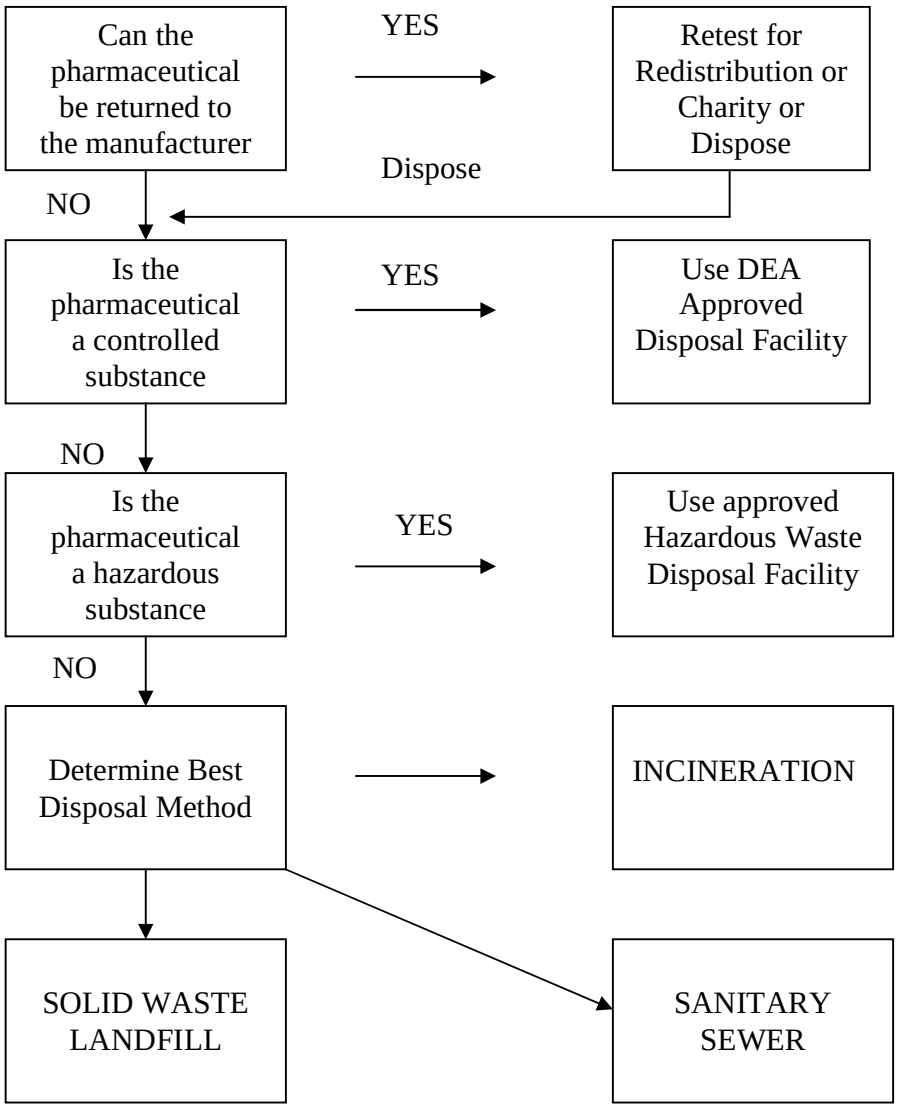


Figure 2.2. Discarded pharmaceutical disposal process
Source: Musson and Townsend (1998)

2.12. Modelling of Waste Quantity and Treatment

The modelling of waste management systems has arisen from the need to optimize the waste system to reduce environmental burdens or economic costs and to improve social acceptability. The first solid waste management models were optimization models and dealt with specific aspects of the problem (Gottinger, 1988; MacDonald, 1996; Berger et al., 1999; Costi et al., 2004). More recent models are centered on integrated waste management, with sustainable waste management becoming a central feature (Kowalewski et al., 1999; Berger et al., 1999; Costi et al., 2004). Other recent models place emphasis on the whole life cycle of products (Bjorklund et al., 1999; Finnveden, 1999; Powell, 2000; Harrison et al., 2001). Many of the models identified are decision support models, using a variety of methods and tools, such as risk assessment, environmental impact assessment, cost benefit analysis, multicriteria decision making or life cycle as part of the decision making process. Advocating for the need of modeling, Woolridge et al. (2005) emphasized that the most effective management of municipal solid waste (MSW) has to relate to local environment, economic and social priorities and must go beyond the traditional consultative approaches that require the expert to draft the solution in advance of public involvement, to a more effective approach through involving the public before key choices have been made.

Awad et al. (2004) carried out statistical analysis to develop models for the prediction of the quantity of waste generated at each hospital (public, teaching, private). In these models number of patients, beds, and type of hospital were revealed to be significant factors on quantity of waste generated. Multiple regressions were also used to estimate the quantities of wastes generated from similar divisions in the three hospitals (surgery, internal diseases, and maternity). In this study, the important variables that effect the quantity of wastes generated from the hospitals have been identified, then simple linear and nonlinear, regression analysis was applied in order to develop predictable models that can be used in estimating or predicting the generated waste in Irbid (Jordan) hospitals. To accomplish this goal the statistical analysis system (SAS) version 6.07 at Jordan University of Science and Technology computer center was used to develop these models. SAS Version 6.07 is a

powerful system, capable of handling regular or simple nonlinear and stepwise regression analysis. As a result of their research work it is concluded that careful sorting, handling, and storage of waste inside hospital is the key to hospital hygiene. Normal wastes should be kept separate from hazardous wastes and each type of hazardous waste should be kept in appropriate containers. There is a great need for establishing a proper hazardous hospital waste management program to control the existing situation in Irbid hospitals. This can be achieved by setting up an official national agency to regulate, control, and plans the procedures of handling these wastes.

The problem of optimally planning and scheduling the collection of medical wastes from a disperse group of facilities is formulated by Shih and Lin (1999) as a periodic vehicle routing problem. Local environmental regulations mandate the treatment of infectious medical waste on a daily basis if it is stored at room temperature. If stored at a temperature lower than 5°C, such waste must be treated within a week. Under this regulation, the collection system must be well designed; the process must be completed within a week as well. Further, Shih and Lin (2003) reported that an infectious waste collection system planning in Taiwan requires solving routing and scheduling problems simultaneously due to an environmental regulation. Previous work on this type of problem that considered a single criterion is extended in this study to a multiple criteria optimization approach. In addition to minimization of the cost, minimization of transportation risk and balancing of worker's carrying loads are considered for hazardous waste collection. Dynamic programming and integer linear programming methods are incorporated as an integral part of decision analysis in which a compromising programming method is adopted to integrate the three criteria of concern. Finally, an illustrative example of infectious waste collection in Taiwan City is presented to demonstrate the application potential of the proposed approach. A geographical information system is used to aid in relevant spatial analyses, such as the location of medical institutions, actual travel distances, and district population density, in the optimization steps. The findings indicate that the incorporation of more objectives in decision analysis may provide a scientifically credible solution for medical waste management in urban areas.

2.12.1. Strategic Waste Achievement Programme (SWAP) Methodology

The Strategic Waste Achievement Programme decision making methodology has been developed to enable stakeholders in the decision making make the best decision possible given the circumstances, to determine the most acceptable set of actions and to determine how success can be measured. Considering the complete life cycle of waste from the prevention of waste through to final disposal is part of this decision making process. The methodology must also allow the adoption of a guiding principle consistent with sustainable waste management, this should include:

- taking into account the wider issue of what makes waste management decision effective;
- taking into account the actual waste composition;
- emphasizing the management of waste rather than the treatment of waste;
- using a transparent weighting mechanism;
- determining the most acceptable set of actions, given the local conditions, by the use of an appropriate evaluation method;
- determining how a decision can be implemented.

In a hospital there are several key players when strategies are being developed. Waste is generated by all departments and each department has overall purchasing power for the items they buy in. However, the cost of waste disposal is not borne by the individual departments, but is paid for from a central budget. The implications are that more waste may be generated in certain areas e.g. where disposable instruments are the preferred option over reusable types. In order to address these issues the management team need to make strategic decisions based on the waste generated from specific types of purchase in addition to the initial cost.

The overall purpose of the SWAP methodology is to design a strategic tool that can be used in large businesses and organizations to develop a waste management programme that is acceptable to all stakeholders. The methodology consists of four steps:

1. the scoping of the project;
2. the generation of a list of possible waste management actions;
3. the selection of the most appropriate waste management actions;

4. the implementation of the agreed waste management actions.

2.12.2. Structured Systems Analysis Design Method (SSADM)

SSADM is the standard methodology used by the UK government for the development of their Information Systems. It is an open method, i.e. there are no fees to use it, and its use does not infringe any copyright laws. SSADM is a prescriptive methodology and takes rational, engineering view of the world.

SSADM has following set of objectives:

. graphically document the boundaries of the system;

. to show the movement of data between the system and its environment;

. to provide hierarchical functional breakdown of the system;

. to document the intra-system information flows;

. to aid communication.

A feasibility study was conducted by Woolridge et al. (2005), at an acute general NHS hospital, in Central England; this showed that a significant proportion of waste in the clinical waste stream is not clinical and should be processed as domestic waste. The available literature does not give easily interpretable practical advice on the disposal of healthcare waste; this study highlights knowledge and implementation gaps. The principle techniques for conducting the investigation in this study were observation and interview; consequently the majority of the research data is qualitative. Where hard data has been published these have been used, but most of the data has been obtained through personal communication either verbally, by letter, telephone or e-mail. In some cases it was possible to weigh the raw materials before they became waste whilst they were still in the stores department. This technique was used for disposable items where it was known that the item and the packaging were destined for the waste stream. Items that were treated in this way were paper towels, surgical gloves, blue roll, aprons, and soiled dressing bags. After considerable discussion it was decided that the following would be the most effective research methods:

. observation of the relevant practices;

. informal interviews;

. work shadowing.

Woolridge and Phillips (2004) used a systems analysis approach to obtain and analyze data. Structured Systems Analysis and Design Method (SSADM) was selected as the preferred method for the analysis as it is highly structured, and has a set of techniques that can be readily applied to business problems. SSADM was developed as a tool for the development of Information System; it analyses a business from three different aspects; functionality, data and time. Historically, data on the composition of waste has come from the splitting of bags and physically separating and weighing the waste composition. The current literature is biased very heavily towards the final disposal of waste, rather than the processes that generate and remove the waste from its source. There is little academic literature on healthcare waste minimization. The majority of UK publications are produced by waste managers or government agencies with little emphasis upon the development of new tools to address this pressing problem. One of the difficulties regarding the disposal of healthcare waste is the interpretation of the legislation that regulates the disposal of this waste. Clinical waste is a subset of healthcare wastes and is defined in accordance with the Collection and Disposal of Waste Regulations 1998 and as amended by the Controlled Waste Regulations 1992. It is disposed of in yellow bags, yellow rigid containers or sharps boxes.

2.12.3. Development of Waste Quantity Prediction Models

To develop a sound and predictable model that can be used to describe or estimate the quantity of waste generated at any hospital, complete and comprehensive database must be gathered. In addition, all variables and factors that could affect the quantity of waste generated should be investigated and analyzed. Establishing the simple correlation matrices between different variables is the first step in model development. This step is crucial for investigating the strength and form of the relationship between the variables included in the analysis. Next, a scattergram should be plotted to determine the ranges and the general trends of the included variables. This can be used in determine the suitable transformation for the variables included in the analysis.

Awad et al. (2004) carried out statistical analysis to develop models for the prediction of the quantity of waste generated at each hospital (public, teaching, private). In these models

number of patients, beds, and type of hospital were revealed to be significant factors on quantity of waste generated. Multiple regressions were also used to estimate the quantities of wastes generated from similar divisions in the three hospitals (surgery, internal diseases, and maternity). In this study, the important variables that effect the quantity of wastes generated from the hospitals have been identified, then simple linear and nonlinear, regression analysis was applied in order to develop predictable models that can be used in estimating or predicting the generated waste in Irbid (Jordan) hospitals. To accomplish this goal the statistical analysis system (SAS) version 6.07 at Jordan University of Science and Technology computer center was used to develop these models. SAS Version 6.07 is a powerful system, capable of handling regular or simple nonlinear and stepwise regression analysis. As a result of their research work it is concluded that careful sorting, handling, and storage of waste inside hospital is the key to hospital hygiene. Normal wastes should be kept separate from hazardous wastes and each type of hazardous waste should be kept in appropriate containers. There is a great need for establishing a proper hazardous hospital waste management program to control the existing situation in Irbid hospitals. This can be achieved by setting up an official national agency to regulate, control, and plans the procedures of handling these wastes.

2.12.4.Optimization for Infectious Medical Waste Collection System

Most small to medium sized hospitals and clinic in Taiwan do not have on-site treatment facilities for their medical and infectious wastes and must rely on outside agencies for its collection and treatment. The problem of optimally planning and scheduling the collection of medical wastes from a disperse group of facilities is formulated by Shih and Lin (1999) as a periodic vehicle routing problem. Local environmental regulations mandate the treatment of infectious medical waste on a daily basis if it is stored at room temperature. If stored at a temperature lower than 5°C, such waste must be treated within a week. Under this regulation, the collection system must be well designed; the process must be completed within a week as well. Previous literature refers to this kind of problem as the periodic vehicle routing problem (PVRP). The PVRP, a generalization of the conventional VRP, attempts to design a set of daily routes for a given T-day period. In this study, T equals 6 days, including Sunday. In this study, the writers recommend solving PVRP in

two phases. Initially, they solve a standard VRP without considering the allowable day combination constraints. Second, a mixed integer programming method is employed to assign daily the obtained routes to balance primarily the workload.

Further, Shih and Lin (2003) reported that an infectious waste collection system planning in Taiwan requires solving routing and scheduling problems simultaneously due to an environmental regulation. Previous work on this type of problem that considered a single criterion is extended in this study to a multiple criteria optimization approach. In addition to minimization of the cost, minimization of transportation risk and balancing of worker's carrying loads are considered for hazardous waste collection. Dynamic programming and integer linear programming methods are incorporated as an integral part of decision analysis in which a compromising programming method is adopted to integrate the three criteria of concern. Finally, an illustrative example of infectious waste collection in Taiwan City is presented to demonstrate the application potential of the proposed approach. A geographical information system is used to aid in relevant spatial analyses, such as the location of medical institutions, actual travel distances, and district population density, in the optimization steps. The findings indicate that the incorporation of more objectives in decision analysis may provide a scientifically credible solution for medical waste management in urban areas.

2.12.5. Modelling of Waste Incineration

Tests in a 10 kg h^{-1} pilot scale incinerator burning medical waste showed that the amounts of PCDD/F formed when cooling from 900 ºC to ambient were almost proportional to the residence time in the 400-200 ºC range. This suggests that gas phase adsorption control rather than kinetic control was operating. A generalized model of PCDD/F formation was developed for a chlorine rich gas phase, based on diffusion of HCl to the fly ash surface. It was necessary to incorporate a "sticking factor" α, which specifies the fraction of molecules that are retained on the ash surface and subsequently enter into reaction. The calculation combines rates for the formation and destruction mechanisms that are effective in the range of 400-225 ºC. Application of the model requires knowledge of the cooling regime, the specific surface area of fly ash, its concentration at the sampling point, and the

initial surface concentration of PCDD/F. It assumes that all the PCDD/F emitted from waste incinerators is associated with the fly ash. The model satisfactorily simulates the upper temperature window for PCDD/F formation and the effect of cooling regime on rate. When tested on a number of commercial incinerators with varying levels of gas cleaning efficiency, the value of α was found to depend on the downstream cleaning facilities, being 4-5 $\times 10^{-8}$ for gas cleaning systems involving only solids removal (wet scrubbing) and 1-3 $\times 10^{-9}$ for those utilizing adsorption processes for gas phase components as well (lime, carbon). The latter appears to be the true value for surface formation processes. The presence of sulfur in the fuel forces the value of α downward (Stanmore and Clunies-Ross, 2000).

For better understanding of the incineration process, process simulation was conducted by Yang et al. (2003) using Computational Fluid Dynamics (CFD) code Phoenics to characterize temperature and species distribution in the incinerator. To include all the waste streams in a single CFD model is difficult, and how to define the different waste streams with different calorific values and chemical composition is a challenge to the CFD modeling. In the current paper, hazardous waste in various forms is firstly converted to a hydrocarbon based virtual fuel mixture. The combustion of the simplified waste was then simulated with a 7-gas combustion model. The distribution of temperature and chemical species is broadly investigated. Distribution of CO concentration, as a good indicator of emission level for the incineration process, could be used to evaluate the emission control. The predicted temperature distribution has been validated with available measurement data from the operating rotary kiln waste incinerator AVR-Chemie in the Netherlands. The incinerator consists of a rotary kiln and a secondary combustion chamber (SCC). The rotary kiln is 4.2 m in diameter and 11.7 m in length, mounted at a 1-2° angle and it rotates at a speed of 0.07 rpm. The SCC is 6.3 m in width, 5.5 m in depth, and 18 m in height. The thermal capacity of the incinerator ranges from 30 to 40 MW, and the waste processing rate is about 7 tons per hour. A wide range of hazardous wastes with heating value of about 5 to 30 MJ/kg is incinerated in the system. New statistical post processing of the standard CFD output has been developed to give an overview of the average temperature profile and overall reactor behaviour for process control.

Ryu and Choi (1997) studied that numerical flow simulations have become very powerful as complex geometry and flow conditions in incinerators can be adequately accommodated. Three-dimensional modeling of turbulent flows along with chemical reactions provides detailed information that could not be attained through experimental measurements. The results of three-dimensional flow simulation are complex, and presentation and interpretation of data are not always simple. It is common to present velocity vector plots or contour lines of velocity and concentration of combustion products. Particle trajectories are drawn and gas residence times calculated. The present study focuses on design considerations relating to cross jet air mixing. Three dimensional flow simulations are applied to the model geometry of the overfire air injection nozzle. Design parameters are identified and the effects of design variables quantitatively evaluated by introducing performance indicators.

A dynamic model for the simulation of energy recovery in an incineration plant has been constructed by Marias and Reneaume (2004). This model is representative of the steam to electricity cycle of an incineration plant of 3.3t/h municipal waste input. The main devices of the cycle have been taken into account. The mathematical formulation of the system leads to a system of 121 equations, 6 of them being ordinary differential ones. Gear's method allows for the solving of the system, even in the case of stiff behavior. Such stiffness might be encountered when operating parameters are suddenly modified.

2.12.6. Numerical Modelling – Bottom Ash Monofill

Municipal solid waste is incinerated to reduce its volume, toxicity and reactivity. Several studies have shown that the resulting bottom ash has a high exothermic capacity. Klein et al. (2003) reported that until the 1970s, bottom ash from municipal solid waste incineration was believed to be almost inert, but since then several studies have shown that many exothermic reactions may cause a temperature increase of up to 90 ºC in the landfill. High temperatures at the bottom of a landfill may affect the stability of the landfill liner system [flexible membrane liner, polymer membrane liner (FML) and mineral clay layer]. Temperatures above 40 ºC may damage the stability of the FML (made of high density polyethylene, HDPE) due to polymerization and oxidation. Due to diffusive transport of

water and water vapour along the temperature gradient in the mineral clay layer, the clay barrier may desiccate and fail to retain leachate. In order to prevent thermal damages to the liner system, it is necessary to minimize the temperatures in the landfill. There are several factors such as the storage time prior to the deposition and the surface to volume ratio influencing the temperature development in a landfill. The most important reactions that cause a temperature increase in the stored bottom ash are the corrosion of iron and aluminium, the hydration of lime (CaO) and the carbonation of portlandite [$Ca(OH)_2$]. The objective of this work was to develop a numerical model incorporating basic concepts from chemistry and physics to simulate the spatial and temporal distribution of heat in a bottom ash landfill. This objective was accomplished in two steps: (1) the observation of the temperature development in a bottom ash landfill under several modes of emplacement, and (2) the development of a heat generation and transport model and validation of this with the data obtained from field experiments. This numerical simulation provides the possibility of predicting the temperature development in a bottom ash landfill under different modes of emplacement.

2.12.7. Neural Network Analysis – Cement Solidified Wastes

Neural network analysis has emerged over the past decades as a practical technique for identifying patterns in large data sets of many variables. The use of neural networks in civil and environmental engineering applications has been the subject of a number of review articles. The idea of neural network analysis to examine relationships between concrete composition and other properties, especially strength and ductility, was first published by Wittmann and Martinola in 1993. Stabilization/solidification with Portland cement or other hydraulic binders (S/S) is commonly recommended for treatment of wastes that cannot be reduced, destroyed or recycled. Development and design of S/S systems is complicated by several factors, including: (1) the existing of numerous cementitious and pozzolanic materials that can be combined in many different ways, resulting in a wide range of properties and costs, and (2) the potential for a variety of complex interactions between cementing components and other chemicals in these systems, which can have important effects on the final product properties. Therefore, to aid design and regulatory approval of S/S systems, it would be useful to develop models that

could be used to predict their behaviour without extensive practical experimentation. A European project was conducted, which collected results from the literature for testing of nearly 8,000 cement-based products into a database MONOLITH. Data collection focused on measurements of setting, strength, and pH and contaminant concentrations in single batch extraction leaching tests, although other incidental measurements were collected as well. This paper summarizes efforts to analyse data from the MONOLITH database using neural networks, to identify useful predictive relationships between product composition and final properties (Stegemann and Buenfeld, 2004).

Technical properties of practical interest for use of S/S products concern the product handling characteristics, structural suitability for utilization, durability and ability to retain toxic contaminants. The data collected in the MONOLITH database were refined into coherent data sets to predict three key properties related to these areas of interest:

1. Setting time, which relates to handling characteristics of an S/S product after mixing and during placement;
2. Unconfined compressive strength (UCS), which relates to the load bearing capacity of a S/S product in a utilization application, and also physical durability; and
3. Leachate pH and acid neutralization capacity (ANC), which relates to chemical durability of a S/S product in a disposal or utilization environment, and also can be used to predict the solubility of toxic contaminants using more mechanistic modeling techniques.

Examination of the entries in the MONOLITH database showed that the most common waste types were incinerator ash, plating sludges, and steel industry dust. Neural network prediction of UCS was conducted for 256 products from 19 references, which were composed of Portland cement with these waste types, as well as additional 28 products for control specimens not containing waste from another six references. The final data set contained 852 data points, of which 15% were used for validation, and another 15% for testing. The 33 different *real wastes* in the data set were divided into five classes, based on broadly similar characteristics:

1. Electric arc furnace (EAF) dust
2. Foundry dust

3. Municipal solid waste incinerator (MSWI) fly ash
4. Other types of ash, which included MSWI combined ash, MSWI bottom ash, sewage sludge ash and hospital waste incinerator bottom ash
5. Sludges and filtercakes from metal plating operations

The above modeling approaches necessitate the following investigations and analysis for efficient treatment and disposal options:

- Data collection and analysis of the prevailing strategies used for the disposal of the medical waste from healthcare facilities/ research institutes.
- Study of prevailing technologies for deactivation of some identified waste categories for safe disposal.
- To develop a model to find suitable treatment and disposal options.
- To validate the proposed model.

3. CLASSIFICATION AND HEALTH IMPACTS

3.1.Categories of Biomedical Wastes

The Medical Waste Tracking Act (MWTA), USA, of 1988 defined medical waste as any solid waste, which is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals. Descriptions of specific classes of medical wastes as detailed in Code of Federal Regulations (CFR) Part 259 are given in Table 3.1.

Table 3.1. Classes of Medical Wastes under Medical Waste Tracking Act, USA.

Description of Different Classes of Medical Wastes
Class 1 – CULTURES AND STOCKS Cultures and stocks of infectious agents and associated biologicals, including cultures from medical and pathological laboratories, cultures and stocks of infectious agents from research and industrial laboratories, wastes from the production of biologicals, discarded live and attenuated vaccines, and culture dishes and devices used to transfer, inoculate, and mix cultures.
Class 2 – PATHOLOGICAL WASTES Human pathological wastes, including tissues, organs, body parts, and body fluids that are removed during surgery and autopsy or other medical procedures, and specimens of body fluids and their containers.
Class 3 – HUMAN BLOOD AND BLOOD PRODUCTS Waste human blood and products of blood, items saturated and/or dripping with human blood; or items that were saturated and/or dripping with human blood that are now caked with dried human blood; including serum, plasma, and other blood components, and their containers, which were used or intended for use in either patient care, testing and laboratory analysis, or the development of pharmaceuticals. Intravenous bags are also included in this category.
Class 4 – USED SHARPS Sharps that have been used in animal or human patient care or in medical, research, or industrial laboratories, including hypodermic needles, syringes, pasteur pipettes, scalpel blades, blood vials, test tubes, needles with attached tubing, and culture dishes (regardless of presence of infectious agents). Also included are other types of broken or unbroken glassware that were in contact with infectious agents, such as used slides and cover slips.
Class 5 – ANIMAL WASTE Contaminated animal carcasses, body parts, and bedding of animals that were known to have been exposed to infectious agents during research (including research in veterinary hospitals), production of biologicals, or testing of pharmaceuticals.
Class 6 – ISOLATION WASTES Biological waste and discarded materials contaminated with blood, excretion, exudates, or secretions from humans who are isolated to protect others from highly communicable diseases or isolated animals known to be infected with highly communicable diseases.
Class 7 – UNUSED SHARPS Unused sharps include the following unused, discarded sharps as a class of regulated medical waste; hypodermic needles, suture needles, syringes, and scalpel blades.

Source: Cole et al., 1993.

In India, Ministry of Environment & Forests (MoEF) has notified Biomedical waste (Management and Handling) Rules, 1998. These rules describe ten categories, which are reproduced in Table 3.2.

Table 3.2. Categories of Biomedical Waste, Ministry of Environment and Forests, India.

Biomedical Waste Categories and their Description
Category No.1 – **Human Anatomical Waste** (human tissues, organs, body parts)
Category No.2 – **Animal Waste** (animal tissues, organs, body parts carcasses, bleeding parts, fluid, blood and experimental animals used in research, waste generated by veterinary hospitals colleges, discharge from hospitals, animal houses)
Category No.3 – **Microbiology & Biotechnology Waste** (wastes from laboratory cultures, stocks or specimens of microorganisms live or attenuated vaccines, human and animal cell culture used in research and infectious agents from research and industrial laboratories, wastes from production of biologicals, toxins, dishes and devices used for transfer of cultures)
Category No.4 – **Waste Sharps** (needles, syringes, scalpels, blades, glass, etc. that may cause puncture and cuts. This includes both used and unused sharps)
Category No.5 – **Discarded Medicines and Cytotoxic Drugs** (wastes comprising of outdated, contaminated and discarded medicines)
Category No.6 – **Solid Waste** (items contaminated with blood, and body fluids including cotton, dressing, soiled plaster casts, linen, beddings, other material contaminated with blood)
Category No.7 – **Solid Waste** (wastes generated from disposable items other than the waste sharps such as tubings, catheters, intravenous sets etc.)
Category No.8 – **Liquid Waste** (waste generated from laboratory and washing, cleaning, housekeeping and disinfecting activities)
Category No.9 – **Incineration Ash** (ash from incineration of any biomedical waste)
Category No.10 – **Chemical Waste** (chemicals used in production of biologicals, chemicals used in disinfection, as insecticides, etc,)

Source: MoEF GoI, 1998.

The Environment Agency (EA) is the regulatory authority responsible for waste management activities in England and Wales. The Health Services Advisory Committee (HSAC) during the year 1999 had published guidance on the 'Safe Disposal of Clinical Waste' and put clinical waste into five categories as shown in Table 3.3. However in place of HSAC guideline, European Waste Catalogue (EWC) is likely to be applicable to

UK clinical waste. Healthcare Wastes in the European Waste Catalogue are principally separated on the basis of their origin, either animal or human. Therefore all five HSAC groups will fall within the 18 01(wastes from natal care, diagnostic, treatment or prevention of disease in humans) or 18 02 (wastes from research, diagnosis, treatment or prevention of disease involving animals) series of waste codes depending on the origin of the waste. However, for some of the groups it may be more appropriate to identify them as arising within the municipal waste stream by using the 20 series waste codes.

Table 3.3. Health Services Advisory Committee (HSAC) Clinical Waste Groups.

Waste Group	Type of Clinical Waste
Group A	Includes the following items: identifiable human tissue, blood, animal carcasses and tissue from veterinary centers, hospital or laboratories. Soiled surgical dressings, swabs and other similar soiled waste. Other waste materials, for example from infectious disease cases, excluding any in Groups B-E.
Group B	Discarded syringe needles, cartridges, broken glass and any other contaminated disposable sharp instruments or items.
Group C	Microbiological cultures and potentially infected waste from pathology departments and other clinical or research laboratories.
Group D	Drugs or other pharmaceutical products.
Group E	Items used to dispose of urine, faeces and other bodily secretions or excretions which do not fall within Group A. This includes used disposable bed pans or bed pan liners, incontinence pads, stoma bags, and urine containers,

Source: EA, 2003.

The European Waste Catalogue (EWC) categorizes waste into 20 chapters; each chapter is linked to a production sector. Within each chapter, wastes are described using 6 digit numerical codes, the first two digits of the code relate to the EWC chapter, the second two digits relate to any sub-grouping within the chapter, and the final two digits are unique to the waste. The Table 3.4 provides a list of all Chapter 18 (Healthcare Waste) EWC codes. Any waste marked with an asterisk (*) is considered as a hazardous waste pursuant to Directive 91/689/EEC on hazardous waste, and subject to the provisions of that Directive unless Article 1(5) of that Directive applies.

Table 3.4. Wastes from Human or Animal Health Care and/or Related Research, EWC.

EWC Code	Description
18 01	**Wastes from natal care, diagnostic, treatment or prevention of disease in humans**
18 01 01	Sharps (except 18 01 03)
18 01 02	Body parts and organs including blood bags and blood preserves (except 18 01 03)
18 01 03*	Wastes whose collection and disposal is subject to special requirements in order to prevent infection
18 01 04	Wastes whose collection and disposal is not subject to special requirements in order to prevent infection (for example dressings, plaster casts, linen, disposable clothing, diapers)
18 01 06*	Chemicals consisting of or containing dangerous substances
18 01 07	Chemicals other than those mentioned in 18 01 06
18 01 08*	Cytotoxic and cytostatic medicines
18 01 09	Medicines other than those mentioned in 18 01 08
18 01 10*	Amalgam waste from dental care
18 02	**Wastes from research, diagnosis, treatment or prevention of disease involving animals**
18 02 01	Sharps (except 18 02 02)
18 02 02*	Wastes whose collection and disposal is subject to special requirements in order to prevent infection
18 02 03	Wastes whose collection and disposal is not subject to special requirements in order to prevent infection
18 02 05*	Chemicals consisting of or containing dangerous substances
18 02 06	Chemicals other than those mentioned in 18 02 05
18 02 07*	Cytotoxic and cytostatic medicines
18 02 08	Medicines other than those mentioned in 18 02 07

Source: EA, 2002.

Alvim-Ferraz and Afonso (2003) observed that medical wastes should be classified according to their source, typology and risk factors associated with their handling, storage and ultimate disposal. The European Union has been making a special effort to

standardize waste classification through the establishment of the Waste European Catalogue. Meanwhile, many different classifications are yet to be considered in legislation and literature. For instance, while in United States of America the segregation of medical waste is made usually considering three types (red bag, pathological and general). Environmental European Agency identifies "specific hospital waste" and "other hospital waste", and Portuguese Legislation settles the following four types: (i) Group I-wastes similar to municipal ones; (ii) Group II-non-hazardous medical wastes that do not require specific treatment and can be considered similar to municipal wastes; (iii) Group III-medical wastes with biological risk that must be pre-treated before elimination as municipal wastes; (iv) Group IV-specific medical wastes with compulsory incineration.

3.2.Colour Coded Segregation System

Biomedical waste needs to be segregated into containers/bags at the point of generation in colour coding schedule prior to its storage, transportation, treatment and disposal. All the containers are labeled with 'Biohazard Symbol' or 'Cytotoxic Hazard Symbol' as applicable. The label shall be non-washable and prominently visible. Colour coding of waste categories with multiple treatment options is selected depending on treatment option chosen. The colour coding adopted in India is shown in Table 3.5.

Table 3.5. Colour Coding and Type of containers for Disposal of Biomedical Wastes, MoEF, India.

Colour Coding	**Type of Container**	**Waste Category** (Cf. Table 3.2)	**Treatment Options**
Yellow	Plastic bag	Cat.1, Cat.2, Cat.3, and Cat.6	Incineration/deep burial
Red	Disinfected container/ plastic bag	Cat.3, Cat.6, and Cat.7	Autoclaving/Microwaving/ Chemical treatment
Blue/White translucent	Plastic bag/puncture proof container	Cat.4, and Cat.7	Autoclaving/Microwaving/ Chemical treatment and destruction/Shredding
Black	Plastic bag	Cat.5, Cat.9, and Cat. 10 (solid)	Disposal in secured landfill

Source: MoEF, GoI, 1998.

Segregation of clinical waste at source is important from the point of view of both health and safety and waste management. The HSAC guidance on the Safe Disposal of Clinical Waste makes the point that proper segregation of different types of waste is critical to

safety and recommends that plastic bags containing clinical waste should be colour-coded as follows (EA, 2003):

- Yellow (Orange in Scotland : for Group A clinical waste.
- Yellow with black stripes : For Group E waste.
- Light blue or transparent with blue lettering : for Group C clinical waste.
- Black : for treaded clinical waste residue.

The problem of dealing with medical waste is further compounded by so-called over-classification, referring to the problematic practice of healthcare workers dumping non-infectious materials, such as writing paper or unused disposables or even food waste, into red bags for disposal. Over-classification is a consequence of an over-conservative approach to infectious waste handling, ambiguous or nonexistent hospital policies, a lack of understanding of what constitutes potentially infectious waste, or simple expediency (HCWH, 2001).

3.3. Microbiological Risk from Clinical waste

Exposure can only occur where an emission of a pathogenic microorganism takes place. Exposure can occur throughout the waste treatment process, from the collection and transfer of the waste from source, through to disposal of treated waste to landfill. The factors that influence the likelihood of the hazard posed by clinical waste to human health and the environment being realized are therefore the potential for emissions of pathogenic microorganisms, and the ability of the microorganism to survive in the environment in the state required to infect its host. For example, a series of events need to occur for HIV, Hepatitis B or Hepatitis C infection to develop following needlestick injury as shown in the Figure 3.1, and explained in the box below (EA, 2003).

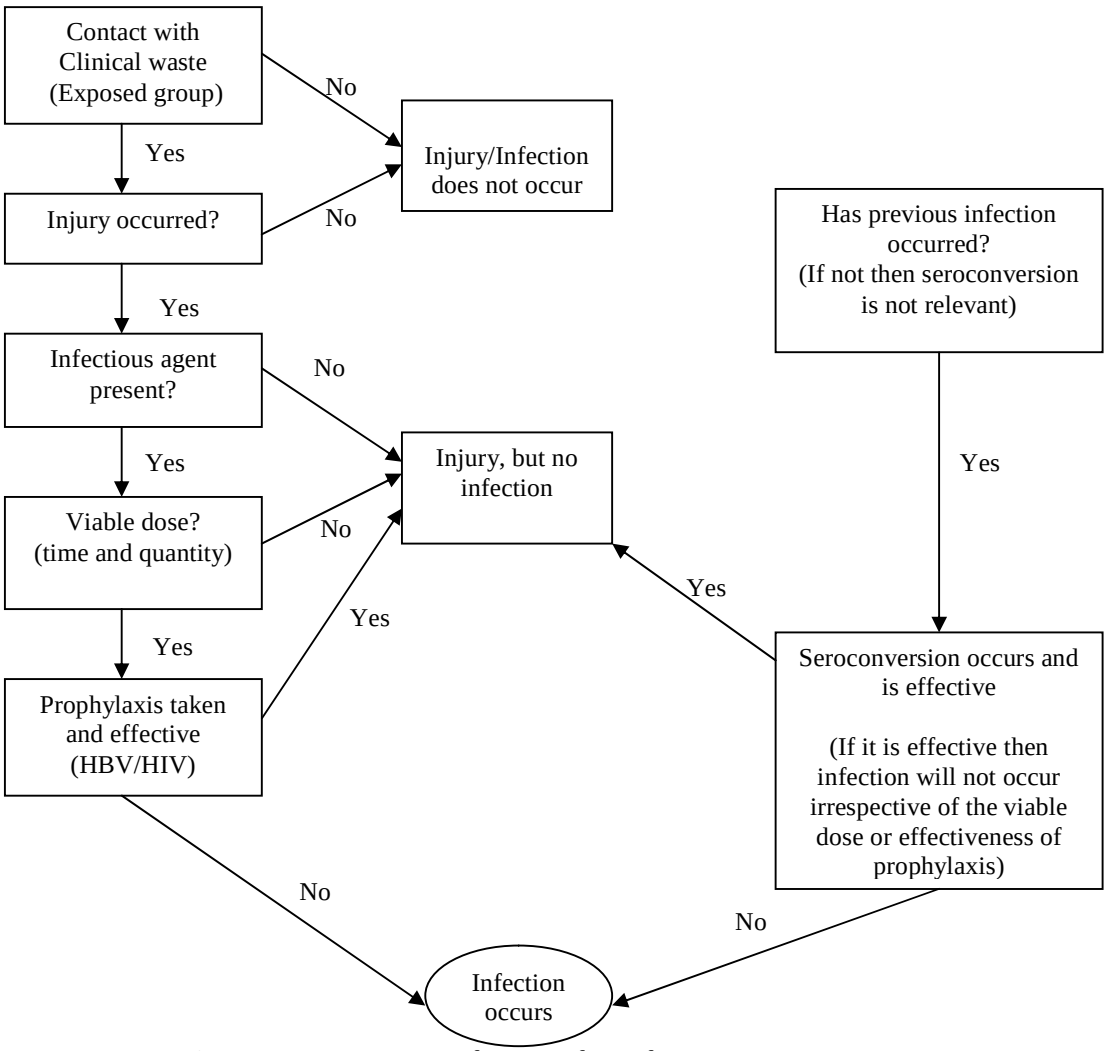


Figure 3.1. Sequence of events for infection

1. ***Contact*** between clinical waste and the "exposed group"
2. Occurrence of ***needlestick injury***: This refers to percutaneous exposure through a needlestick injury.
3. If an injury does occur, the needle has to be ***contaminated with the infectious agent*** i.e. HIV, Hepatitis B virus (HBV) and Hepatitis C virus (HCV).
4. A ***viable dose*** has to be transferred via the injury in terms of a sufficient quantity and viability of the infective agent.
5. If ***prophylaxis*** is taken and is effective, an infection will not occur. Prophylaxis refers to immunization against developing an infection.
6. ***Seroconversion*** has to occur, i.e. the development of antibodies not previously present resulting from a primary infection.

3.3.1. Presence of pathogenic microorganisms in clinical waste

The single most important hazard posed by clinical waste to human health and the environment, which needs to be assessed, is the potential presence of pathogenic microorganisms. Blood-borne viruses, in particular hepatitis, give most concern but a large number of other microorganisms may also be present in clinical waste. The identified pathogens are listed in Table 3.6.

Table 3.6. Pathogens of concern.

Pathogen	Comment
Blood Borne Pathogens	
HIV	Due to public concern
Hepatitis B	Due to its resilience
Hepatitis C	
Bacteriological Organisms	
Staphlyococcus aureus	For consideration of soft tissue infections, ingestion risks etc.
Streptococcus pyogenes	
Escherichia coli	
Salmonella	
Shigella	
Gram negative organisms	
Airborne Organisms	
TB bacilli	Due to its increasing prevalence

Source: EA, 2003.

3.3.2. Release of microorganisms into the environment

Pathogens may be released, by, for example

- Needlestick injury as a result of sharps being placed in yellow bags instead of in designated sharps containers.
- Waste being incorrectly or poorly packaged and/or stored resulting in spillage and leakages.
- Waste being poorly handled on site resulting in bags or containers bursting.
- Unauthorized access to the waste.

Such releases into the general environment may occur at various stages of the disposal or treatment process including: unloading, storage, handling, pretreatment, treatment, post treatment, disposal, cleaning of vehicles or storage areas.

3.4.Occupational Safety and Health

Personnel involved in the treatment of medical waste are exposed to infectious agents through several routes including skin penetration, skin contact, or by the aerogenic route. Exposure routes vary with the type of treatment used. Medical waste contains a variety of human pathogens including bacteria, fungi, viruses, and parasitic organisms as well as microbial toxins (Cole et al., 1993).

Consideration of occupational safety and health should always be part of a framework for medical waste management. There are many potential hazards when dealing with medical waste. Some hazards are associated with handling and transport as (HCWH, 2001):

- needle-stick
- injuries due to other sharps, such as broken glass
- ergonomic issues especially related to lifting
- blood splatter during waste handling
- aerosolized pathogens (disease causing microorganisms released as aerosols or tiny droplets suspended in air) during loading, compaction, or break up of untreated waste
- spills
- chemical and hazardous drug exposure

Other hazards depend on which treatment technology is used:

- hot surfaces that cause burns
- steam from a treatment chamber
- elevated temperatures in the work area due to insufficient cooling and ventilation
- volatile organic compounds and other chemicals released into the workplace
- toxic pollutants from a short exhaust stack
- ionizing radiation from irradiative processes
- non-ionizing radiation such as from microwaves
- noxious odours
- noise pollution

Minimizing these hazards may entail: warning systems, engineering controls such as safer needle devices, safe work practices, use of personal protective equipment, and administrative controls.

The risks to workers handling cytotoxic drugs are a combined result of the drugs' inherent toxicity and the extent to which workers are directly exposed. The main routes of exposure to cytotoxic drugs are through the inhalation of the drug dusts or aerosols, skin absorption, inadvertent ingestion through contact with contaminated food or

cigarettes, and needle stick injuries. Opportunities for exposure can occur during preparation and administration of the drugs, handling of body fluids from patients receiving cytotoxic drugs, handling and disposal of cytotoxic wastes and related trace contaminated material, and transportation of cytotoxic drugs. Other factors include the susceptibility of the individual to the drugs' toxic effects, and co-factors such as dietary habits, smoking, and man-made or natural environmental contaminants (OSHS, 1997).

3.5. Identification of Biomedical Waste Categories for Present Study

The nature and extent of the biomedical waste categorization by different agencies exhibit mainly solid infectious waste handling and management. Proper segregation of different types of waste is critical to safe management of healthcare waste and helps control management costs. Carriage and waste regulation require that waste is handled, transported and disposed of in a safe and effective manner. It has been observed that reference is made to the minimum required standard of waste treatment/ disposal. However, waste may be sent to alternative treatment/disposal methods, which operate to an equivalent or higher standard.

Yellow bag infectious waste requires disposal by incineration in a suitably licensed or permitted central treatment facility. This waste stream specifically includes Human Anatomical Waste (Category No.1), Animal Waste (Category No.2), Microbiology & Biotechnology Waste (Category No.3), and Solid Waste (Category No.6) and may include other wastes, which require incineration to comply with national or regional regulation including un-autoclaved waste from pathological laboratories.

Thus, the yellow bag waste has been identified for carrying out detailed study of its generation rate in kg/day as well as kg/bed /day. Therefore, it is proposed to collect relevant data for two consecutive years concerning waste generation, indoor patient record, and other details from major distinct specialty healthcare facilities at Shimla, India. Further the data of total waste incinerated for the period of study have been collected for centralized treatment facility installed by Municipal Corporation Shimla. Hence the data collected from different healthcare facilities needs further analysis and developing mathematical model.

4. TREATMENT AND DISPOSAL OPTIONS

4.1. Prevailing Treatment Technologies

Biomedical waste may be treated and disposed of in a number of different ways. Treatment and disposal systems can be classified into incineration and non-incineration or high temperature and alternative. Incineration used to be the method of choice for most hazardous health care wastes and is still widely used. Alternative treatment is the name used to describe a broad range of waste management treatment that operates at temperatures less than 1000 ^{o}C. The broad types of alternative technology are heat, chemical, and irradiation. Treatment methods need to be reliable and consistently achieve the claimed standard of treatment. The performance needs to be measurable, and the process controlled precisely enough to reproduce the target standard. All treatment or disposal facilities, regardless of size or type of technology used are required to 'render safe' the waste. Microbial inactivation is a critical element of the 'rendering safe' of certain healthcare waste. Microbial inactivation as used in this study refers to the effects of physical or chemical processes that render microorganisms incapable of multiplication.

Certain treatment options may effectively reduce the infectious hazards of health care waste and prevent scavenging but, at the same time, give rise to other health and environmental hazards. Incineration of certain types of health care waste, particularly those containing chlorine or heavy metals, may under certain conditions (such as insufficiently high incineration temperatures, inadequate control of emissions) release toxic material into the atmosphere. Land disposal may result in groundwater pollution if the landfill site is inadequately designed and/or operated. In choosing a treatment or disposal method for health care waste, particularly if there is a risk of toxic emissions or other hazardous consequences, the relative risks, as well as the integration into the overall framework of comprehensive waste strategy, should therefore be carefully evaluated in the light of local circumstances. Advantages and disadvantages of the various treatment and disposal technologies are summarized in Table 4.1.

Table 4.1. Main Advantages and Disadvantages of Treatment and Disposal Options

Treatment/ Disposal Method	**Advantages**	**Disadvantages**
Rotary Kiln	Adequate for all infectious waste, most chemical waste, and pharmaceutical waste.	High investment and operating costs.
Pyrolytic Incineration	Very high disinfection efficiency. Adequate for all infectious waste and most pharmaceutical and chemical waste.	Incomplete destruction of cytotoxics. Relatively high investment and operating costs.
Single chamber Incineration	Good disinfection efficiency. Drastic reduction of weight and volume of waste. The residues may be disposed of in landfills. No need for highly trained operators. Relatively low investment and operating costs.	Significant emissions of atmospheric pollutants. Need for periodic removal of slag and soot. Inefficiency in destroying thermally resistant chemicals and drugs as cytotoxics.
Drum or Brick Incinerator	Drastic reduction of weight and volume of waste. Very low investment and operating costs.	Destroys only 99% of microorganisms. No destruction of many chemicals and pharmaceuticals. Massive emission of black smoke, fly ash, toxic flue gas, and odours.
Chemical Disinfection	Highly efficient disinfection under good operating conditions. Some chemical disinfectants are relatively inexpensive. Drastic reduction in waste volume.	Requires highly qualified technicians for operation of the process. Uses hazardous substances that require comprehensive safety measures. Inadequate for pharmaceutical, chemical, and some types of infectious waste.
Wet Thermal Treatment	Environmentally sound. Drastic reduction in waste volume. Relatively low investment and operating costs.	Shredders are subject to frequent breakdowns and poor functioning. Operation requires qualified technicians. Inadequate for anatomical, pharmaceutical, and chemical waste and waste that is not readily steam-permeable.
Microwave Irradiation	Good disinfection efficiency under appropriate operating conditions. Drastic reduction in waste volume. Environmentally sound.	Relatively high investment and operating costs. Potential operation and maintenance problems.
Encapsulation	Simple, low-cost, and safe. May also be applied to pharmaceuticals	Not recommended for non-sharp infectious waste.
Safe Burying	Low costs. Relatively safe if access to site is restricted and where natural infiltration is limited.	Safe only if access to site is limited and certain precautions are taken.
Inertization	Relatively inexpensive	Not applicable to infectious waste.

Source: Pruss et al., 1999.

4.2. Incineration

Treatment by incineration and disposal of the resultant ash by landfilling is the most widely used treatment process for managing biomedical waste.

4.2.1. Principles of Incineration

Incineration is a high temperature dry oxidation process that reduces organic and combustible waste to inorganic, incombustible matter and results in a very significant reduction of waste volume and weight. This process is usually selected to treat wastes that cannot be recycled, reused, or disposed of in a landfill site. The combustion of organic compounds produces mainly gaseous emissions, including steam, carbon dioxide, nitrogen oxides, and certain toxic substances, particulate matter, and solid residue in the form of ashes. The process flow is illustrated schematically in Figure 4.1.

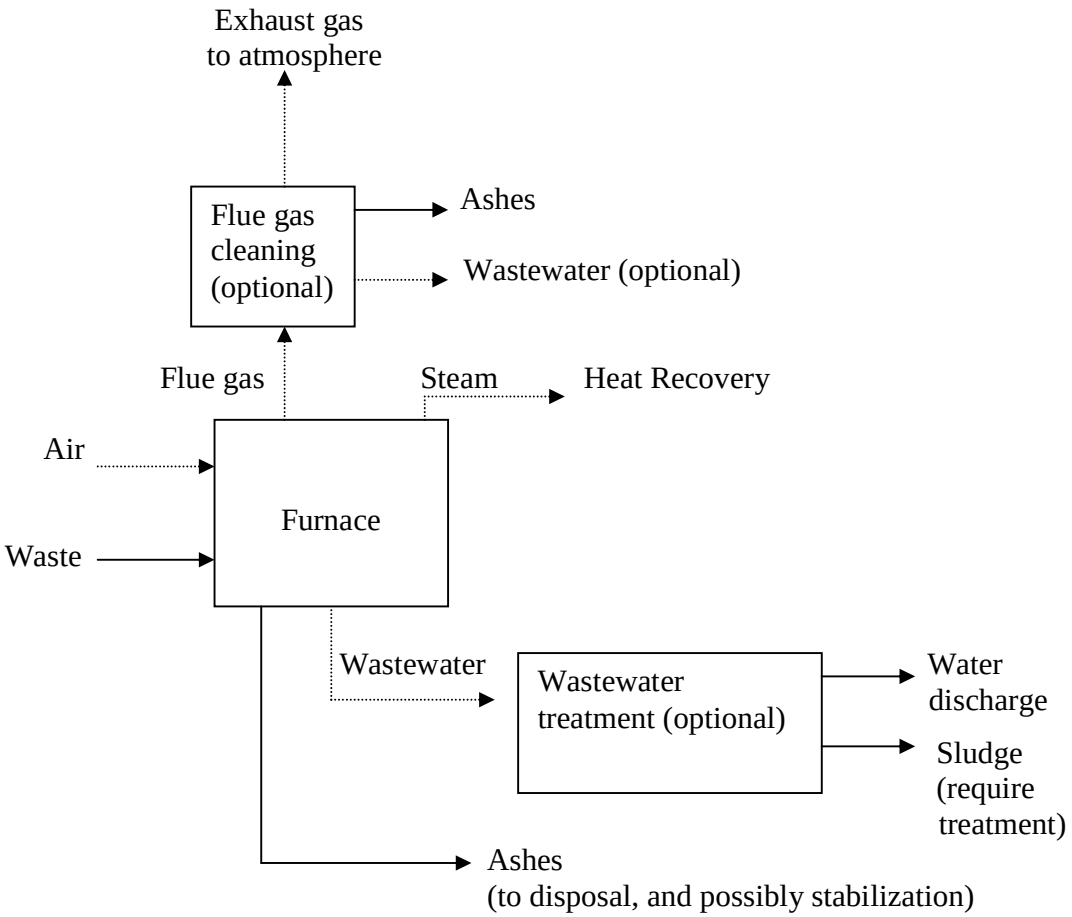


Figure 4.1. Simplified flow scheme of incinerator. Source: Pruss et al., 1999.

4.2.2. Required Waste Characteristics

Incineration of waste is affordable and feasible only if the "heating value" of the waste reaches at least 2000 kcal/kg (8370 kJ/kg). The characteristics that make waste suitable for incineration are (Pruss et al., 1999):

- Low heating value above 2000 kcal/kg (8370 kJ/kg) for single chamber incinerators, and above 3500 kcal/kg (14640 kJ/kg) for Pyrolytic double chamber incinerators.
- Content of combustible matter above 60%
- Content of non-combustible solids below 5%
- Content of non-combustible fines below 20%
- Moisture content below 30%

Alvim-Ferraz and Afonso (2003) reported that the small heating value of medical wastes with compulsory incineration, when collected using a rigorous segregation practice, required the utilization of an auxiliary fuel amount for incineration 35 times higher than for the other waste types, which affects pollutant emissions of CO, NO_x and SO_2 (28%, 20% and practically 100% of the respective emitted amounts were related with fuel combustion). Nevertheless, the incineration of those wastes led to the smallest amount of emitted pollutants and the emitted amount of SO_2 and NO_x reduced to 93% and the emitted amount of CO and HCl to more than 99%, enhancing how important is the implementation of rigorous segregation practices and adequate methodologies of waste management.

The chemical and physical characteristics of the different medical waste materials vary widely. Hospital waste can vary considerably in composition and, consequently, in heat content, moisture content, and bulk density. Hospital waste can vary in Btu content from a low value of 3,400 kJ/kg (1,500 Btu/lb) to 45,000 kJ/kg (20,000 Btu/lb). Because of the potential for a wide range in waste characteristics and the impact on incinerator performance, large volumes of wastes with unusually high or low Btu or moisture content should be identified so that incinerator charging procedures and rates can be adjusted accordingly. All categories of medical waste may be incinerated. However, if low level radioactive, hazardous, or cytotoxic wastes are to be incinerated special permits are required (Cole et al., 1993).

4.2.3. Types of Incinerator

Three basic kinds of incineration technology are of interest for treating biomedical/health care waste:

- double-chamber pyrolytic incinerators, which may be especially designed to burn infectious health care waste
- single-chamber furnaces with static grate, which should be used only if pyrolytic incinerators are not affordable
- rotary kilns operating at high temperature, capable of causing decomposition of genotoxic substances and heat resistant chemicals

Multiple chamber pathological waste incinerators are often designed and used specifically for pathological wastes which have high moisture content and may contain bulk liquids. Consequently, these incinerators are always designed with a fixed hearth. A raised lip at the door is often included to prevent liquids from spilling during charging. Because the heating value of pathological waste is not sufficient to maintain combustion, one or more auxiliary burners are designed for continuous operation to provide the additional heat input required.

Controlled air incinerators allow for sequential combustion of waste in two separate chambers. The primary chamber accepts the waste and the combustion process begins in an atmosphere containing oxygen concentrations below the stoichiometric level. The amount of combustion air admitted to the primary chamber is regulated. The combustion air is usually fed as underfire air. Three processes occur in the primary chamber. In the secondary chamber the combustion air is regulated to provide excess air, turbulence, and good mixing of the combustion gas and air. Several types of controlled air incinerators are available including batch, intermittent duty, and continuous duty models. In the batch type, the incinerator is charged with waste; the waste incinerated; the incinerator cooled; the ash removed; and the cycle repeated. The intermittent duty incinerators permit multiple charges during the 12 to 14 hour operating period before final burndown is initiated. Continuous duty incinerators provide a mechanism for automatically removing ash from the hearth. These units also typically have mechanical waste feeding systems (Cole et al., 1993).

The most reliable and commonly used treatment processes for health care waste is pyrolytic incineration, also called controlled air incineration or double chamber incineration. Grochowalski (1998) described the typical process of incineration of hospital wastes in pyrolytic chamber, which has been realized in Poland since 1994 is given in Figure 4.2. This is a two-stage process. In pre-chamber for pyrolysis, cartridges of wastes

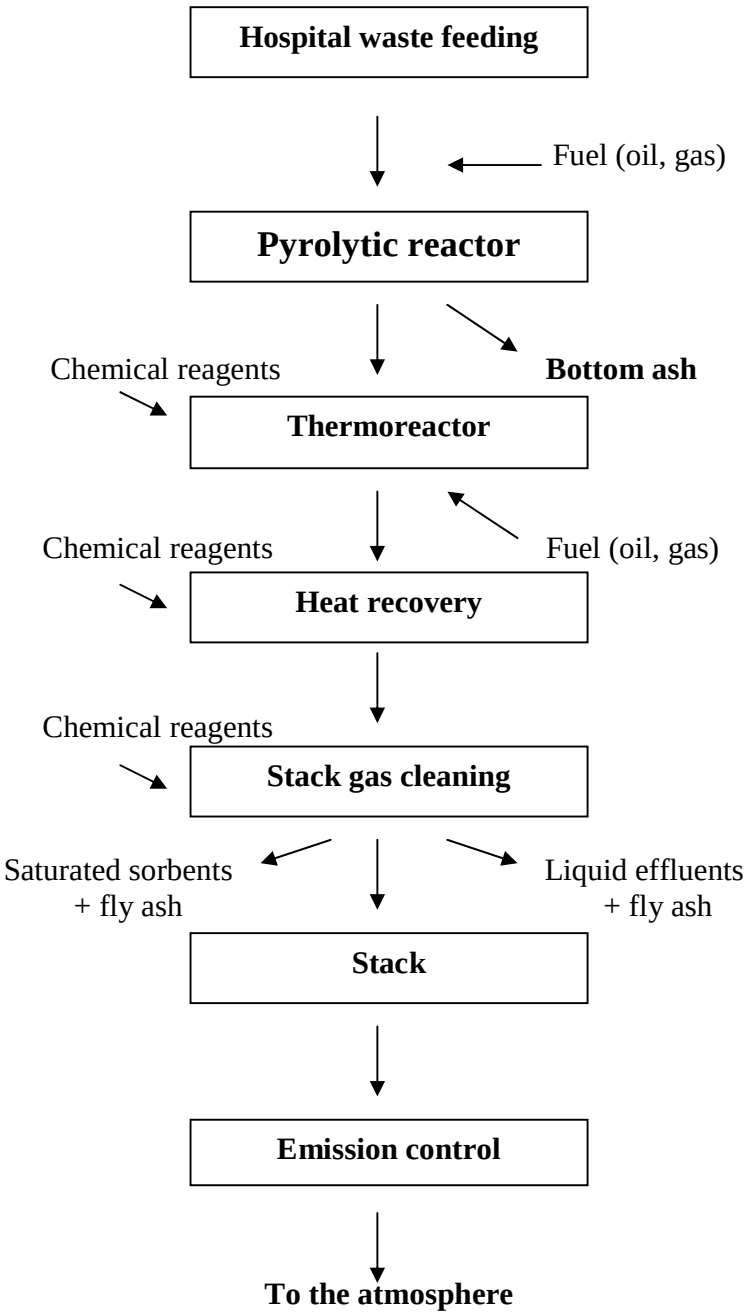


Figure 4.2. Typical process of incineration of hospital wastes in pyrolytic chamber.

are degassed at temperatures 550-900 ºC. Pyrolytic gases are burnt in the excess of oxygen at temperatures 1100-1200 ºC during 2-3 seconds in thermoreactor. Hot combustion gases are cooled to temperatures 250-300 ºC in a heat exchanger and by water injection in Venturi nozzles (quenching). In most solutions, there are applied multi-step cleaning combustion gas technologies, in which the gas is purified by adsorption and chemisorption.

Incinerators can range from extremely sophisticated, high temperature operating plants to very basic combustion units that operate at much lower temperatures. All types of incinerator, if operated properly, eliminate pathogens from waste and reduce the waste ashes. However, certain types of health care wastes, e.g., pharmaceutical or chemical wastes, require higher temperatures for complete destruction. Higher operating temperatures and cleaning of exhaust gases limit the atmospheric pollution and other odours produced by the incineration process. Incinerators designed especially for treatment of health care waste are required to operate at temperatures between 900 and 1200 ^{o}C. Low-cost, high temperature incinerators of simple design are currently being developed. Incineration equipment are required to be carefully chosen on the basis of available resources, local situation, risk-benefit considerations, and balancing the public health benefits of pathogen elimination before waste disposal against the potential risks of air or groundwater pollution caused by inadequate destruction of certain wastes.

Small-scale incinerators may be built on-site, locally constructed, fixed and/or portable. Units typically operate for 1 to 6 hours per week or month in a batch or intermittent mode to destroy sharps and other health care waste. Remmen (1998) advocates that from a categorization standpoint, facilities which process less than 200 lbs/h (91 kg/h) are considered to be small application. A facility which processes more than 200lbs/h but less than 500 lbs/h (227 kg/h) of medical waste is considered to be a medium sized application. Those facilities which have equipment with design throughput capacities of greater than 500 lbs/h are considered to be large application and are thereby required to meet much more restrictive levels of emissions. Batterman (2004) derived recommendations of key design/operating parameters for small-scale intermittent incinerators given in Table 4.2.

Table 4.2. Key Design/Operating Parameters for Small-scale Intermittent Incinerators.

Type	Parameter	Recommendation
Capacity	Destruction rate, safety boxes capacity	District/subdistrict in Taylor (2003) that regularly used incinerators destroyed an average of 58 safety boxes per month, about 14 per week, equivalent to ~12 kg/week. Remote areas may only generate 1 kg per month. Proper sizing is important. Ideally, unit should burn for long periods (~4 hours) to save fuel. (De Montfort units are not suitable for short sharp burns without a warm up period, though this appears to be common practice).
Temperatures	Primary Chamber Secondary chamber Gas entering air pollution control devices, if any	540 to 980 ^{o}C 980 to 1200 ^{o}C (EPA 1990 recommendations) >850/1100* ^{o}C (S.Africa and EU standards) >1000/1100* ^{o}C (Indian and Thai standards) * more than 1% chlorinated organic matter in waste < 230 ^{o}C
Residence times	Gas(secondary chamber)	> 1s
Air flows	Total combustion air Supply and distribution of air in the incinerator Mixing of combustion gas and air in all zones Particulate matter entrainment into flue gas leaving the incinerator	140 - 200% excess Adequate Good mixing Minimize by keeping moderate air velocity to avoid fluidization of the waste, especially if high (>2%) ash waste is burned.
Control & Monitoring	Temperature and many other parameters	Continuous for some, periodic for others
Waste	Waste destruction efficiency Uniform waste feed Minimizing emissions of HCl, D/F, metals, other pollutants Load/charge only when incinerator operating conditions are appropriate	>90% by weight Uniform waste feed; avoid overloading the incinerator Avoid plastics that contain chlorine (polyvinyl chloride products, e.g., blood bags, IV bags, IV tubes, etc. Avoid heavy metals, e.g., mercury from broken thermometers etc. Pre-heat incinerator; ensure temperatures above 800 ^{o}C Avoid overheating
Enclosure	Roof	A roof may be fitted to protect the operator from rain, but only minimum walls
Chimney	Height	At least 4-5 m high, needed for both adequate dispersion plus draft for proper air flow
Pollution control equipment	Installing air pollution control devices (APCD)	Most frequently used controls include packed bed, venturi or other wet scrubbers, fabric filter typically used with a dry injection system, and infrequently electrostatic precipitator (ESP) Modern emission limits cannot be met without APCD

4.2.4. Guidelines and Standards for Incineration

MoEF, GoI (1998) has made mandatory for the operator of a central treatment facility to incinerate biomedical waste in compliance with the standards prescribed in Table 4.3.

Table 4.3. Operating and Emission Standards for Incinerators in India.

Type	Standards
A.	**Operating Standards** 1. Combustion efficiency (CE) shall be at least 99.00%. 2. The Combustion efficiency is computed as follows: $$C.E. = \frac{\%CO_2}{\%CO_2 + \%CO} \times 100$$ 3. The temperature of the primary chamber shall be 800±50 ^{o}C. 4. The secondary chamber gas residence time shall be at least 1 (one) second at 1050±50 ^{o}C, with minimum 3% Oxygen in the stack gas.
B.	**Emission Standards** Parameters — Concentration mg/Nm^3 at (12% CO_2 correction) (1) Particulate matter — 150 (2) Nitrogen Oxides — 450 (3) HCl — 50 (4) Minimum stack height shall be 30 meters above ground (5) Volatile organic compounds in ash shall not be more than 0.01%.
Note: . Suitable designed pollution control devices should be installed/retrofitted with the incinerator to achieve the above emission limits, if necessary. . Wastes to be incinerated shall not be chemically treated with any chlorinated disinfectants. . Chlorinated plastics shall not be incinerated. . Toxic metals in incineration ash shall be limited within the regulatory quantities as defined under the Hazardous Waste (management and Handling)Rules, 1989. . Only low sulphur fuel like L.D.O./L.S.H.S./Diesel shall be used as fuel in the incinerator.	

Ministry of the Environment (MOE), Ontario, Canada, has issued guideline on 'Combustion, air Pollution Control and Monitoring Requirements for Biomedical waste Incinerators in Ontario', which applies to all incinerators burning biomedical waste in Ontario, including both new and existing facilities on any size. Biomedical waste incinerators are required to meet the emission limits set out in Table 4.4 below in exhaust gases discharged to the atmosphere or at the location specified:

Table 4.4. Emission Limits for Biomedical waste Incinerators in Ontario.

Parameter	Emission Limit	Comments
Particulate Matter (total)	17 mg/Rm^3	calculated as the arithmetic average of three stack tests conducted in accordance with standard methods
Cadmium	14 μg/Rm^3	calculated as the arithmetic average of three stack tests conducted in accordance with standard methods
Lead	49 μg/Rm^3	calculated as the arithmetic average of three stack tests conducted in accordance with standard methods
Mercury	20 μg/Rm^3*	calculated as the arithmetic average of three stack tests conducted in accordance with standard methods
Dioxins and Furans	80 pg/Rm^3 as I-TEQ**	calculated as the arithmetic average of three stack tests conducted in accordance with standard methods
Sulphur Dioxide	21 ppmdv (56 mg/Rm^3)	calculated as the arithmetic average of three stack tests conducted in accordance with standard methods, or as the rolling geometric average of 8 hours of data from a continuous emission monitoring system
Nitrogen Oxides	172 ppmdv (324 mg/Rm^3) [expressed as equivalent nitrogen dioxide]	calculated as the arithmetic average of three stack tests conducted in accordance with standard methods, or as the rolling arithmetic average of 8 hours of data from a continuous emission monitoring system
Hydrochloric Acid (HCl)	10 ppmdv (17 mg/Rm^3) or an HCl removal efficiency of not less than 99%	calculated as the arithmetic average of three stack tests conducted in accordance with standard methods, or as the rolling arithmetic average of 8 hours of data from a continuous emission monitoring system
Carbon Monoxide	30 ppmdv (35 mg/Rm^3)	Calculated as a 30 minute block arithmetic average at the outlet of the secondary chamber before dilution with any other gaseous stream, measured by a continuous emission monitoring system installed on either a permanent or temporary basis
Organic Matter	50 ppmv [expressed as equivalent methane]	Calculated as a 10 minute block arithmetic average at the outlet of the secondary chamber before dilution with any other gaseous stream, measured by a continuous emission monitoring system installed on either a permanent or temporary basis
Opacity	5%	Calculated as a 6 minute block arithmetic average measured by a continuous emission monitoring system

* for facilities incinerating less than 120 tonnes/year a determined effort must be undertaken to achieve 40μg/Rm^3

** I-TEQ means 2,3,7,8-TCDD toxicity equivalents calculated according to the international toxicity equivalence system developed by the North Atlantic Treaty Organization's Committee on the Challenges of Modern Society (NATO/CCMS) in 1989 and adopted by Canada in 1990.

Source: MOE, 2002.

The Western Australian Environmental Protection Authority (WAEPA, 2000) documented that an essential ingredient for any incinerator is regular on-stream monitoring of certain air quality parameters. The EPA's environmental objective for the management of emissions from biomedical waste incinerators is to ensure that humans and other living things are not adversely affected by emissions either from incineration or from disposal of flyash. The standards required for the operation of the Stephenson & Ward incinerator

should be the minimum standards required for the operation of biomedical waste incinerators throughout Western Australia. The Stephenson & Ward incinerator is licensed under the Environmental Protection Act 1986 (WA) and therefore needed to comply with a set of license conditions. The dioxin and furan limit of 0.1 ng/m^3 has been internationally accepted as a "goal" and not as a strict emission standard for a number of years because there is still incinerator technology in use that cannot achieve such low emission limits. Testing on the Stephenson & ward incinerator following the upgrading of the pollution control equipment has indicated that the dioxin and furan goal of 0.1 ng/m^3 can be easily achieved. The EPA has adopted a standard of 0.1 ng/m^3 criteria for dioxin and furans. The Department of Environmental Protection (DEP) is required to license biomedical incinerators operating in Western Australia. The exhaust gases of biomedical waste incinerators are normally required to be analyzed for the contaminants specified in Table 4.5.

Table 4.5. Emission Levels for Biomedical waste Incinerators, EPA, Western Australia.

Emission	**Measure as**	**Levels**
Smoke	Ringelmann scale	1
Soot	Bacharach scale	3
Solid particles	Adjusted to 12% CO_2	0.070 g/m^3
Hydrogen sulphide	H_2S	0.005 g/m^3
Nitrogen oxides	NO_2	0.500 g/m^3
Carbon monoxide	CO	0.150 g/m^3
Sulphur trioxide or H_2SO_4 mist	SO_3	0.100 g/m^3
Chlorine and chlorine compounds	HCl	0.050 g/m^3
Fluorine and fluorine compounds	HF	0.005 g/m^3
Organic compounds	C	0.030 g/m^3
Antimony, arsenic, cadmium, lead, mercury	Total as element or in compounds	0.010 g/m^3
Cadmium and compounds	Maximum concentrations of each as elements or compounds	0.003 g/m^3
Mercury and compounds	Maximum concentrations of each as elements or compounds	0.003 g/m^3
Dioxins and furans	Total toxic equivalents	0.100 ng/m^3

4.3. Alternative Treatment Technologies

Alternative treatment is the name used to describe a broad range of waste management treatments that operate at temperatures less than 1000 ^{o}C. A relatively large number of systems are available to treat biomedical/clinical waste, by reducing the concentration of potentially pathogenic microorganisms such that the waste no longer poses a danger to public health and safety. The fundamental requirement for the treatment of clinical waste is that it should be rendered safe. To define microbial inactivation requires consideration of both qualitative aspects (the form and type of organisms) and quantitative aspects (the required level of reduction). The term sterilization and disinfection have been used historically in relation to medical instruments and supplies. Sterilization is commonly defined as the complete elimination or destruction of all forms of microbial life, including highly resistant bacterial endospores. Since complete elimination or destruction is difficult to prove, sterilization is usually expressed as a probability function in terms of the number of microorganisms surviving a particular treatment process. This function is usually expressed as 6 $\log_{10}$ reduction [defined as 6 decade reduction or a one millionth (0.000001) survival probability in a microbial population; i.e., 99.9999% reduction] of the most resistant microorganisms to the sterilization process in question. Spore suspensions of resistant *Bacillus sp.* Species are often used as biological indicators for determining the efficacy of the sterilization process. Disinfection can be defined as a procedure that reduces the level of microbial contamination.

Microbial inactivation refers to the effects of physical or chemical processes that render microorganisms incapable of multiplication. A consortium of state regulatory agencies called the State and Territorial Association on Alternative Treatment Technologies (STAATT) met in 1994 and 1998 to develop consensus criteria for medical treatment efficacy. STAATT concluded that the use of spore inactivation served two functions: to demonstrate that bacterial spore formers can be inactivated, and to provide a margin of safety beyond the inactivation of vegetative bacteria, fungi, viruses, parasites and mycobacteria. In the USA, STAATT has proposed four levels to define the levels of microbial inactivation required for clinical waste treatment given in Table 4.6.

Table 4.6. Definition of the Levels of Microbial Inactivation (STAATT)

Level	Description
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* spores and *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
*Level III was selected as the recommended minimum criteria by STAATT. A 6 Log 10 reduction (or a 10^6 kill) is equivalent to a one millionth survival probability in a microbial population or a 99.9999 percent reduction of the given microorganism as a result of the treatment process.	

Sources: Cole et al., 1993; HCWH, 2001; and EA (2003).

All the alternative systems use the same fundamental principles of heat, chemicals, irradiation, or combinations of these. There are three broad types of alternative technology: heat, chemical, and irradiation.

4.3.1. Heat Treatment

Thermal systems use heat to inactivate pathogenic microorganisms and, in those that utilize high temperatures, simultaneously destroy the waste. Most pathogens are rapidly inactivated at 60 to 80 ^{o}C. Different temperatures will achieve inactivation, according to whether heat is dry or moist and according to treatment pressure and treatment time. Wet heat is reported as the most dependable procedure for the destruction of all microorganisms. Dry heat is less efficient than wet heat sterilization and therefore requires longer times and/or higher temperatures for comparable efficiency.

4.3.1.1. Low Temperature Systems

Autoclaves or steam sterilization have been used for over a century as a means of treating specific forms of waste, such as infected samples from pathology departments. Saturated steam is introduced into a vessel, forcing out the air in the chamber by its heavier mass (gravity displacement or gravity autoclave) or the steam is pulled into the vessel after the air has been exhausted by a vacuum system (vacuum displacement or vacuum autoclave). As the steam accumulates, the pressure and temperature within the chamber increases until

the minimum temperature/pressure requirements for treatment of the waste have been met. The Table 4.7 set out the prevailing standards on autoclaving the biomedical waste for the purposes of disinfecting and treating scheduled in the Biomedical Waste (Management and Handling) Rules, 1998.

Table 4.7. Standards for Biomedical Waste Autoclaving, MoEF, GoI, India.

Option	Operating, Monitoring, and Validation Parameters
I	**Gravity Flow Autoclave** When operating a gravity flow autoclave, medical waste shall be subjected to: . a temperature of not less than 121 ^{o}C and pressure of 15 pounds per square inch (psi) for an autoclave residence time of not less than 60 minutes; or . a temperature of not less than 135 ^{o}C and pressure of 31 psi for an autoclave residence time of not less than 45 minutes; or . a temperature of not less than 149 ^{o}C and pressure of 52 psi for an autoclave residence time of not less than 30 minutes.
II	**Vacuum Autoclave** When operating a vacuum autoclave, medical waste shall be subjected to a minimum of pre-vacuum pulse to purge the autoclave of all air. The waste shall be subjected to the following: . a temperature of not less than 121 ^{o}C and pressure of 15 psi for an autoclave residence time of not less than 45 minutes; or . a temperature of not less than 135 ^{o}C and pressure of 31 psi for an autoclave residence time of not less than 30 minutes.
III	Medical waste shall not be considered properly treated unless the time, temperature and pressure indicators indicate that the required time, temperature and pressure were reached during the autoclave process. If for any reasons, time, temperature or pressure indicator indicates that the required temperature, pressure or residence time was not reached, the entire load of medical waste must be autoclaved again until the proper temperature, pressure and residence time were achieved.
IV	**Recording of operational parameters** Each autoclave shall have graphic or computer recording devices which will automatically and continuously monitor and record date, time of day, load identification number and operating parameters throughout the entire length of the autoclave cycle.
V	**Validation test** **Spore testing:** The autoclave should completely and consistently kill the approved biological indicator at the maximum design capacity of each autoclave unit. Biological indicator for autoclave shall be *Bacillus stearothermophilus* spores using vials or spore strips, with at least 1×10^{4} spores per milliliter. Under no circumstances will an autoclave have minimum operating parameters less than a residence time of 30 minutes, regardless of temperature and pressure, a temperature less than 121 ^{o}C or a pressure less than 15 psi.
VI	**Routine Test** A chemical indicator strip/tape that changes colour when a certain temperature is reached can be used to verify that a specific temperature has been achieved. It may be necessary to use more than one strip over the waste package at different location to ensure that the inner content of the package has been adequately autoclaved.

Source: MoEF, GoI, 1998.

Microwaves are electromagnetic waves with a frequency between radio waves and infrared waves on the electromagnetic scale. When applied to the treatment of waste, the mechanism of microbial inactivation is thermal. It is important for the waste to be wet, either as a result of moisture naturally occurring in the waste stream or by the addition of moisture in the form of steam. The combination of the two, microwaves and moisture, create the thermal process. Some treatment processes utilize microwaves to heat water to form steam which is then applied to the clinical waste stream. A dry microwave system is also available. This uses direct microwave energy in a nitrogen atmosphere to treat the waste and produces higher treatment temperatures than those used by wet microwave technologies.

4.3.1.2. Chemical Processes

Chemical processes employ disinfectants such as dissolved chlorine dioxide, bleach (sodium hypochlorite), peracetic acid, or dry inorganic chemicals. To enhance exposure of the waste to the chemical agent, chemical processes often involve shredding, grinding, or mixing. In liquid systems, the waste may go through a dewatering section to remove and recycle the disinfectant. Besides chemical disinfectants, there are also encapsulating compounds that can solidify sharps, blood, or other body fluids within a solid matrix prior to disposal (HCWH, 2001). Pruss et al. (1999) described that chemical disinfection is usually carried out on hospital premises. Recently, however, commercial, self-contained, and fully automatic systems have been developed for health care waste treatment and are being operated in industrial zones. The disinfected waste may be disposed of as non-risk health care waste, but the chemical disinfectants may create serious environmental problems in case of leakage or after disposal.

4.3.1.3. Irradiative Processes

Gamma irradiation (e.g., Cobalt-60) has been used for many years as a means of inactivating potential pathogens on the surfaces of many different medical products. Since the appropriate dose of radiation can be precisely calculated, it has been found to be an extremely reliable treatment system. A newer form of irradiation system employs an electron beam generated by an accelerator to sterilize medical products and, potentially, clinical waste. Irradiation systems require extensive shielding to protect the workers, can

only treat relatively small quantities of waste and do not alter the physical appearance of the material (EA, 2003). HCWH (2001) recorded that these technologies require shielding to prevent occupational exposures. Irradiation does not alter the waste physically and would require a grinder or shredder to render the waste unrecognizable.

4.4. High Temperature Treatment

High-heat thermal processes generally operate at temperatures ranging from around 1,000°F to 15,000°F (540°C – 8,300°C) or higher. High heat processes involve chemical and physical changes resulting in total destruction of the waste. A significant reduction in the mass and volume of the waste also occurs.

4.4.1. Pyrolysis

Pyrolysis involves the high temperature (545 to 1000 ^{o}C) combustion of waste in the absence of oxygen. In generating these high temperatures, the systems treat, destroy, and reduce the volume of clinical waste (EA, 2003). HCWH (2001) published that the Bio-Oxidizer, a commercialized technology, uses a two-step process. Firstly, the waste enters a pyrolysis chamber where it is heated from 200 ^{o}F to 1100 ^{o}F (93 ^{o}C –590 ^{o}C). This causes organic solids and liquids to vaporize, leaving behind an inert ash including inorganic material such as glass and metal fragments. In the second step, an induced draft fan draws the vapors from the pyrolysis chamber into a two-stage oxidation chamber operating at 1800 ^{o}F and 2000 ^{o}F (980 ^{o}C -1090 ^{o}C). Controlled amounts of oxygen are added in the oxidation chamber to complete the combustion process. With the addition of pollution control devices, the result is a relatively clean exhaust stream.

4.4.2. Plasma Technology

In a plasma system, an electric current is discharged through an inert gas (e.g., argon) to ionize it and in turn cause an electric arc to create temperatures as high as 6000 ^{o}C. The clinical waste within the system is brought to temperatures between 1300 to 1700 ^{o}C, destroying potentially pathogenic microbes and converting the waste into a glassy rock or slag, ferrous metal, and inert gases (EA, 2003). In a plasma torch, an arc is established between two electrodes. A carrier gas, which may be inert or have some heating value, passes between the electrodes and transfers the energy to the waste material. In a non-

transferred system, the, the anode and cathode are both part of the plasma torch. Another design is to use a DC (direct current) plasma arc, wherein the arc forms between a graphite electrode directly to the metal in a molten bath formed from the waste in the treatment chamber (HCWH, 2001).

4.5. Zonal/Common Treatment Facility

A common biomedical waste treatment facility (CBWTF) is a set up where biomedical waste, generated from a number of healthcare units, is imparted necessary treatment to reduce adverse effects that this waste may pose. The treated waste may finally be sent for disposal in a landfill or for recycling purposes. Installation of individual treatment facilities by small healthcare units requires comparatively high capital investment. In addition, it requires separate manpower and infrastructure development for proper operation and maintenance of treatment systems. The concept of CBWTF not only addresses such problems but also prevents proliferation of treatment equipment in a city. In turn it reduces the monitoring pressure on regulatory agencies. By running the treatment equipment at CBWTF to its full capacity, the cost of treatment of per kilogram gets significantly reduced. Its considerable advantages have made CBWTF popular and proven concept in many developed countries (CPCB, 2003).

CBWTF as an option has also been legally introduced in India. The Biomedical Waste (Management & Handling) Rules, 1998, gives an option to the biomedical waste generator that such waste can also be treated at the common biomedical waste treatment facility. The Second Amendment of the Rules in June, 2000, further eased the bottleneck in upbringing the CBWTF by making Local authority responsible for providing suitable site within its jurisdiction. The concept of CBWTF is also being widely accepted in India among the healthcare units, medical associations and entrepreneurs.

In order to set up a CBWTF to its maximum perfection, care shall be taken in choosing the right technology, development of area, proper designing of transportation system to achieve optimum results. The key features and guidelines for the establishment of CBWTF are given in Table 4.8.

Table 4.8. Key features and guidelines for the establishment of CBWTF

Component	Description
Location	A CBWTF shall be located at a place reasonably far away from residential and sensitive area so that it has minimal impact on these areas. The CBWTF shall be located as near to its area of operation as possible in order to minimize the travel distance in waste collection, thus enhancing its operational flexibility. The location shall be decided in consultation with the state Pollution Control Board (SPCB)/Pollution Control Committee (PCC).
Land requirement	Sufficient land shall be allocated for CBWTF to provide all requisite systems. It is felt that a central treatment facility will require minimum of 1-acre land area.
Coverage Area	In any area, only one central treatment facility may be allowed to cater up to 10,000 beds at the approved rate by the Prescribed Authority. A CBWTF shall not be allowed to cater healthcare units situated beyond a radius of 150 km. However, in an area where 10,000 beds are not available within a radius of 150 km, another CBWTF may be allowed to cater the healthcare units situated outside the said 150 km.
Treatment Equipment	As per the provisions of Biomedical Waste (Management & Handling) Rules, waste falling in most of the categories can be treated in systems based on non-burn technologies. Such waste account for about 90% of the total waste streams in a healthcare unit. In the brain storming session held during the workshop at Hyderabad (February 25-26, 2003), it was unanimously decided that the CBWTF should emphasize more on non-burn technologies. It is mandatory to impart incineration/deep burial (depending upon the population of town) to anatomical and other types of waste falling under categories 1 and 2. Therefore, an incinerator of adequate capacity to cater only categories 1 and 2 waste shall be installed. If secured landfill is not available, category 5 may also be incinerated. CBWTF shall have facilities like incineration, autoclaving/ microwaving/ hydroclaving, shredder, sharp pit/ encapsulation, vehicle/ container washing facility, effluent treatment plant etc.
Infrastructure Setup	The CBWTF shall have enough space within it to install required treatment equipment, incoming and out going waste storage area, vehicle parking and washing area. Effluent treatment plant, staff room etc. A separate housing may be provided for each treatment equipment at the CBWTF such as incinerator room, autoclave room, microwave room etc, as applicable. Each room shall have well designed roof and walls. Such room shall be well ventilated and easy to wash. The floor and interior finishing of the room shall be such that chances of sticking/harbouring of microorganisms are minimized. In addition a CBWTF shall have adequate space to accommodate main waste storage room, treated waste storage room, administrative room, generator set, site security, parking, sign board, green belt, washing room.
Record Keeping	Maintenance of records for all operations carried out at the CBWTF is very important to monitor overall operation of the CBWTF. Daily records shall be maintained for the waste accepted and treated waste removed from the site. This record shall include the following minimum details: . Waste Accepted – Waste Collection Date, Name of the healthcare unit, Waste category as per the Rules, Quantity of waste, Vehicle number and Receiving date (at site) . Treated Waste removed – Date, Treated waste type, Quantity, Vehicle number and location of disposal

Source: CPCB, 2003.

4.6. Disposal of Treated Biomedical Waste

Landfill sites have traditionally been used for the disposal of residues from biomedical /clinical waste treatment processes. The use of a landfill as an acceptable means of clinical waste disposal is limited due to increased risks in respect of (EA, 2003):

- The possibility of subsequent harm to those handling the waste.
- The possibility of unauthorized materials recovery, particularly sharps.
- The ethical inappropriateness of some wastes, e.g., body parts, for landfill disposal.
- Landfill sites handle wastes with low infection characteristics.
- The disposal operation does not sterile the waste.

The primary objections to landfill disposal of hazardous health care waste, especially untreated waste, may be cultural or religious or based on a perceived risk of the release of pathogens to air and water or on the risk of access by scavengers.

4.6.1. An Engineered Disposal Facility

Sanitary landfills are designed to have at least four advantages over open dumps: geological isolation of wastes from the environment, appropriate engineering preparations before the site is ready to accept wastes, staff present on site to control operations, and organized deposit and daily coverage of waste. Some of the essential elements for design and operation of sanitary landfills are:

- Access to site and working areas possible for waste delivery and the site vehicles.
- Presence of site personnel capable of effective control of daily operations.
- Division of the site into manageable phases, appropriately prepared, before landfill starts.
- Adequate sealing of the base and sides of the site to minimize the movement of wastewater (leachate) off the site.
- Adequate mechanisms for leachate collection, and treatment systems if necessary.
- Organized deposit of wastes in a small area, allowing them to be spread, compacted, and covered daily.
- Surface water collection trenches around site boundaries.
- Construction of a final cover to minimize rainwater infiltration when each phase of the landfill is completed.

Disposing of certain types of health care waste (infectious waste and small quantities of pharmaceutical waste) in sanitary landfills is acceptable. Upgrading from open dumping directly to sophisticated sanitary landfills may be technically and financially difficult for many municipalities. It has often been found impossible to sustain such efforts from the available local resources. However, this is no reason for municipal authorities to abandon the move towards safer land disposal techniques, perhaps by a gradual approach, such as that outlined in Table 4.9.

Table 4.9. Proposed pathways for gradual upgrading of landfills.

Pathway	Upgradation Description
1	**From open dumping to "controlled dumping"** This involves reduction of the working area of the site to a more manageable size(2 ha for a medium size town), covering unneeded areas of the site with soil, extinguishing fires, and agreeing rules of on-site working with scavengers if they cannot be excluded completely.
2	**From controlled dumping to "engineered landfill"** This involves the gradual adoption of engineering techniques to prevent surface water from entering the waste, extract and spread soils to cover wastes, gather wastewater (leachate) into lagoons, spread and compact waste into thinner layers, prepare new parts of the landfill with excavation equipment, and isolate the waste from the surrounding geology (e.g., with plastic sheeting under the waste)
3	**From engineered landfill to "sanitary landfill"** This involves the continuing refinement, with increasing design and construction complexity, of the engineering techniques begun for engineered landfill. In addition, there should be landfill gas control measures, environmental monitoring points and bore holes (for monitoring air and groundwater quality), a highly organized and well trained work force, detailed record keeping by the site office, and, in some circumstances, on-site treatment of leachate.

Source: Pruss et al., 1999.

Wei et al. (1998) experienced that locating waste landfills in Taiwan has become extremely difficult owing to limited land space. As an alternative, incineration has the advantages of reduction in waste volume and stability in resulting ash. However, without waste separation, heavy metals can be introduced into an incinerator. The subsequent transformation and vaporization of volatile metals depend on the incineration environment. Some metals may be adsorbed by incombustible materials and left in bottom ash. Other metals may escape with flue gas, when passing through its dewpoint to form nuclei, or they may condense around existing particles, which can be removed by an air pollution control device as fly ash. As a result, bottom and fly ash could be toxic. Determining the stability of such wastes before being sent to landfills is a relevant task. If the leached concentrations

of these wastes as measured by the Toxicity Characteristic Leaching Procedure (TCLP) are lower than regulatory limits, they can be directly placed in the landfill; otherwise, further processing is required. Without adequate treatment, the leachates of toxic heavy metals are potentially hazardous.

Many methods can be used to evaluate the stability of heavy metal products after incineration, such as the EP (Extraction Procedure), the TCLP (Toxicity Characteristic Leaching Procedure), and the ASTM D-3987-85. These procedures employ static methods. Some studies propose that the Hazard Assessment Test should accompany the static method. Many procedures have been used to reduce the leached amounts of heavy metals, e.g. solidification of incineration residues and high temperature stabilization of wastes (vitrification).

4.6.2. Survival of Pathogenic Microorganisms in Landfill

At a microbial level, a landfill site is an extremely heterogeneous environment. Conditions of temperature, nutrient availability, oxygen availability and competition from other microorganisms vary considerably throughout the landfill profile. Each type of microorganism possesses a number of characteristics that enable it to survive in its environment. Human pathogens are usually very specialized microorganisms, and consequently are unable to survive in conditions different to those of the human body. Conditions in a landfill site are very unlikely to offer the same conditions to those encountered in the human body. Conditions are also likely to be less stable. Obligate human pathogens are not suited to life in a landfill site, and because they are highly adapted to life in the human body do not have the capability to adapt to landfill conditions (EA, 2003).

4.7. Analysis and Selection of Suitable Treatment Technology

There is a need to make the biomedical waste treatment and disposal as simple as possible because of significant number of waste streams produced as a normal consequence of health care activities. The criteria would need to make it explicit that waste generators could make their own decisions based on the implications at local level. Health care waste producers may adopt the under mentioned approach to aid the identification and segregation of their waste:

- The first step is to optimize waste sorting with proper definition of the different categories, adequate containers (collection stations, colour-coded sacks), waste circuits, intermediate then central storage areas, and finally transfer to an incineration unit/ central biomedical waste treatment facility (CBWTF).
- Elimination of drugs and related products is a second aspect: packaging, perfusion pouches, tubing, and radiopharmacentric agents. These later products are managed with non-sealed sources whose elimination depends on the radioactive period, requiring selective sorting and specific holding area while radioactivity declines.
- The differences in the infrastructure and the consequences for waste segregation and disposal under economic and ecological aspects.
- Data on different types of treatment and disposal procedures used by waste generators, enabling an estimate on the amount of on-site and off-site waste generated.

The various technologies should be evaluated using comparable health, environmental and economic criteria. Often, this is difficult given uncertainties but it is possible to describe possible risks, benefits and costs. Importantly, the feasibility and desirability of most waste treatment options will likely depend on waste volumes currently generated and trends for the near term. In their evaluation, waste generators ideally should undertake a waste audit, formulate appropriate indicators to assess and forecast waste generation trends and assume moderate to intensive efforts to minimize waste. The following criteria could be considered in evaluating different treatment options for biomedical waste:

- Effectiveness: Wastes should be completely sterilized and rendered into a form that prevents hazards or reuse.

- Cost effectiveness: The technology should be economically competitive with other available options. A life cycle cost basis that accounts for all costs, e.g., capital, operating, training, regulatory, energy, liability, waste disposal, etc
- Safety: The construction, operation, and closure of the technology/facility should not present unacceptable environmental or human health risks. This includes consideration of occupational, community and environmental risks resulting from any air emissions, water effluents, and solid wastes generated.
- Simple: Alternative technologies for small establishments should ideally be easy to manufacture, operate and maintain.
- Robust: The technology should consistently meet air emission and other health and safety criteria under a variety of operating conditions.

Following factors are needed to be considered in selecting an appropriate treatment technology:

- Disinfection Efficiency/ Microbial Inactivation efficiency
- Waste Reduction
- Types of Waste Treated
- Capacity of the System/Model
- Infrastructure/Space Requirements
- Operation and Maintenance Considerations
- Environmental Emissions and waste residues
- Options for Final Disposal
- Investment and Operation Cost
- Occupational Safety and health
- Public Acceptability
- Regulatory requirements/Acceptance

The main disadvantage of medical waste incineration is the emission of pollutants to the atmosphere, some of them extremely toxic. Pollutants are usually emitted either in condensed (particulate matter) or in gaseous phases. Many organic and metallic compounds have known effects on human health and environment. While some general

information is available from recently published work, the behaviour of the metals in the bottom ash of medical waste incinerators is yet to be understood. Although the bottom ash can be utilized for recovery from the conventional incinerators based on the grate system, a major portion of these residues are still landfilled. A bottom ash landfill can be regarded as a heterogeneous fixed bed reactor, where fast and slow acid-base reactions occur and continue for long term, with an unknown end point. Major cation and anion concentrations observed in aqueous extracts and leachates reflect the advance of those primarily inorganic reactions.

Statistical analysis to be carried out to develop models for the prediction of the quantity of waste generated at each health care facility (public, teaching & research, private etc.). In these models number of patients, beds, and type of hospital, revealed to be significant factors on quantity of waste generated.

5. DATA COLLECTION AND ANALYSIS

5.1. Rationale for Gathering Comprehensive Data

Growing concern of Government and enforcement of new rules necessitates a better understanding of the biomedical waste generation and disposal system so that quantitative analysis/prediction can be made. In the present work, the objective of data collection from health care facilities (HCFs) has been to develop a numerical model incorporating basic concepts from prevailing biomedical waste treatment and disposal practices to correlate waste generation rate in terms of seasonal variation. This objective can be accomplished in three steps: (1) the study of nature of waste segregation at source at different specialty hospitals (2) the study of generation rate in kg/bed/day as well as kg/patient/day for different categories of waste, and (3) the waste treatment at centralized treatment facility. These information were utilized in development of a mathematical correlation that provides the possibility of predicting the expected generation rate, which in turn, may prove to be helpful in strategic planning for the waste disposal.

5.2. Sustainable Biomedical Waste Management Strategy

The Ministry of Environment and Forests (MoEF), Government of India (GoI), had issued the notification on the Bio-Medical Waste (Management and Handling) Rules, 1998, stipulated detailed guidelines on infectious waste handling. Bio-medical waste shall be treated and disposed off in accordance with Schedule I & II (Figure 5.1).

Further, Bio-Medical Waste (Management and Handling) (Amendment) Rules, 2000, apply to all persons who generate, collect, receive, store, transport, treat, dispose, or handle bio-medical waste in any form. Every occupier, where required, shall set up in accordance with the time-schedule in Schedule VI (reproduced in Table 5.1), requisite bio-medical waste treatment facilities like incinerator, autoclave, microwave system for the treatment of waste, or, ensure requisite treatment of waste at a common waste treatment facility or any other waste treatment facility.

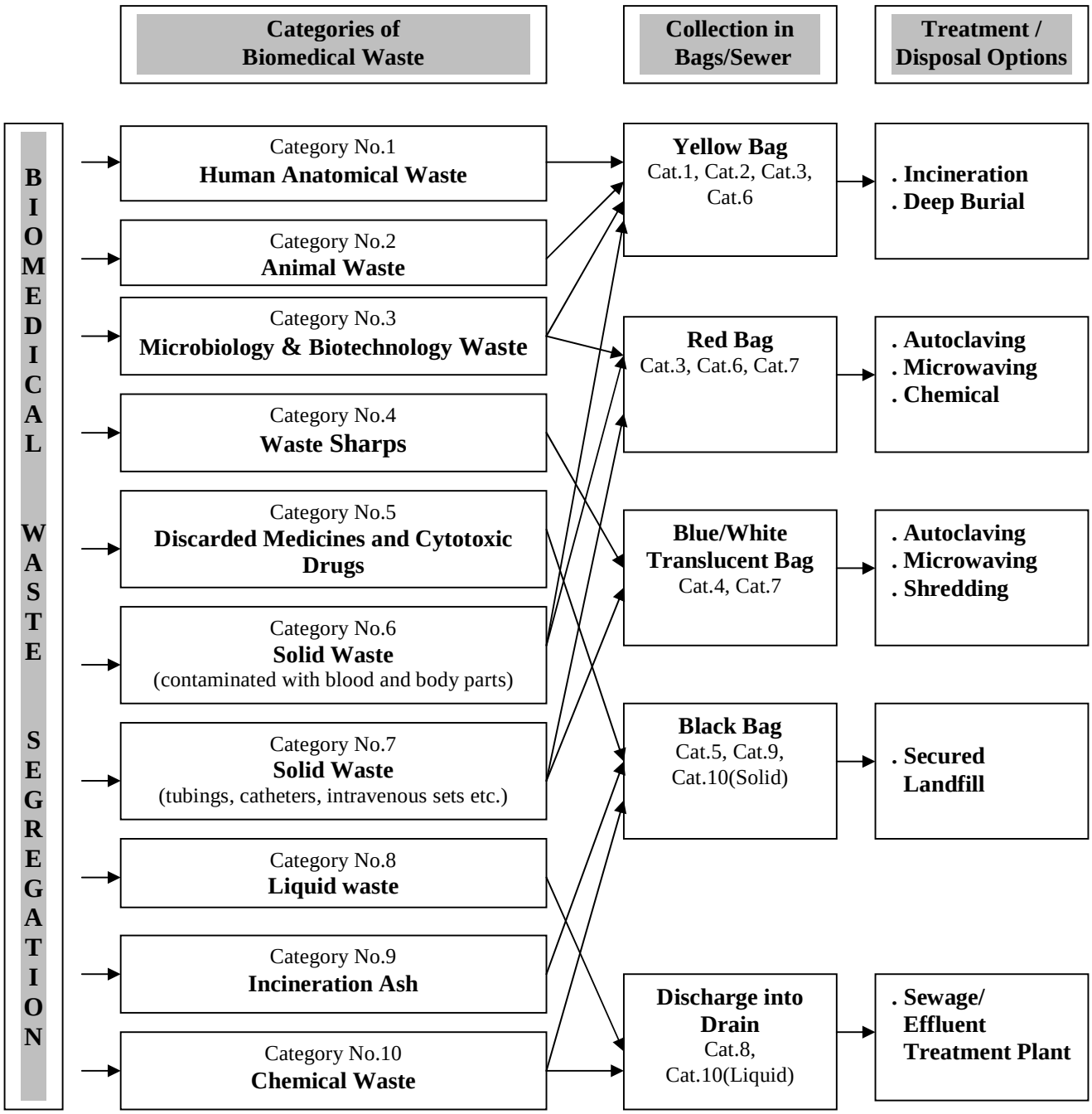


Figure 5.1. Prescribed strategy for management of biomedical waste.

Table 5.1. Schedule for Waste Management Facilities like Incinerator/ Autoclave/ Microwave System.

A. Hospitals and nursing homes in towns with population of 30 lakhs and above	By 30th June, 2000 or earlier
B. Hospitals and nursing homes in towns with population of below 30 lakhs-	
(a) with 500 beds and above	By 30th June, 2000 or earlier
(b) with 200 beds and above but less than 500 beds	By 31st December, 2000 or earlier
(c) with 50 beds and above but less than 200 beds	By 31st December, 2001 or earlier
(d) with less than 50 beds	By 31st December, 2002 or earlier
C. All other institutions generating bio-medical waste not included in **A** and **B** above	By 31st December, 2002 or earlier

In accordance with the guideline, and in addition to other treatment options, Municipal Corporation, Shimla, commissioned a central treatment facility (which is the key location of the present investigation) to cater to the needs of biomedical waste disposal of several health care facilities in and around Shimla town.

5.3. Study of Health Care Facilities at Shimla town

Shimla is the Capital Town of Himachal Pradesh, India, situated at latitude 31.06º N and longitude 77.13º E. It was formerly the summer capital during the British Rule. Its altitude is about 2100 m and surrounded by pine, deodar, oak, and rhododendron forests. Shimla has a multilingual, cosmopolitan character. People speak and understand both Hindi and English. The area of town is about 25 km^2 and population as per 2001 census is 1.60 lacs (0.016 million). Shimla has the only natural ice-skating rink in India. All the seasons of nature visit Shimla during the year. The duration and temperatures of different seasons are given in Table 5.2.

Table 5.2. Duration and temperature of different seasons of Shimla Town.

Season	Months	Temperature	Conditions
Spring	March- April	10 ºC to 20 ºC	Generally clear skies with occasional short lasting rains with thunder.
Summer	May-June	16 ºC to 28 ºC	Generally clear skies. Sometimes forest fires in this season cause the air to be smoky.
Monsoon	July-September	13 ºC to 20 ºC	Cool and humid atmosphere. It can rain for days continuously.
Autumn	October-November	10 ºC to 23 ºC	Skies are clear, with evenings becoming chilly.
Winter	December-February	-7 ºC to 10 ºC	Generally dull weather with frequent snowfall.

There are around 100 clinics and health care facilities in the limits of Municipal Corporation of Shimla. In the present study only five major health care facilities are considered (Table 5.3).

Table 5.3. Major Health Care Facilities (HCFs) at Shimla Town, India.

Address of Health Care Facility	Specialty	Number of Beds
IGMC Hospital (IGMCH), Snowdon, Shimla.	State level general government hospital attached to medical college with state of the art facility: Medicine, Surgery, Cardiology, Psychiatry, Orthopaedics, Paediatrics, ENT, Eye, Plastic Surgery, Urology, Radiotherapy etc.	738
KN Hospital (KNH), Marrina, Shimla.	Exclusively female care, Gynaecology & Obstetrics and attached to Government Medical College	130
DDU Hospital (DDUH), Bus Stand, Shimla.	District level general male & female indoor and outdoor health care.	150
Indus Hospital(IH), Jakhu, Shimla.	Private hospital for general male & female health care with modern machines.	100
Sanatorium (SS), Chaura Maidan, Shimla	TB Sanatorium	50

In compliance to Biomedical Waste (Management and Handling) Rules, Municipal Corporation of Shimla established a centralized treatment facility for incineration of infectious hospital waste during the month of August 2002. Initially, the responsibility of incinerating an estimated yellow bag waste quantity of 1000 kg/day was given on contract to M/s Haat Incinerators India Private Limited for a period of three years. The charges of

running the incinerator had been Rs.15.00 lacs (nearly 33,000 US$) per annum. The brief specifications of the two incinerator units installed at centralized incineration facility are detailed in Table 5.4:

Table 5.4. Brief Specifications of Centralized Treatment Facility at Shimla (HP).

Incinerator Type	Manufacturer	Technical specifications
PD 12	Haat Incinerators India Private Limited BANGALORE – 562106	Burning Rate = 70 kg/h Weight = 5000 kg Fuel (Diesel oil) Consumption = 12-15 L/h
PD 18	Haat Incinerators India Private Limited BANGALORE – 562106	Burning Rate = 100 kg/h Weight = 7500 kg Fuel (Diesel Oil) consumption = 20-25 L/h

5.4. Waste Generation and Preliminary Trends

Biomedical waste generation data at major health care facilities of Shimla town on daily basis under present study have been collected for two consecutive years (2003 & 2004) and tabulated (different tables in Appendices A, B, C and D). Thereafter preliminary trends for infectious waste collected in colour coded bags from IGMCH, KNH, DDUH, IH, and SS were analyzed.

As evident from the data given in Appendices (Tables A-1 to A-10, D-1, and D-2), there are frequent missing information because of the fact that sometimes wastes were collected after a gap of one or two days (some times even up to 4 days, e.g., for IGMCH, between January 23 to January 26, 2004). However, it appears that most of the waste material is accumulated and is sent for incineration at the time of next collection. Therefore, it was decided to take monthly average values of waste generation rate (kg/day) for the purpose of analysis, so that the irregularity in waste collection can be smoothed out. These average values are shown in Figure 5.2 and Figure 5.3. These waste data include both in door and out door patients visiting hospitals. Since no information was available how much waste is coming from out door and how much from in door. These waste generation data were

plotted (Figures 5.4 to 5.9) by dividing number of patients visiting hospital (kg/patient/day) and number of beds occupied (kg/bed/day). The following relation is being used by the authorities of IGMCH, Shimla for calculating the percent bed occupancy:

$$PBO = \frac{100.X}{Y.Z} \qquad \text{----- (5.1)}$$

where PBO – Percentage Bed Occupancy

X – Total number of inpatients/inpatients service days for a period

Y – Total number of inpatient bed count or bed strength

Z – Number of days in the period

These figures show almost similar variation in waste generates calculated either on per bed basis or per day basis. This indicates that there exists almost a linear relationship between the number of indoor and outdoor patients. Since more reliable data is available for the indoor patients, for further studies, waste generation rate is taken as kg/bed/day.

The comparative colour coded collections in different bags of two hospitals are shown in Figures 5.10, 5.11, and 5.12. Finally, Figure 5.13 shows monthly average data of yellow bag (kg/day) received at the central incineration facility.

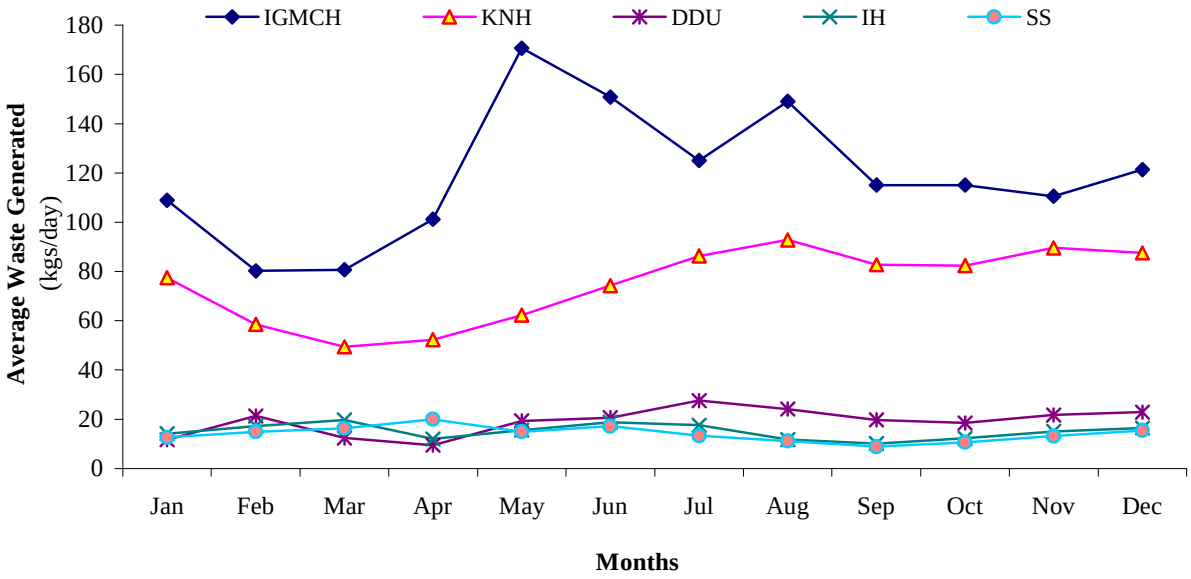


Fig. 5.2. Biomedical Waste Generation Rate at HCFs, Shimla, Year 2003

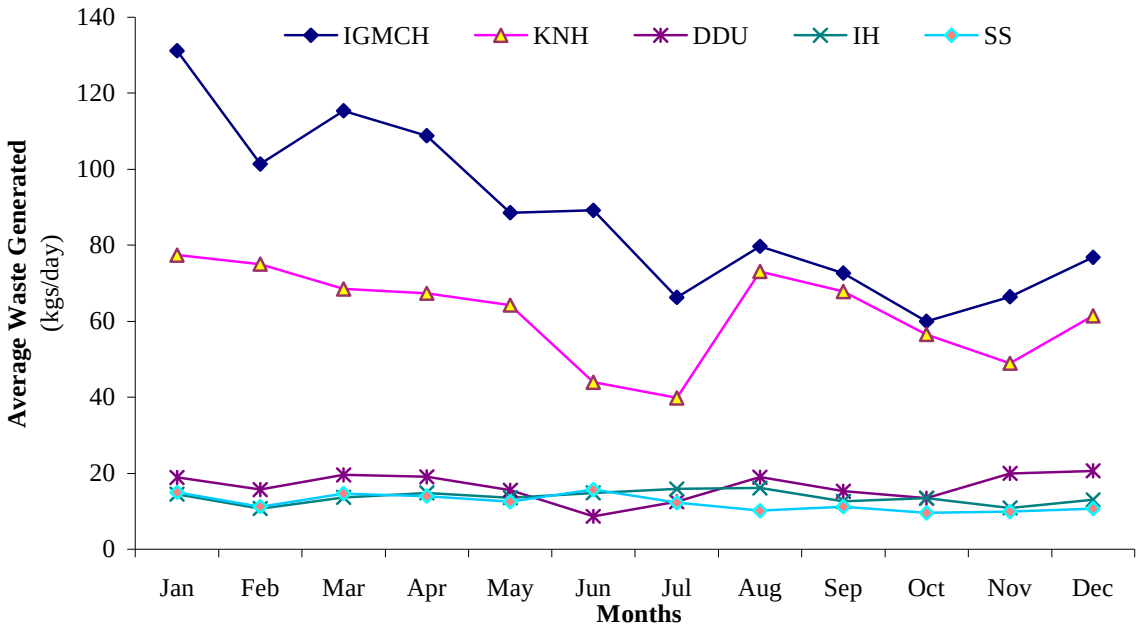


Fig.5.3. Biomedical Waste Generation Rate at HCFs, Shimla, Year 2004

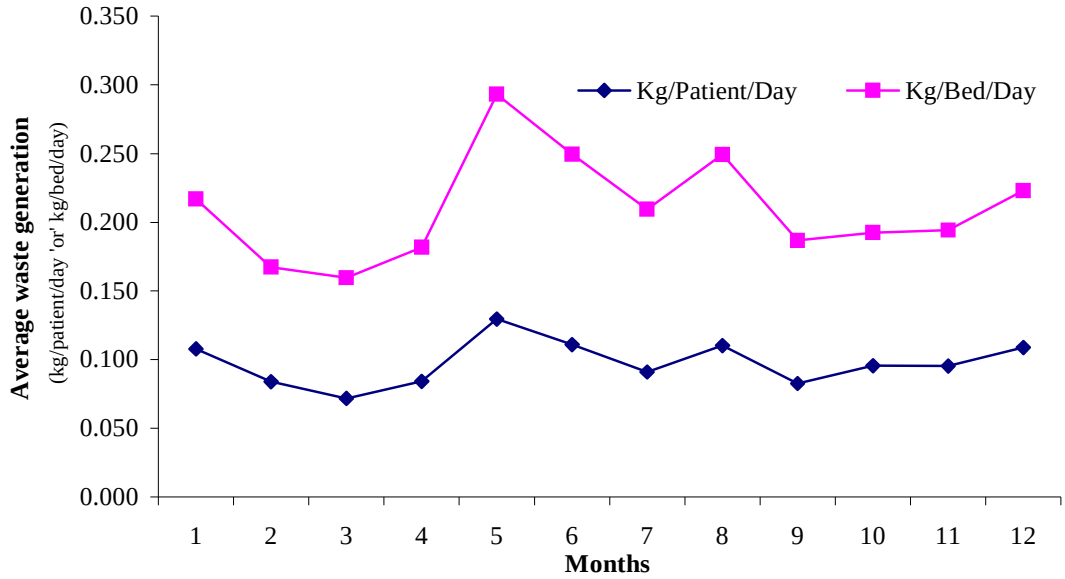


Fig. 5.4. Biomedical waste generation (patient or bed/day) **at IGMCH, Shimla, Year 2003.**

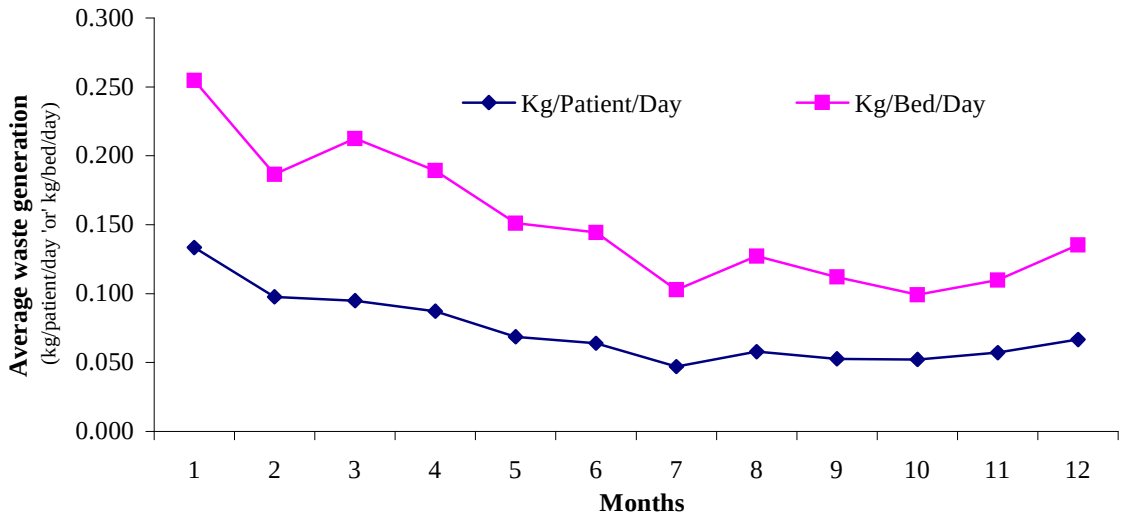


Fig.5.5.Biomedical waste generation (patient or bed/day) **at IGMCH, Shimla, Year 2004.**

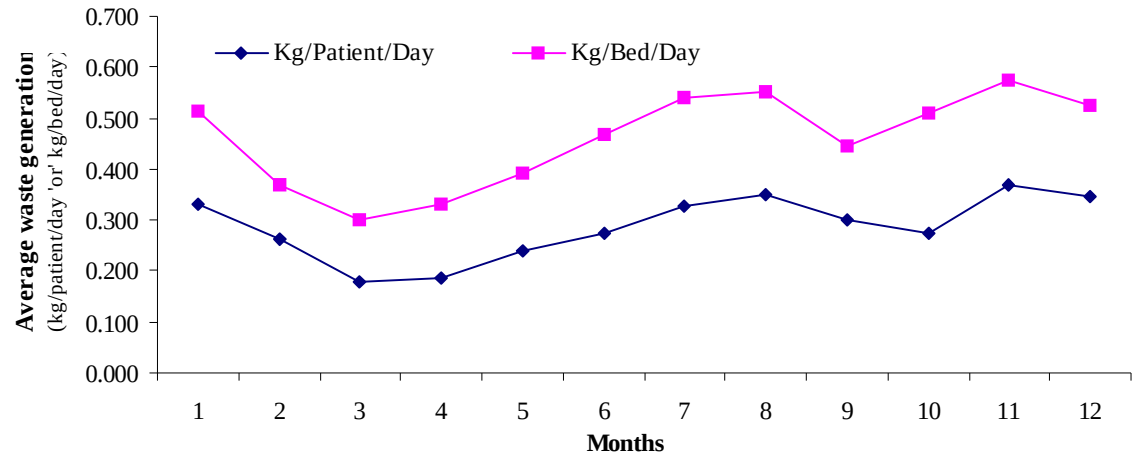


Fig.5.6. Biomedical waste generation (patient or bed/day) **at KNH, Shimla, Year 2003.**

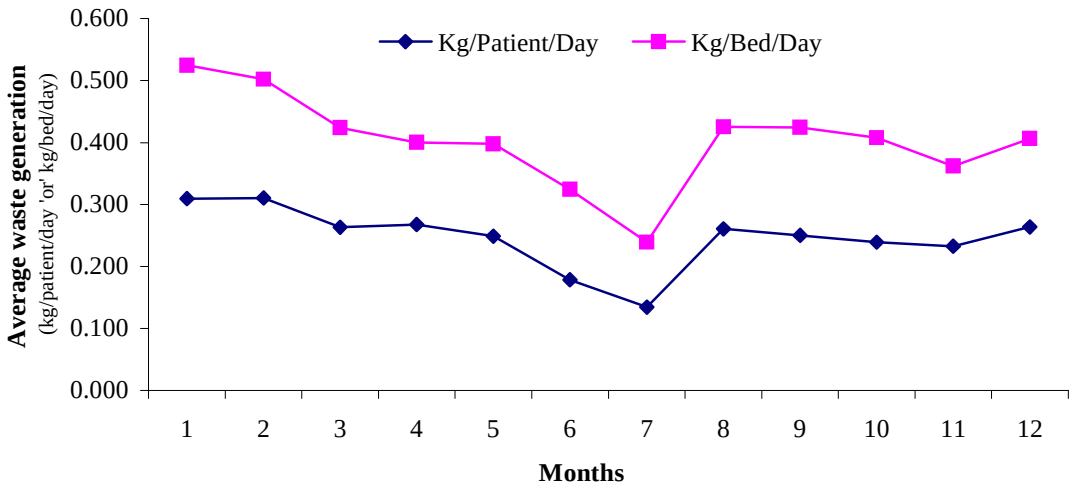


Fig.5.7.Biomedical waste generation (patient or bed/day) **at KNH, Shimla, Year 2004.**

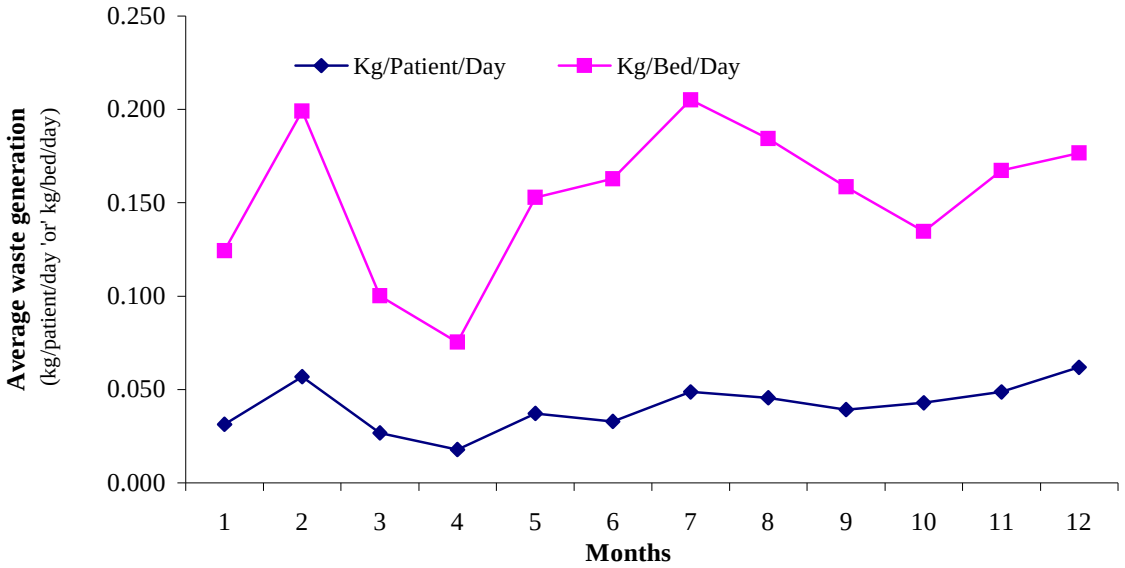


Fig.5.8. Biomedical waste generation (patient or bed/day) **at DDUH, Shimla, Year 2003.**

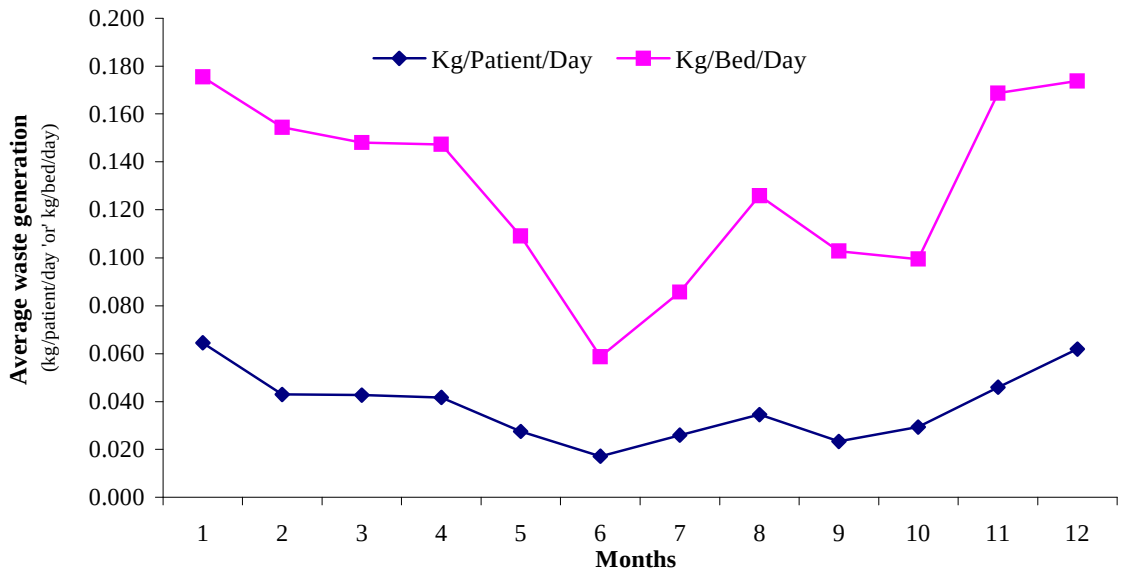


Fig.5.9. Biomedical waste generation (patient or bed/day) **at DDUH, Shimla, Year 2004**

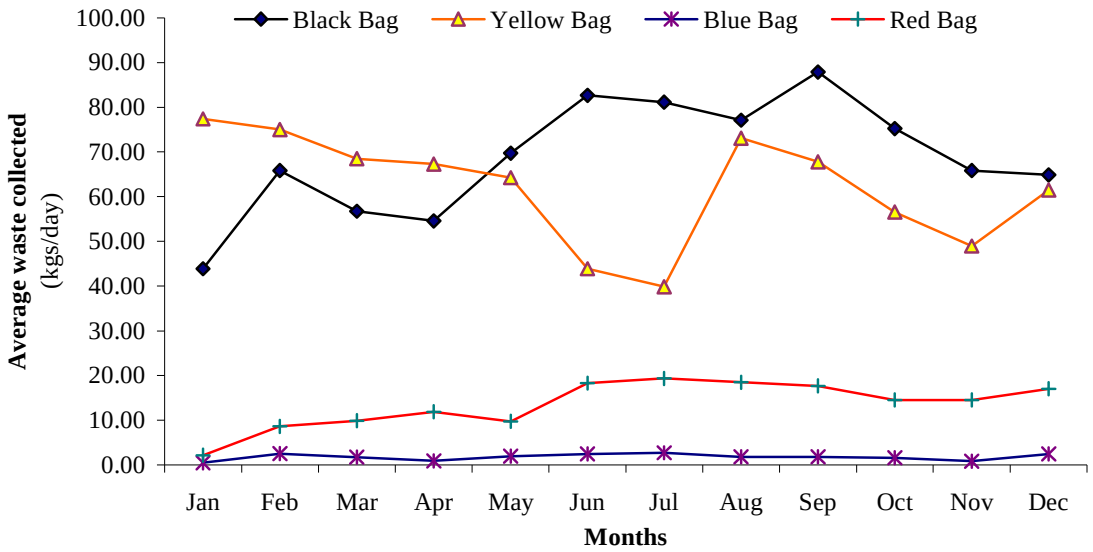


Fig.5.10. Biomedical waste collection in coloured bags at KNH Shimla, Year 2004

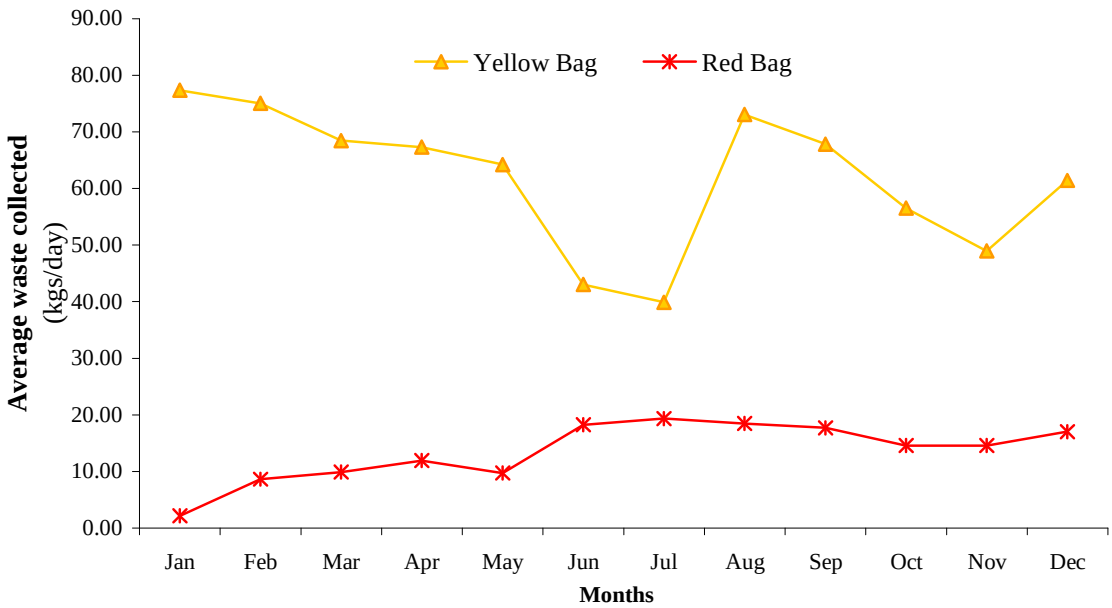


Fig. 5.11.Biomedical waste collection in yellow/red bags at KNH Shimla,Year 2004.

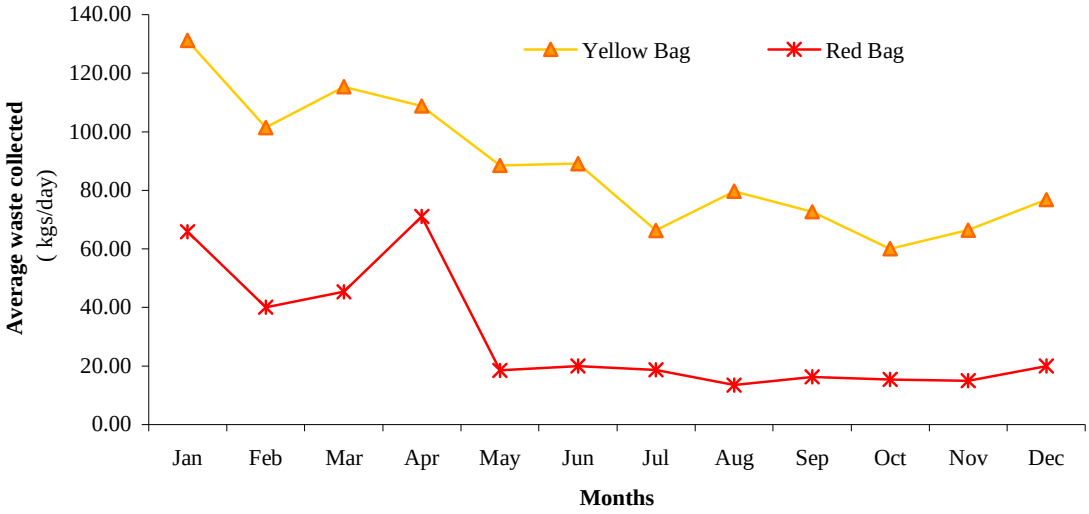


Fig. 5.12.Biomedical waste collection in yellow/red bags at IGMCH Shimla, Year 2004.

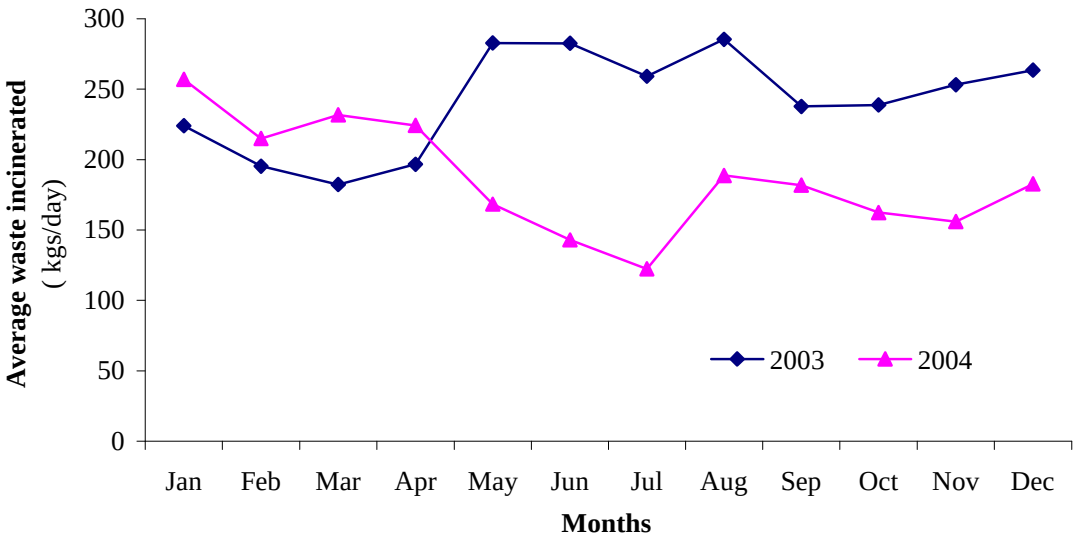


Fig.5.13. Incineration of yellow bag at MC Incinerator, Shimla, Year 2003 -2004

6. MODELLING HEALTH CARE WASTE MANAGEMENT

6.1. Modelling Waste Management

Modeling of waste management system is rather less developed, perhaps due to the fact that the process invokes a large number of parameters having unknown behavior. However, need of some predictive tool is clearly visualized by many researchers. With this objective, some mathematical models have been developed but most of them are limited to optimize the waste system to reduce environmental burdens or economic costs and to improve social acceptability. Many of the models are decision support models, using a variety of methods and tools, such as risk assessment, environmental impact assessment, cost benefit analysis, multicriteria decision making or life cycle as part of the decision making process. Keeping these in view, present work is aimed at developing a mathematical model to study the effect of season on waste generation rate from some selected health care facilities.

6.2. Present Case Study – Development of Model

The general technique, by which much of modern engineering modeling proceeds, is by the identification and solution of the set of mathematical equations, mostly differential equations representing rate laws. These equations describe the dynamic behaviour of various key variables, whose values, when the equations are solved, predict the state of the system at any instant of time (Kumar and Upadhyay, 2000). Unfortunately, real environmental systems are horribly complex and involve several interlinked parameters; therefore, it is extremely difficult to measure the various constants of rigorous mathematical models with any accuracy. This is particularly true when the dynamic behavior of such systems is considered. Without the values of all the constants, the set of model equations have no practical importance (Parsons and Dohnal, 1995). As a result, most of the modeling approach (including present one) is empirical in nature.

6.2.1. Relation between Bed Occupancy and Waste Generation Rate

In order to get better understanding of biomedical waste management and treatment in the present case study, firstly, it is assumed that the infectious waste generated from the health

care facility (HCF) should be proportional to the bed occupancy. Therefore, a linear relationship between waste generation rate and bed occupancy is expected (Awad et al., 2004). Even if, bed occupancy is zero, there should be some waste generated for the maintenance of hospital premises. Therefore, a linear relationship with a positive intercept on y-axir, represented by line 'a' in Figure 6.1, is expected. However, there may be several other factors that may influence waste generation rate. For example, if the bed occupancy increases to a great extent from its sanctioned strength, slight variation in waste generation rate can easily be envisaged due to changed efficiency of the waste handling system. Thus,

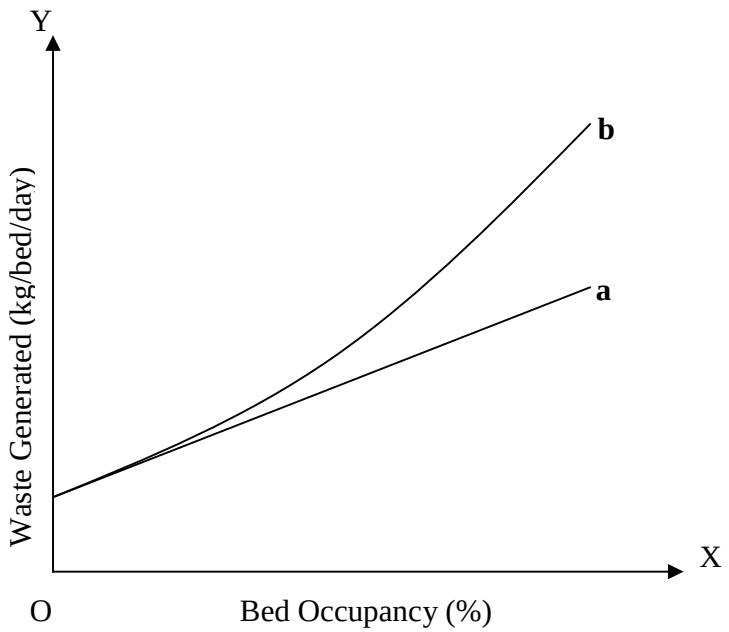


Figure 6.1. Schematic representation of HCW Generation Rate

to accommodate effect of other factors in the model, in place of the linear relationship a non-linear curve (curve 'b' in Figure 6.1) can be a better choice. It is proposed that the average rate of waste generation, W_0 (kg/day), can be represented by the following quadratic equation in a better way.

$$W_0 = k_1 + k_2.B + k_3.B^2 \qquad \text{----- (6.1)}$$

where k_1, k_2, and k_3 are constants and B is the average bed occupancy (average number of beds used/day in one month) calculated by using Equation (5.1).

Here it is worth mentioning that Equation (6.1) assumes that W_0 is the waste generated per bed per day that remains unchanged throughout the year, and there is no any effect of weather / season on its value. Also this rate may be different for number and type of specialties in a particular health care facility. However, the data shows a regular pattern in the variation of waste generation rate during one calendar year (Figures 5.4 to 5.9). Therefore a correction factor ψ depending on season can be incorporated in Equation (6.1) by using a correction factor that depends on the month of a year. Thus Equation (6.1) can be modified to

$$W = W_0.\psi \qquad \text{----- (6.2)}$$

where ψ is a correction factor that depends on the month of a calendar year.

6.2.2. Seasonal Variation in the Rate of Waste generation

The raw data for the monthly waste generation rate (Figures 5.4 to 5.9) indicates that the effect of season is considerable and there are at the most only one maxima or minima in a year. Thus it appears that to account this seasonal variation one needs atleast a polynomial of degree three or a trigonometric function involving sine or cosine function. But the waste generation data shows an uneven trend of positive and negative variation from a mean value, therefore sine or cosine functions are not suitable for the present purpose. Therefore, a polynomial would be more suitable form of equation for the present work.

First of all following polynomial of degree three is considered,

$$\psi = a + b.x + c.x^2 + d.x^3 \qquad \text{----- (6.3)}$$

where ψ is the correction factor and x is the representative number of the month.

For the sake of convenience, months are numbered as 0, 1, 2, ----, 11 for January, February, March, ----, December. Thus for the month of January, x is zero, for February, x is 1 and for December, x is 11. Here it should be noted that ψ is a correction factor depending on month of year, its numerical value should remain same for a particular month in different years, and that, Equation (6.3) is defined for values of x raging from 0 to 11 only. However, to make this function continuous round the year, it is required that the

function values and its slopes are equal at $x = 0$ and $x = 12$ ($x = 12$ represent the month of January of the next year).

In other words

$$\psi(0) = \psi(12) \qquad \text{----- (6.4)}$$

and

$$\left.\frac{d\psi}{dx}\right|_{x=0} = \left.\frac{d\psi}{dx}\right|_{x=12} \qquad \text{----- (6.5)}$$

Thus from Equation (6.5) we get

$$b + 2c(0) + 3d(0) = b + 2c(12) + 3d(12)^2 \qquad \text{----- (6.6)}$$

or $$2c(12) + 3d(12)^2 = 0 \qquad \text{----- (6.7)}$$

or $$c = -18.d \qquad \text{----- (6.8)}$$

and from Equation (6.4) we have

$$a + b(0) + c(0) + d(0) = a + b(12) + c(12)^2 + d(12)^3 \qquad \text{----- (6.9)}$$

or $$b + 12.c + 12^2.d = 0 \qquad \text{----- (6.10)}$$

Carrying the value of c from equation (6.8) to equation (6.10), we get

$$b + 12(-18d) + 12^2 d = 0 \qquad \text{----- (6.11)}$$

or $$b = 72.d \qquad \text{----- (6.12)}$$

Thus the required correction factor (equation 6.3) reduces to,

$$\psi = a + 72x - 18dx^2 + dx^3 \qquad \text{----- (6.13)}$$

or $$\psi = a + d.(72x - 18x^2 + x^3) \qquad \text{----- (6.14)}$$

In the above equation 'a' is the mean value (approximately equal to unity) about which the correction factor ψ oscillates and d is the parameter that sets magnitude of the oscillation. In this case the function has fixed value of x (for all values of d) when ψ approaches its mean value a viz. at $x = 0$, 6, and 12. Fig. 6.2 presents ψ calculated by Equation (6.14) at three different values, –0.05, –0.04, and +0.05 of d.

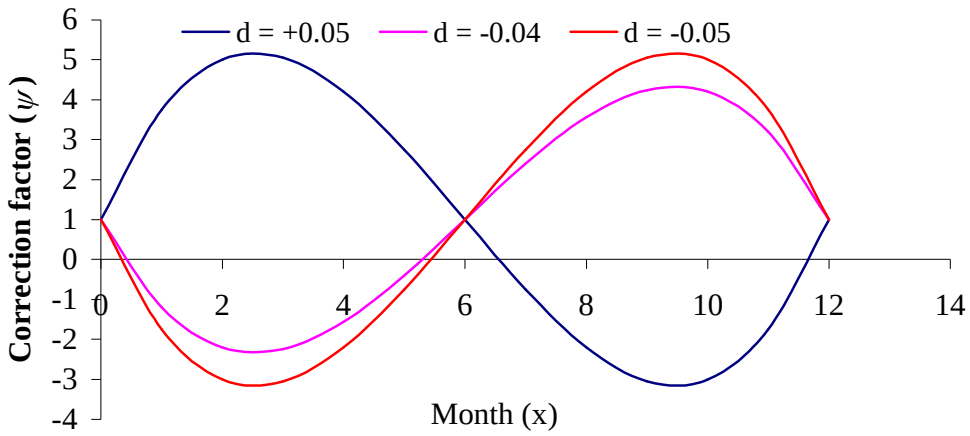


Figure 6.2.Correction factor (ψ) versus month (x) ,equation no.6.14.

However, this is not the actual case. This indicates that we need more number of parameters in the required equation to accommodate the waste generation data i.e., a polynomial of higher degree is required. Therefore, the following polynomial of fourth degree was considered as next possibility

$$\psi = a + b.x + c.x^2 + d.x^3 + e.x^4 \qquad \text{----- (6.15)}$$

This equation should also be such that the condition of Equations (6.4) and (6.5) is applied. Therefore for condition at Equation (6.5), we get

$$b + 2c(0) + 3d(0) + 4e(0) = b + 2c(12) + 3d(12)^2 + 4e(12)^3 \qquad \text{----- (6.16)}$$

or $$2c(12) + 3d(12)^2 + 4e(12)^3 = 0 \qquad \text{----- (6.17)}$$

or $$2c + 3d(12) + 4e(12)^2 = 0 \qquad \text{----- (6.18)}$$

or $$c = -(18d + 288e) \qquad \text{----- (6.19)}$$

and for condition at Equation (6.4), we have

$$a + b(0) + c(0) + d(0) + e(0) = a + b(12) + c(12)^2 + d(12)^3 + e(12)^4 \qquad \text{----- (6.20)}$$

or $$b(12) + c(12)^2 + d(12)^3 + e(12)^4 = 0 \qquad \text{----- (6.21)}$$

or $$b = -\left(12c + 12^2 d + 12^3 e\right) \qquad \text{----- (6.22)}$$

Substituting values of b from equations (6.22) in Equation (6.15), the polynomial reduces to

$$\psi = a - (12c + 12^2 d + 12^3 e)x + cx^2 + dx^3 + ex^4 \qquad \text{----- (6.23)}$$

or $$\psi = a + c(x^2 - 12x) + d(x^3 - 12^2 x) + e(x^4 - 12^3 x)$$ ----- (6.24)

Again, substituting value of *c* from Equation (6.19) in Equation (6.24), we get

$$\psi = a - (18d + 288e)(x^2 - 12x) + d(x^3 - 12^2 x) + e(x^4 - 12^3 x)$$ ----- (6.25)

or $$\psi = a + d(72d + 1728e)x - (18d + 288e)x^2 + dx^3 + ex^4$$ ----- (6.26)

or $$\psi = a + d.(72x - 18x^2 + x^3) + e.(1728x - 288x^2 + x^4)$$ ----- (6.27)

Now, we have three adjustable parameters *a*, *d*, and *e* to accommodate seasonal variation. However, even this equation could not explain the data in a satisfactory manner. Additional degree of freedom in the form of coefficient *e*, can be used to shift the point of inflection, however, magnitude of oscillation of the function cannot be adjusted in this equation. Therefore, in order to make waste generation data more representative, one more parameter is introduced, i.e., following polynomial of fifth degree is considered

$$\psi = a + b.x + c.x^2 + d.x^3 + e.x^4 + f.x^5$$ ----- (6.28)

Again this equation should be such that condition of Equation (6.4) and (6.5) is satisfied. Therefore for equal slope of the function at $x = 0$ and $x = 12$ (Equation 6.5), we get

$$b + 2c(0) + 3d(0) + 4e(0) + 5f(0) = b + 2c(12) + 3d(12)^2 + 4e(12)^3 + 5f(12)^4$$

----- (6.29)

or $$2c(12) + 3d(12)^2 + 4e(12)^3 + 5f(12)^4 = 0$$ ----- (6.30)

or $$2c + 3d(12) + 4e(12)^2 + 5f(12)^3 = 0$$ ----- (6.31)

or $$c + 18d + 288e + 4320f = 0$$ ----- (6.32)

or $$c = -(18d + 288e + 4320f)$$ ----- (6.33)

and for condition expressed in Equation (6.4), we have

$$a + b(0) + c(0) + d(0) + e(0) + f(0) = a + b(12) + c(12)^2 + d(12)^3 + e(12)^4 + f(12)^5$$

----- (6.34)

or $$b(12) + c(12)^2 + d(12)^3 + e(12)^4 + f(12)^5 = 0$$ ----- (6.35)

or $$b = -(12c + 12^2 d + 12^3 e + 12^4 f$$ ----- (6.36)

Combining equations (6.28), (6.33), and (6.36), the required polynomial to express the correction factor ψ becomes

$$\psi = a - (12c + 12^2 d + 12^3 e + 12^4 f)x + cx^2 + dx^3 + ex^4 + fx^5 \quad \text{----- (6.37)}$$

or $$\psi = a + c(x^2 - 12x) + d(x^3 - 12^2 x) + e(x^4 - 12^3 x) + f(x^5 - 12^4 x) \quad \text{----- (6.38)}$$

or $$\psi = a - (18d + 288e + 4320f)(x^2 - 12x) + d(x^3 - 12^2 x) + e(x^4 - 12^3 x) + f(x^5 - 12^4 x)$$

----- (6.39)

or $$\psi = a + (72d + 1728e + 31104f)x - (18d + 288e + 4320f)x^2 + dx^3 + ex^4 + fx^5$$

----- (6.40)

or $$\psi = a + d(72x - 18x^2 + x^3) + e(1728x - 288x^2 + x^4) + f(31104x - 4320x^2 + x^5)$$

-----(6.41)

Thus we have an equation with four parameters (*a*, *d*, *e*, and *f*) that can be adjusted to obtain the correction factor by regression analysis using available data.

Next, the values of constants *a*, *d*, *e*, and *f* of Equation (6.41), and k_1, k_2, k_3, of Equation (6.1), were determined for individual health care facilities by using NPSOL. NPSOL is a collection of FORTRAN 77 subroutines designed to solve nonlinear programming problems (Gill et al., 1986). The subroutines of the package can be used as a tool for minimizing a multivariate non-linear function (with more than 900 variables). The multivariate non-linear optimization technique is a well known technique generally used for finding optimum vales of parameters of a system of nonlinear equations. A detailed analysis of this method can be seen in any text or reference book on numerical techniques such as Golub and Ortega (1992). This technique relies upon formation of an objective function that represents all the model equations. In the present case, we have twelve predicted values of waste generation rates, $W_0.\psi$, in terms of seven coefficients (k_1, k_2, k_3, *a*, *d*, *e*, and *f*), corresponding to twelve data point of one particular hospital in a calendar year. Now, our objective is to find values of seven coefficients in such a way that the absolute value of difference between actual and predicted values of waste generation rate (the discrepancy) is minimal. To achieve this, the following objective function was minimized to determine the optimal values of the coefficients.

$$O(k_1, k_2, k_3, a, d, e, f) = \sum_{x=0}^{11} \left[W_{actual} - W_0(k_1, k_2, k_3, B).\psi(a, d, e, f, x) \right]^2 \quad \text{----- (6.42)}$$

In the above equation ψ is calculated by Equation (6.41) and W_0 by Equation (6.1). Here it should be noted that the objective function is the sum of squares of all the discrepancies in one calendar year.

To begin with, an initial guess values of the coefficients k_1, k_2, k_3, a, d, e, and f were assumed. The software calculates the value of $W_0\psi$ at this assumed value. Squares of the difference between W_{actual}, and $W_0\psi$ are the discrepancy between the data collected from hospitals and that calculated by the model equations. Now, the objective of the computer program is to minimize sum of all the discrepancies, calculated by Equation (6.41), by adjusting values of coefficients (k_1, k_2, k_3, a, d, e, and f).

In other words it can be said that the present technique is equivalent to the least square multivariate-nonlinear-regression analysis. The programming to obtain numerical values of coefficients of Equations (6.1) and (6.41) is given in Appendix 'E'.

7. RESULTS AND DISCUSSION

7.1. Model Tuning

A mathematical model containing some arbitrary constants needs to be tuned for a particular system. In the present case, as discussed earlier, the average waste generation per bed per day is expressed in the following manner

$$W = W_0.\psi \qquad \text{----- (6.2)}$$

where W_0, the average rate of waste generation (kg/day), follows a non-linear quadratic equation

$$W_0 = k_1 + k_2.B + k_3.B^2 \qquad \text{----- (6.1)}$$

having k_1, k_2, and k_3 as constants, and B is the average bed occupancy (number of beds occupied per day). The correction factor ψ in the Equation (6.2), representing seasonal variation in waste generation rate, is given by the following polynomial of degree five

$$\psi = a + d(72x - 18x^2 + x^3) + e(1728x - 288x^2 + x^4) + f(31104x - 4320x^2 + x^5) \text{ --- (6.41)}$$

that contain four more arbitrary constants. For tuning the model, values of constants k_1, k_2, k_3, a, d, e, and f appearing in the Equations (6.1), and (6.41) were determined for the each individual health care facilities by using multivariate non-linear optimization technique by minimizing the objective function

$$O(k_1, k_2, k_3, a, d, e, f) = \sum_{x=0}^{11} \left[W_{actual} - W_0(k_1, k_2, k_3, B).\psi(a, d, e, f, x) \right]^2 \qquad \text{----- (6.42)}$$

For the determination of the values of coefficients, waste generation data were collected from five major hospitals in Shimla (Appendix A, Table A-1 to A-10), however, in the present study, only three major hospitals (IGMCH, KNH, and DDUH) could be considered, as bed occupancy data for other two hospitals were either inconsistent or not made available. However, the three hospitals considered are the major sources of biomedical waste. About 85% of waste materials (yellow bags) being incinerated at the centralized treatment facility at Shimla, come from these three hospitals.

The numerical values of the coefficients of Equations (6.1) and (6.41) are determined with the help of a computer program (listed in Appendix E) based on the software, NPSOL (Gill

et al, 1986) using the average biomedical waste generation (kg/day of yellow bag) and average bed occupancy (number of bed used/day) data presented in Appendix-B (IGMCH: Tables B-1 and B-2; KNH: Tables B-3 and B-4; and DDUH: Tables B-5 and B-6). The values of coefficients obtained are listed in Table 7.1.

Table-7.1. Numerical Values of Coefficients of Equation (6.1) and (6.41)

Parameter	IGMC Hospital		KN Hospital		DDU Hospital	
	2003	**2004**	**2003**	**2004**	**2003**	**2004**
k_1	-876.016	2075.88	980.022	-1102.76	82.3809	-20.6351
k_2	3.22012	-6.33083	-11.377	14.788	-1.31561	0.76094
k_3	-0.00256	0.005	0.03565	-0.04662	0.00651	-0.00357
a	0.933257	0.942589	0.983753	1.161019	0.886594	0.97992
b (Eqn. 6.36)	*-0.20237*	*-0.12431*	*-0.42929*	*-0.42149*	*-0.25447*	*-0.2112*
c (Eqn. 6.33)	*0.184053*	*0.168063*	*0.231403*	*0.235915*	*0.200602*	*0.191082*
d	-0.04531	-0.04441	-0.04669	-0.04979	-0.04621	-0.04621
e	0.004302	0.004262	0.004202	0.004603	0.004259	0.004333
f	-0.00014	-0.00014	-0.00014	-0.00015	-0.00014	-0.00014

7.2. Model Validation

7.2.1. Bed Occupancy versus Waste Generation

The proposed model consists of two model equations. First equation (Equation 6.1) correlates waste generation rate in terms of number of beds occupied in a hospital. To verify this part of the model, all monthly average waste generation data are plotted against bed occupancy and the curve predicted by Equation (6.1), using coefficients listed in Table 7.1 (solid line), is compared with the best fit line (trend line, represented by dashes) in Figures 7.1 to 7.6. It is evident from these figures that the best fit curve and the curve represented by equation (6.1) are almost similar. Here it should be noted that the values of coefficients k_1, k_2, and k_3, (for equation 6.1) were obtained concurrently with the coefficients *a*, *d*, *e*, and *f* (for equation 6.41), whereas the trend line simply correlates waste generation data with bed occupancy. This indicates that there is no any significant infringement between the two equations representing waste generation in terms of bed occupancy and in terms of seasonal changes.

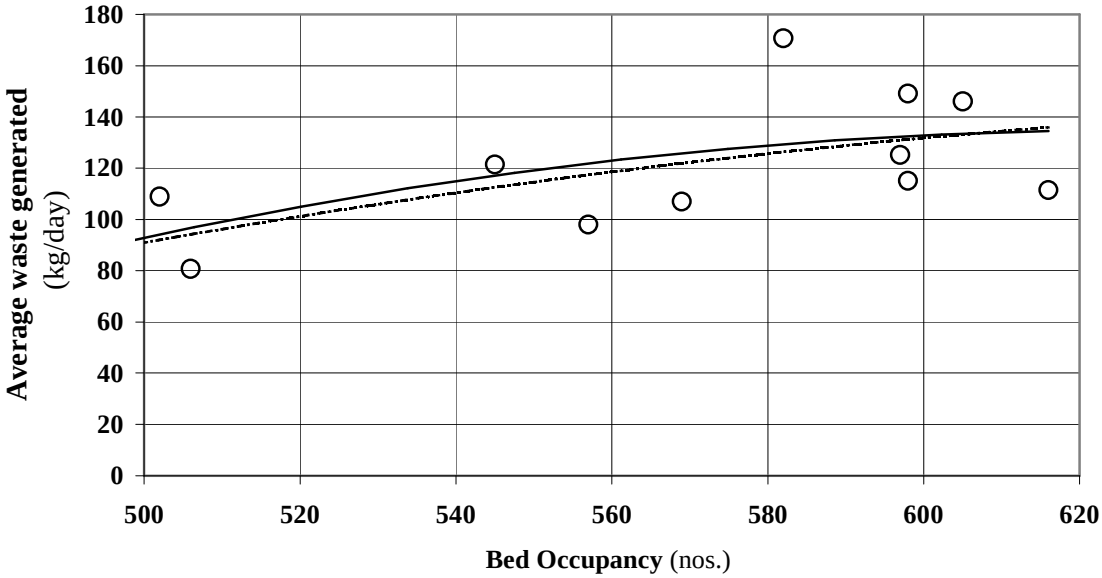


Fig.7.1. Bed occupancy vs waste generation, IGMCH, Year 2003.

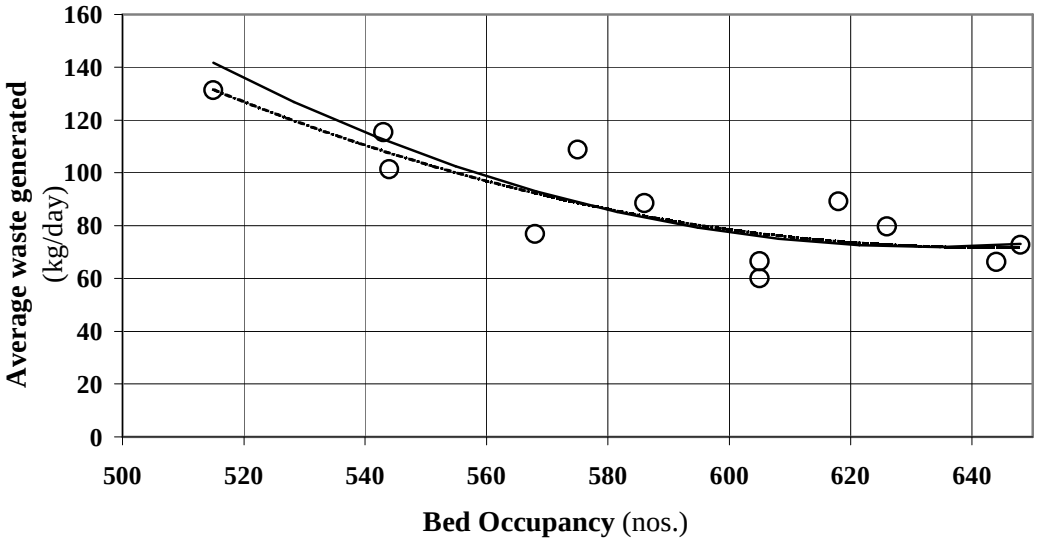


Fig.7.2. Bed occupancy vs waste generation, IGMCH, 2004.

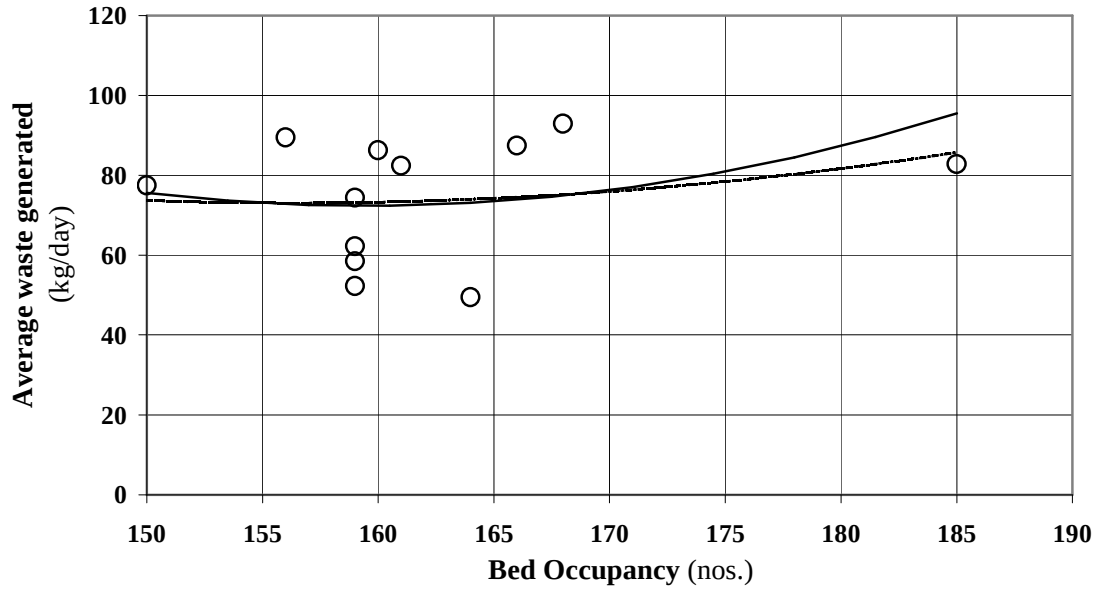


Fig.7.3. Bed Occupancy versus waste generation, KNH, 2003

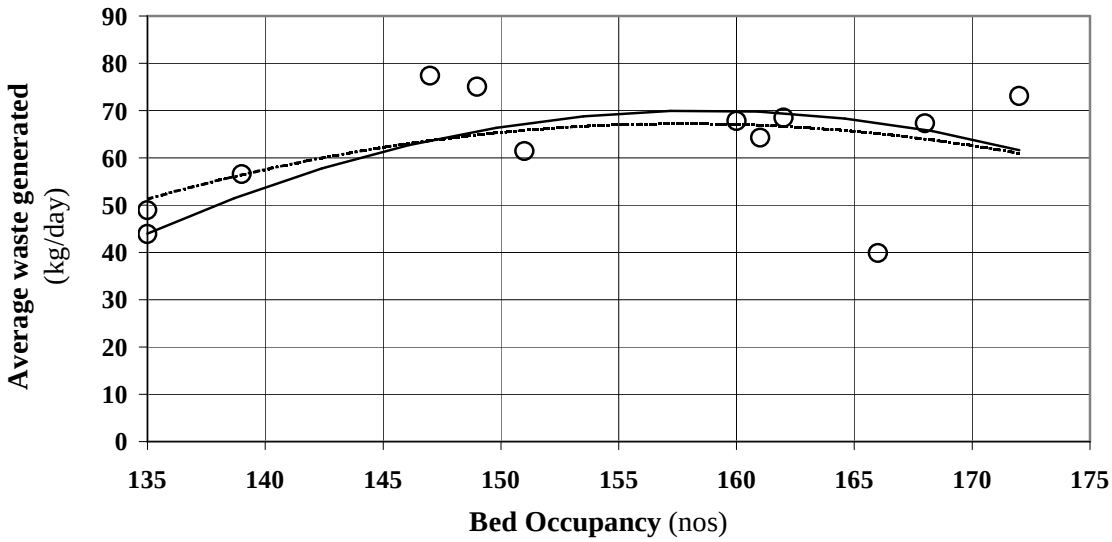


Fig.7.4.Bed Occupancy versus waste generation, KNH, 2004.

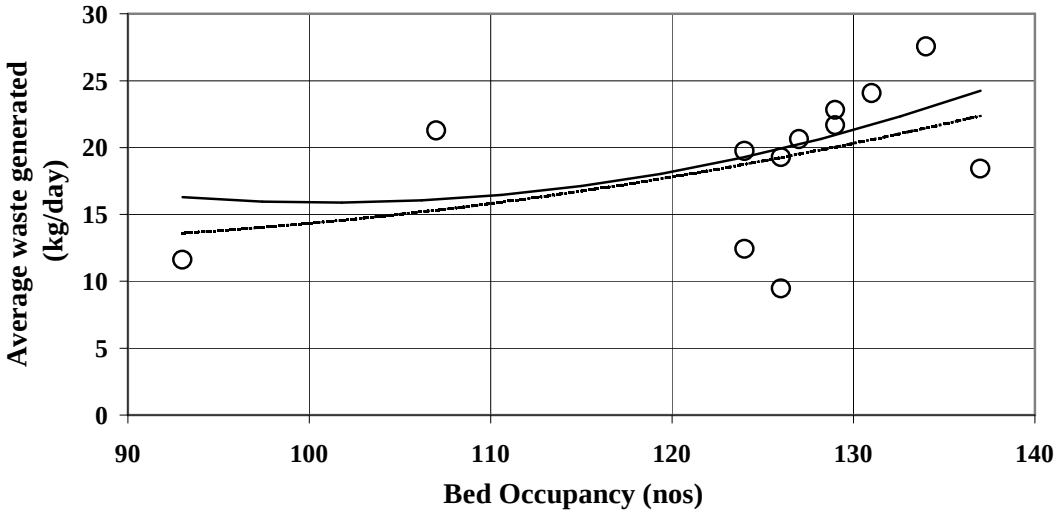


Fig.7.5. Bed Occupancy versus waste generation, DDUH, Year 2003

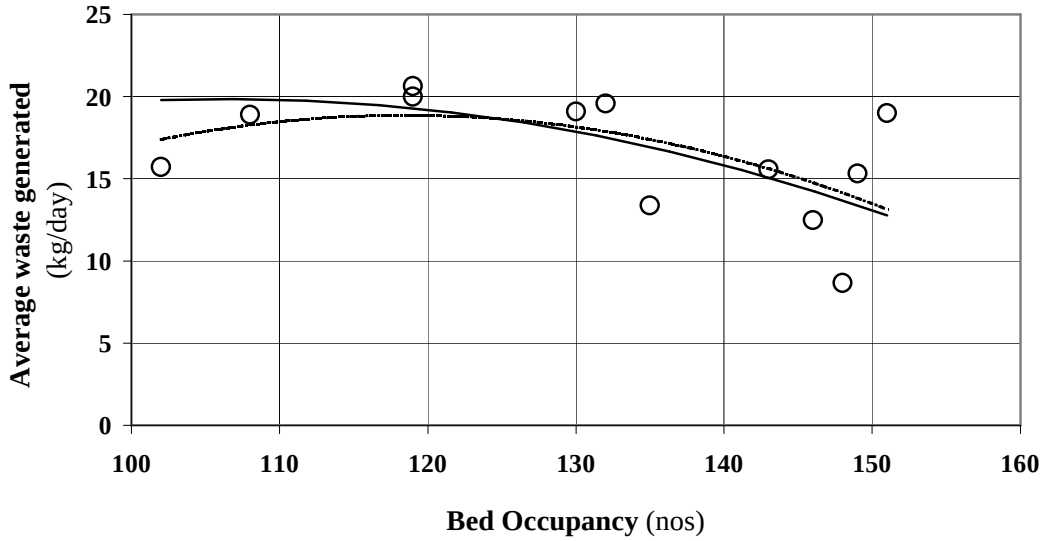


Fig.7.6. Bed Occupancy versus waste generation, DDUH, 2004.

From Figures 7.1, to 7.6 it is also evident that the rate of waste generation per bed from IGMCH, KNH, and DDUH are significantly different for the two consecutive years (2003 and 2004). One of the reasons could be the fact that variation in waste generation rate due to different nature of illness of patients being admitted to hospitals in different seasons. As an illustration, even if, the number of patients is more in winter due common cough and cold, the rate of waste generation may not be very high, on the other hand, the same number of patients with reparatory illness may lead to higher rate of waste generation. Another reason of this could be the improper segregation of the categorized infectious waste in two consecutive years.

7.2.2. Annual Pattern of Waste Generation

As discussed in the previous section, the amount of waste generation as a function of number of beds occupied using a quadratic equation has considerable deviation (large number of data points deviates up to ±30%). This is because of the fact that Equation (6.1) assumes that W_0 is the waste generated per bed per day that remains unchanged throughout the year, and there is no any effect of weather / season on its value. However, in actual case it is observed that the type of illness of patients being admitted to hospitals has a definite seasonal pattern. Asthma and respiratory ailments are triggered during the harvesting seasons. Infectious diseases, diarrhea, dysentery are prevalent between June to September due to contamination. During winter (November to February), a large number of orthopedic cases are also admitted from high altitude regions due to snowfall. Certainly, the rate of waste generation for different ailment is different. With this in view, the correction factor ψ depending on season was introduced in Equation (6.1). Comparison of the actual and predicted values of monthly average biomedical waste generation from three hospitals during 2003-04 is given in Figure 7.7 to 7.12. Point values in these figures represent actual waste generation data (with ±15% error bars) obtained from hospitals and solid lines represent predicted values. It is evident from these figures that baring a few data points most of the predicted values are within ±15% error.

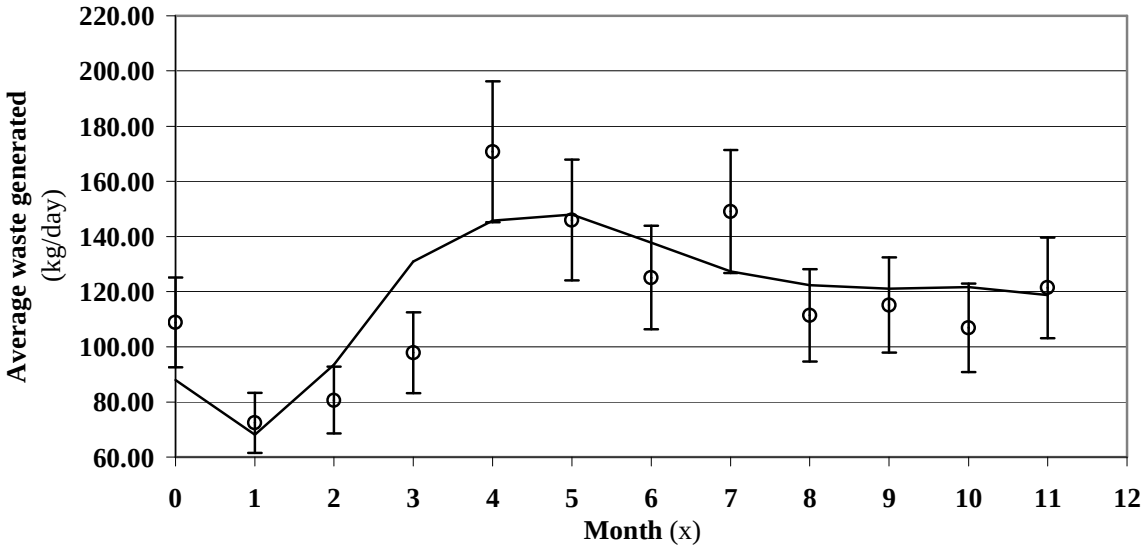


Fig.7.7.Biomedical waste generation at IGMCH, Year 2003

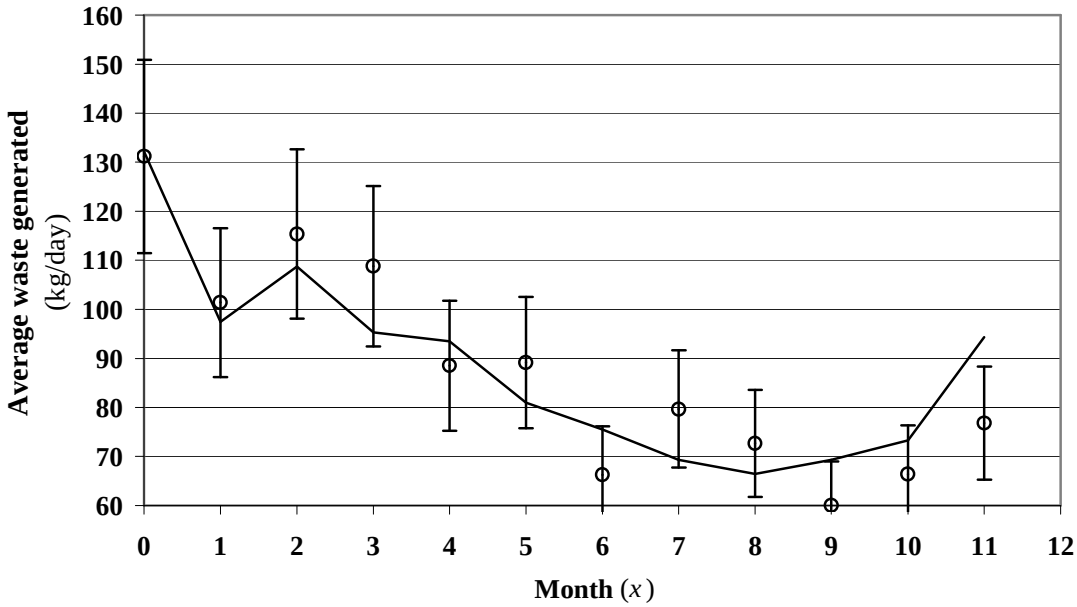


Fig.7.8. Biomedical waste generation at IGMCH, Year 2004.

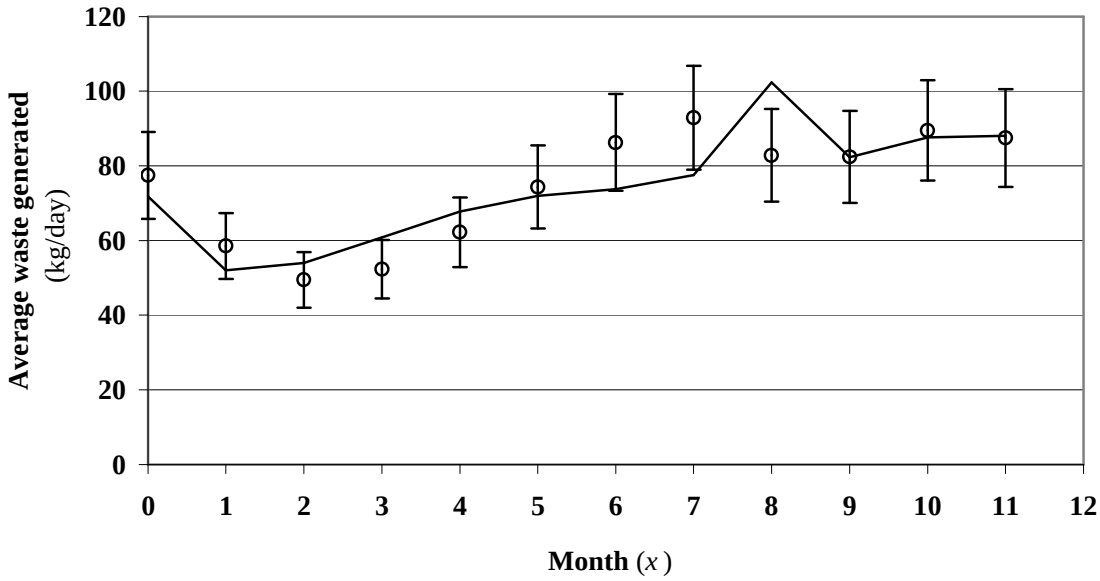


Fig.7.9. Biomedical waste generation at KNH, Year 2003

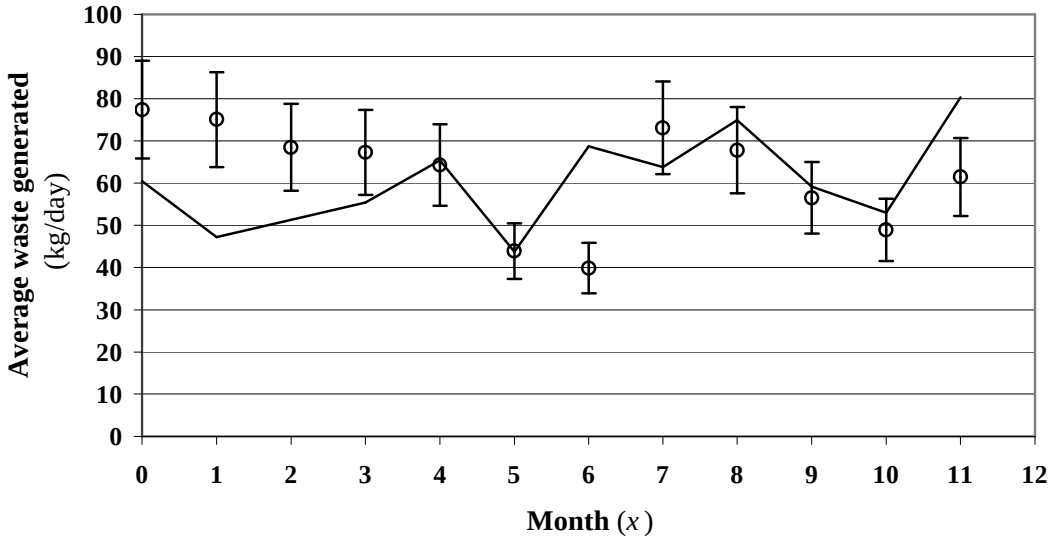


Fig.7.10. Biomedical waste generation at KNH, Year 2004.

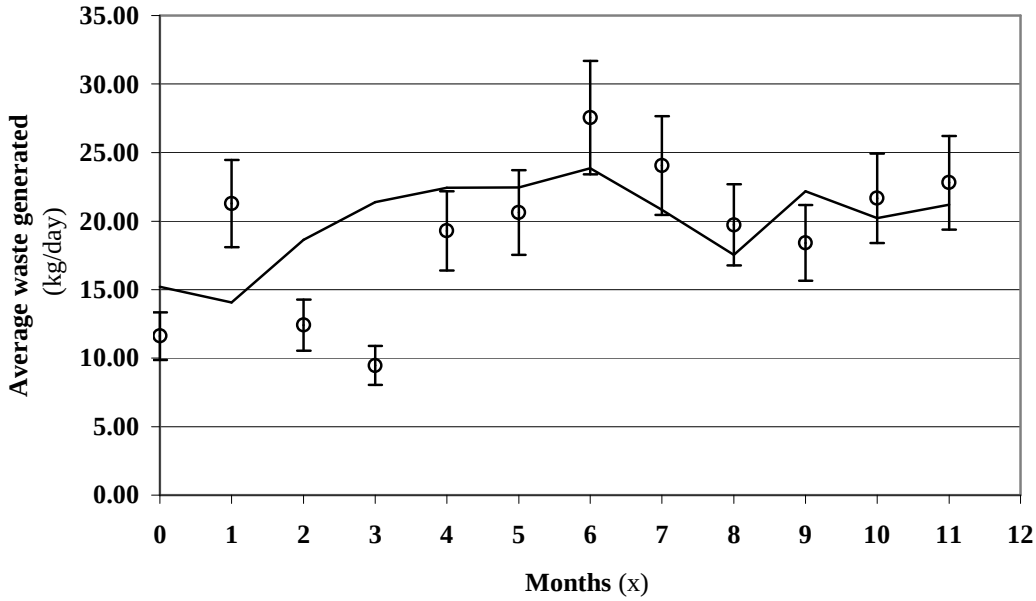


Fig.7.11.Biomedical waste generation at DDUH, Year 2003

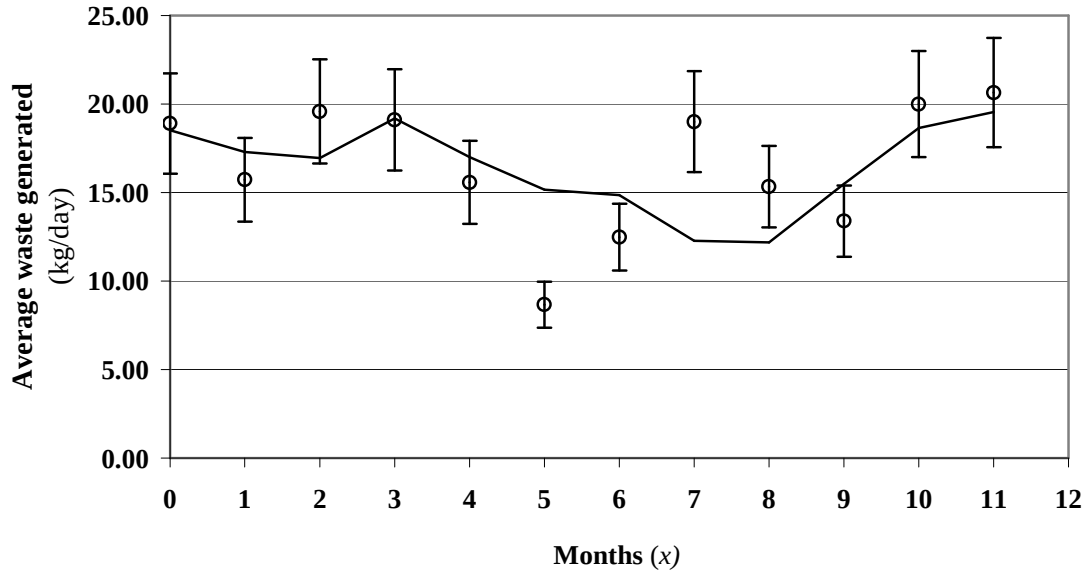


Fig.7.12.Biomedical waste generation at DDUH, Year 2004.

7.3. Seasonal Variation in Waste Generation

The values of correction factor (ψ) are calculated for all the months of a calendar year (x) and plotted as seasonal variation in waste generation (Figures 7.13 to 7.18). The same data is given in Table 7.2 also.

Table 7.2. Values of Correction Factor (ψ) for Seasonal Variation Equation 6.41.

Month	**No** (x)	**Correction Factor (ψ)**					
		IGMC Hospital		**KN Hospital**		**DDU Hospital**	
		2003	**2004**	**2003**	**2004**	**2003**	**2004**
January	0	0.9332568	0.94258937	0.9837529	1.1610186	0.8865940	0.9799196
February	1	0.8737913	0.94606135	0.7432465	0.9301016	0.7906386	0.9177813
March	2	0.9666004	1.07471900	0.7400831	0.9320961	0.8741020	1.0169656
April	3	1.0736276	1.19478856	0.8245484	1.0108678	0.9923638	1.1350842
May	4	1.1263178	1.24164022	0.9143779	1.0837908	1.0699476	1.2000071
June	5	1.1087392	1.20324784	0.9780538	1.1232646	1.0839805	1.1930010
July	6	1.040706	1.10364850	1.0181013	1.1382319	1.0476531	1.1318685
August	7	0.9608998	0.98640225	1.0543854	1.1556958	0.9936788	1.0540873
September	8	0.9099921	0.89805171	1.1074069	1.2022377	0.9577536	0.9999489
October	9	0.9137663	0.87158170	1.1815994	1.2855343	0.9620156	0.9956975
November	10	0.9662398	0.90987895	1.2486254	1.3758752	0.9985051	1.0366693
December	11	1.0127861	0.96919170	1.2306732	1.3876806	1.0126236	1.0704311
January	12	0.9332568	0.94258937	0.9837529	1.1610186	0.8865940	0.9799196

It is observed from table and figures that the seasonal variation for IGMCH (Figures 7.13 and 7.14) and DDUH (Figures 7.17 and 7.18) follows same trend for both the years, whereas the trend for KNH is significantly different from that of IGMCH and DDUH but

has its own trend in both the years. The variation in the trend of KNH may be due to the fact that IGMCH and DDUH have been rendering general type of health care services covering many specialties under one roof whereas the KNH is devoted exclusively to female care. It is evident from these curves that during summer (April to July) at IGMCH and DDUH the rate of waste generation is significantly higher than that in winter (October to February). This may be attributed to the fact that during April and May, number of patients with respiratory problem is more. It is interesting to note that during summer and monsoon (June to September), number of patients with diarrhea and dysentery is more but the rate of biomedical-waste generation is lower than April-May. This is due to the fact that rate of generation of waste of yellow bag category per patient (that needs to be incinerated) is more for patients with respiratory illness than from diarrhea. The second peak between November to February is an indicator of higher biomedical waste generation for orthopedic cases.

In Figures 7.15 and 7.16, values of ψ for KNH are presented. In this case also, like IGMCH and DDUH, the minimum is in the month of February followed by an increase in waste generation rate up to about May-June perhaps due to more number of patients with respiratory illness. However, unlike IGMCH and DDUH, after slight slow down between June-July, it again starts increasing up to December. This increase in biomedical waste generation may be due to higher percentage of first childbirth. The number of first chilled delivery is more during August to December due to fixed season of marriages in the region. The peak season of marriages in the region usually spans from November to March.

For a better comparative study the seasonal variation, parameter (ψ) is plotted on a radial diagram in Figures 7.19 and 7.20.

From the above discussion, it is clear that there is a relation between season and illness, which in turn affect the rate of biomedical-waste generation. In addition, the customs of the society also plays significant role on the waste generation rate, particularly in a female care hospital.

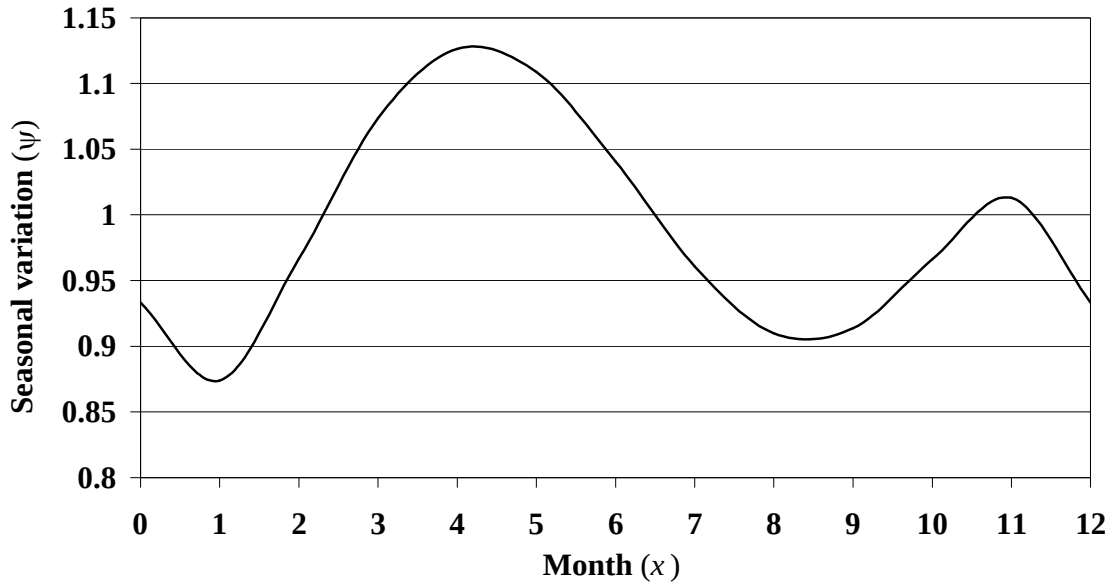


Fig.7.13. Seasonal variation in waste generation, IGMCH, Year 2003.

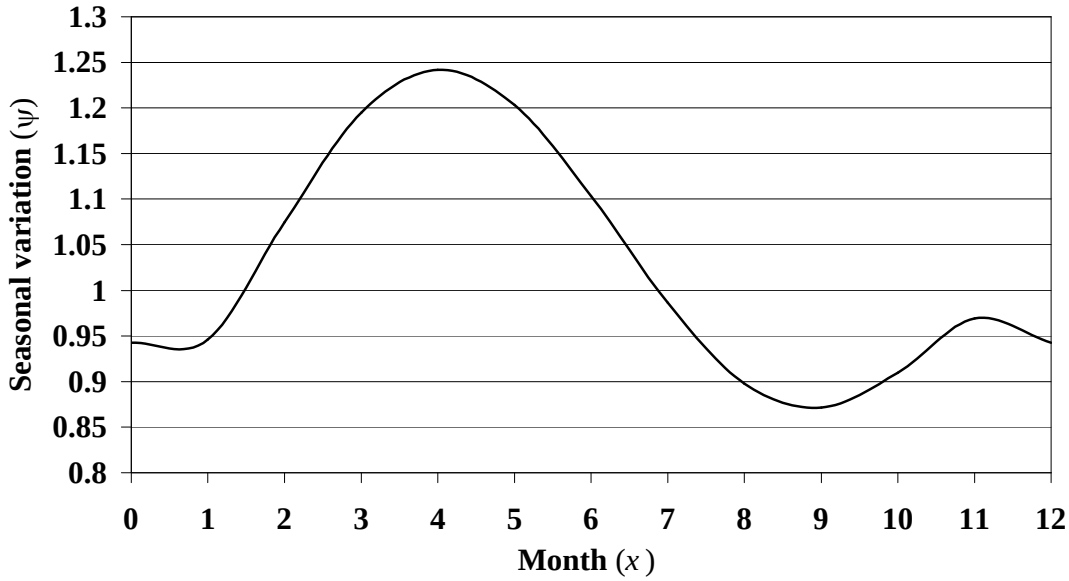


Fig.7.14. Seasonal variation in waste generation, IGMCH, Year 2004.

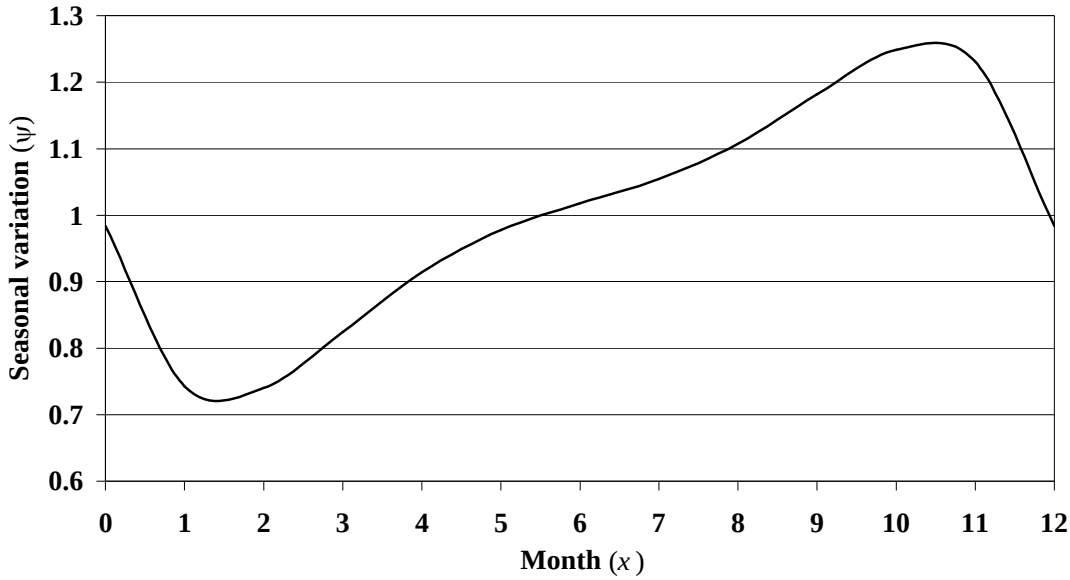


Fig.7.15.Seasonal variation in waste generation, KNH, Year 2003.

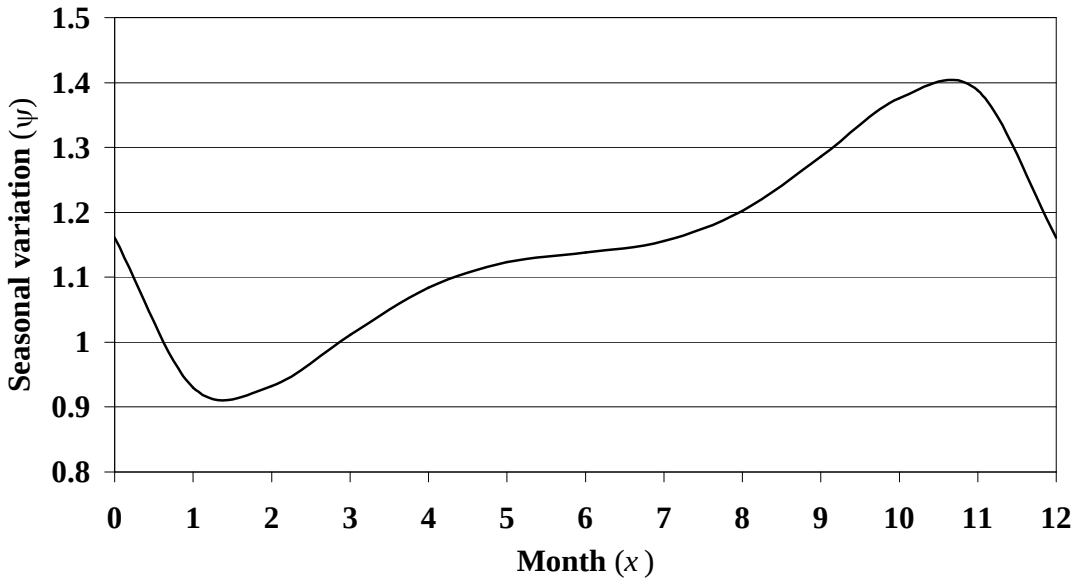


Fig.7.16. Seasonal variation in waste generation, KNH, Year 2004.

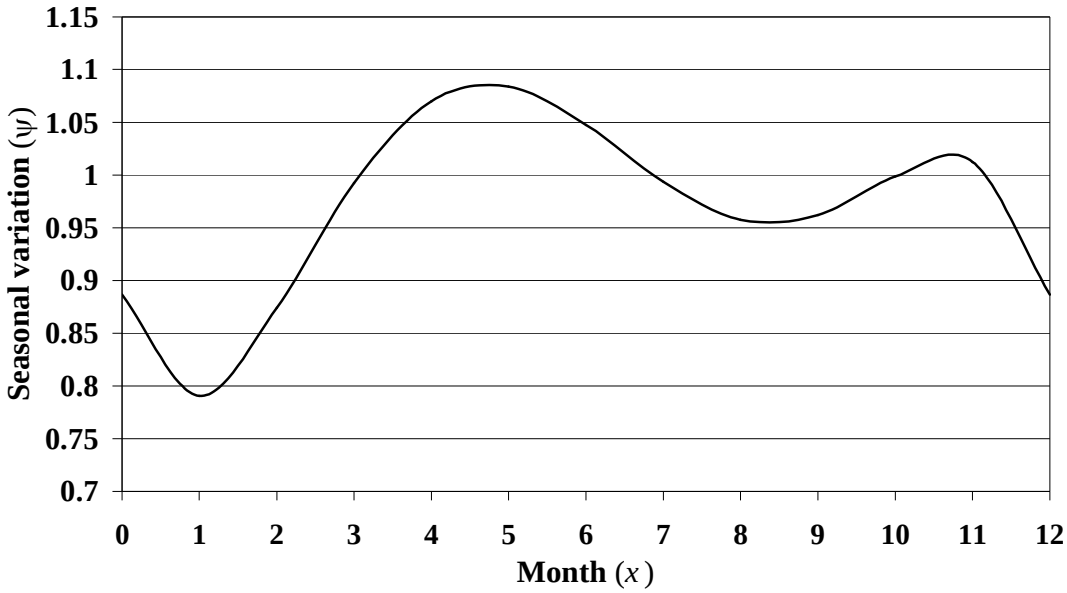


Fig.7.17. Seasonal variation in waste generation, DDUH, Year 2003.

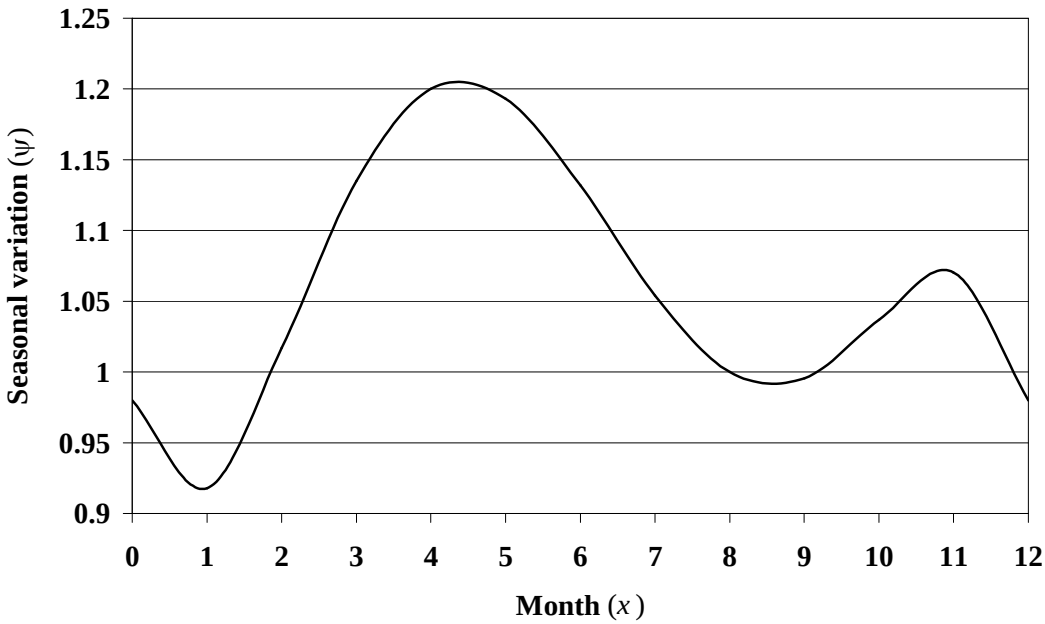


Fig.7.18. Seasonal variation in waste generation, DDUH, Year 2004.

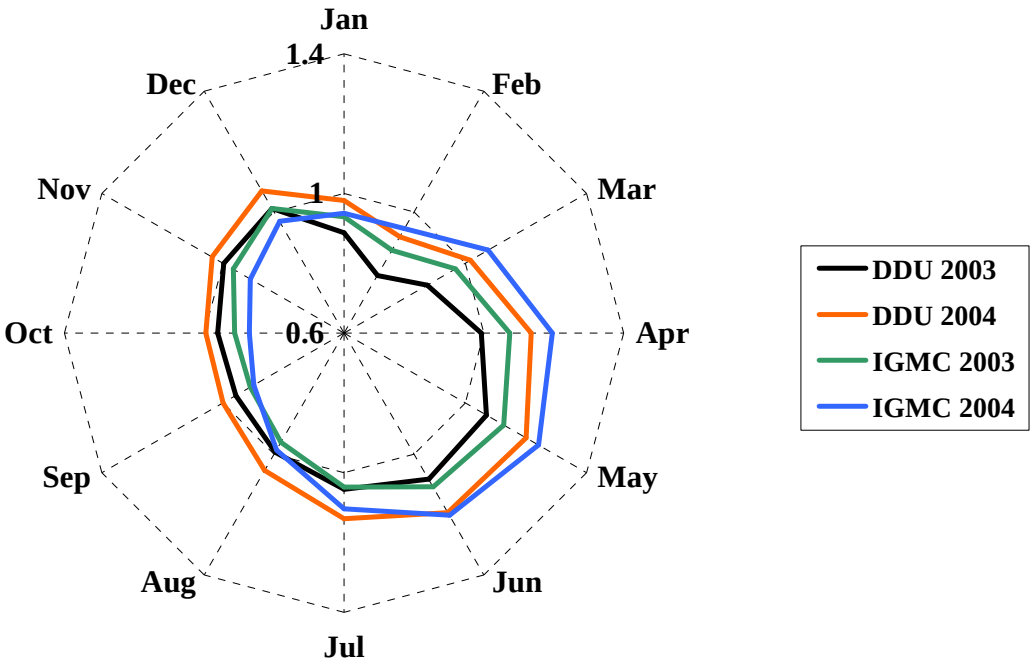


Fig.7.19. Seasonal Variation Curves for IGMCH and DDUH, Shimla

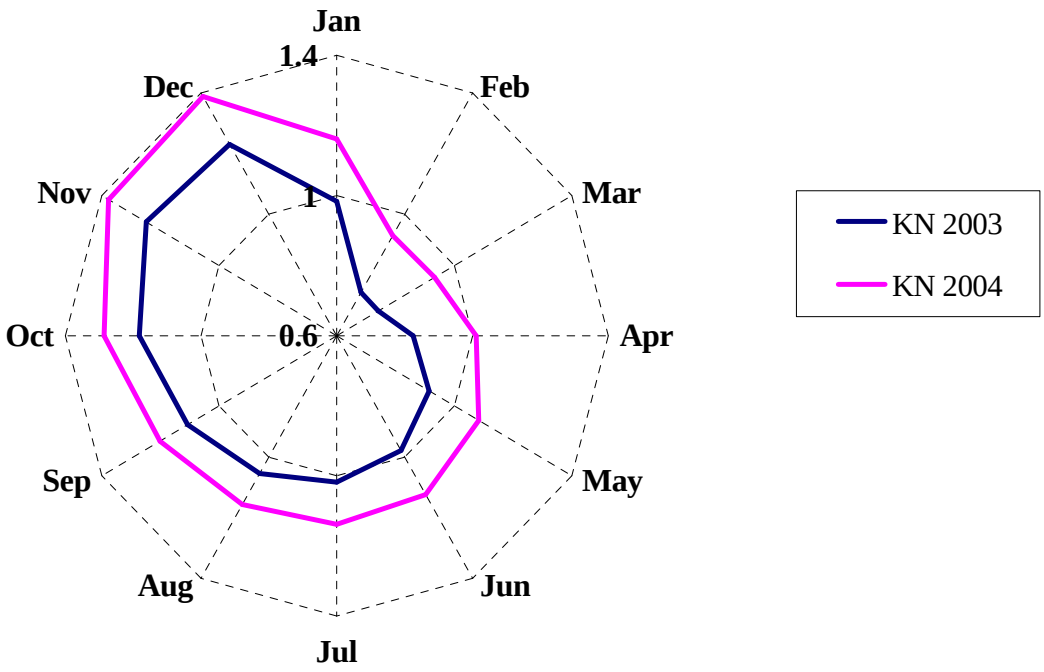


Fig.7.20. Seasonal Variation Curves for KN Hospital, Shimla.

7.4. Application of the Model to CTF Load Prediction

Biomedical waste (yellow bag) collected from different health care establishments has been incinerated in a centralized treatment facility (CTF) established by Municipal Corporation of Shimla since August 2002. All biomedical waste generated in and around Shimla town is transported to this CTF for incineration. As discussed earlier, for the present study data for the waste generated and bed occupancy at various hospitals near Shimla town along with the waste incinerated at the central facility were collected on daily basis. However, due to irregularity in waste removal from hospitals as well as in incineration of waste material at CTF, there was considerable fluctuation in amount of waste incinerated every day. Due to this fact monthly average data for the amount of waste incinerated were considered for the analysis. The average bed occupancy (bed occupied/day) obtained from three hospitals (Indira Gandhi Medical College and Hospital, IGMCH; Kamla Nehru Hospital, KNH; and Deen Dayal Upadhyay Hospital, DDUH) and data of average waste incinerated (kg/day) at CTF for two consecutive years (2003 and 2004) are given in Appendices A and B. In addition, Appendix A also contains biomedical waste generation data from two other sources, i.e., Indus Hospital (IH) and Shimla Sanatorium (SS). The waste incineration data is also shown in Figure 7.21 as point values and those for total of three hospitals considered for the development of model are shown by continuous curves. It is observed that although waste incineration rate trends are significantly different for two consecutive years, there is a close agreement between the trends of waste incinerated and waste generated from three hospitals. This indicates that there exists a correlation between waste received at CTF from all sources and waste generated at three hospitals.

With this in view, the model developed for the prediction of rate of waste generation from hospitals in terms of bed occupancy is applied to predict CTF load. First of all the values of correction factor, $\psi(x)$ (Equation 6.41), are calculated for all the months of a calendar year. After calculating seasonal variation, waste generation rate W (kg/day) was calculated for three hospitals individually with their respective bed occupancy. It is observed that the sum of waste generated from these hospitals is between 10 to 15 % less than the total waste

incinerated at the CTF. This indicates that most of the waste received is from these three hospitals and rest (nearly 15%) is from other two hospitals.

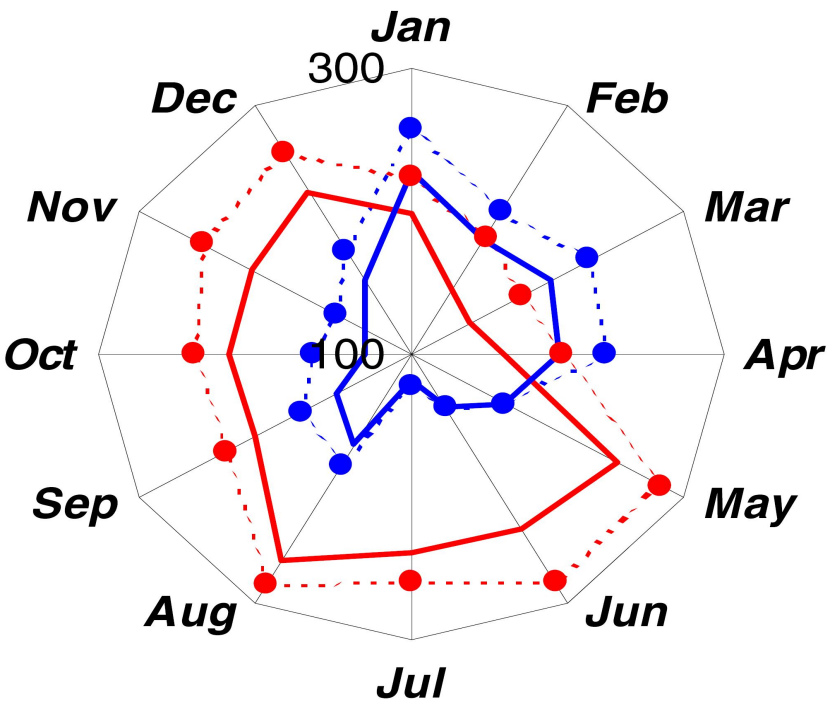


Fig.7.21. Yellow Bags Incinerated at CTF, Shimla (point values). Solid lines represent waste generated from three hospitals, IGMCH, KNH, and DDUH.

Keeping this in mind, amount of waste generated from three hospitals were calculated by using Equations (6.1), (6.2), and (6.41) with coefficients as indicated in Table 7.1. To accommodate waste received from other two hospitals a suitable multiplying factor to be used in conjunction with Equation (6.2), was determined by minimizing root mean square (RMS) value of errors. A correction of 12% and 13% for the year 2003 and 2004, respectively, were found to predict the waste incineration data with RMS value of about 26 (kg/day). A comparison of the total waste predicted for three hospitals by the proposed model, with the correction factor of 1.12 and 1.13 for the year 2003 and 2004 is presented in Figures 7.22, and 7.23.

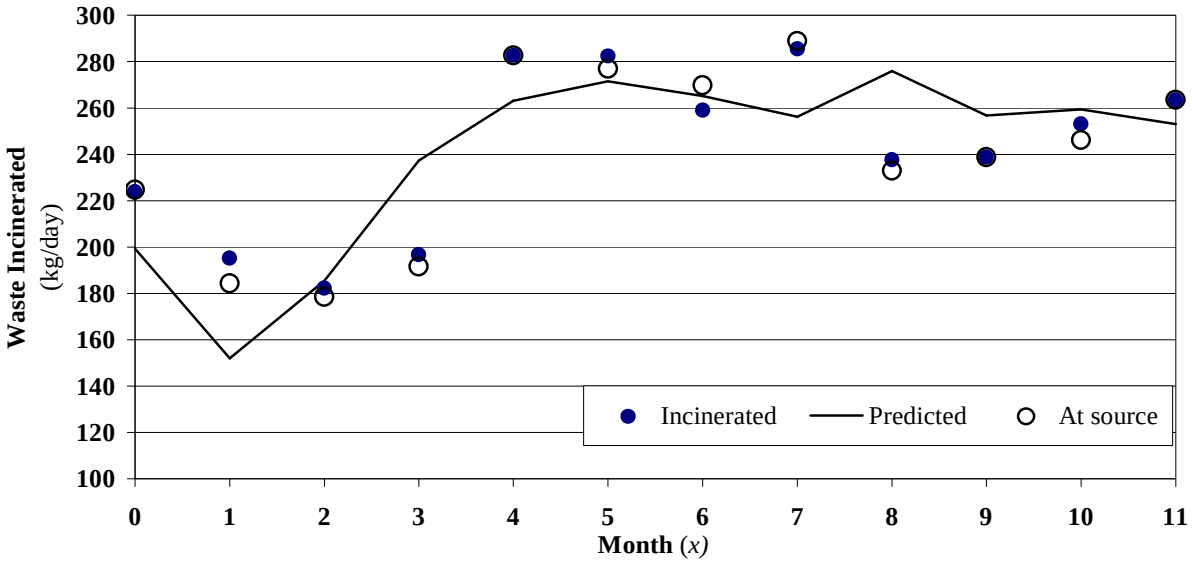


Fig.7.22. Biomedical Waste Incinerated versus Predicted at CTF, MC Shimla, 2003

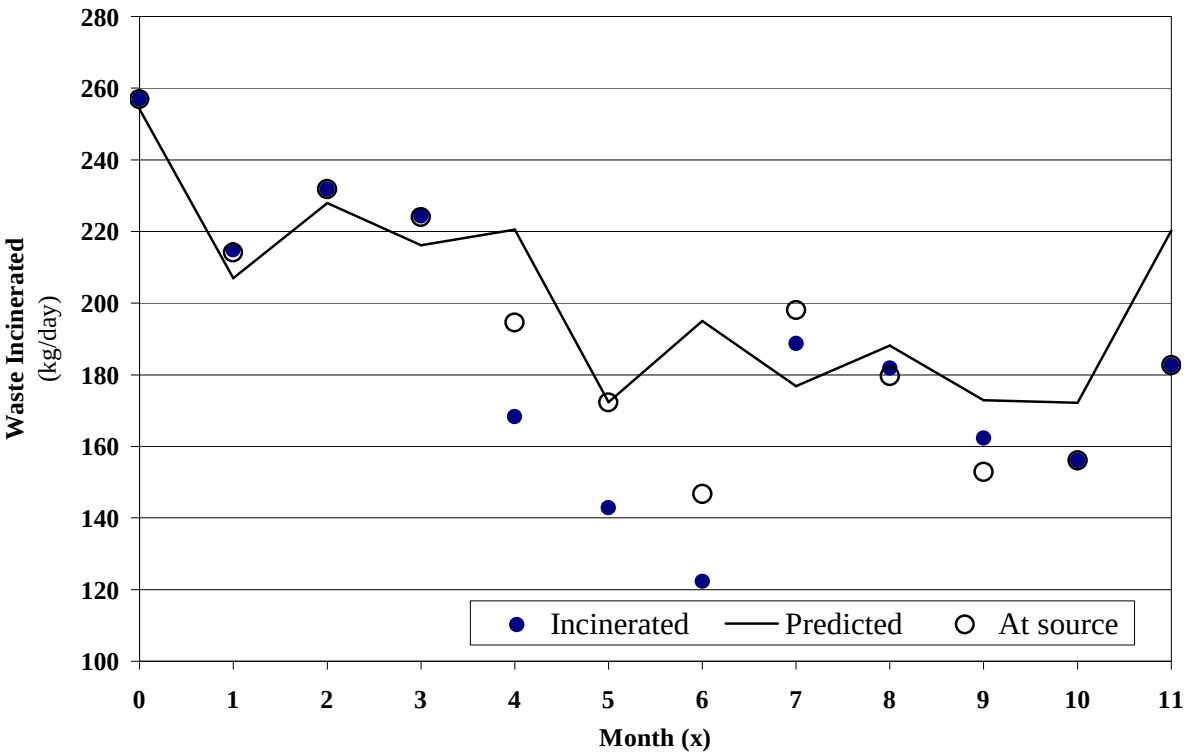


Fig.7.23. Biomedical Waste Incinerated versus Predicted at CTF, MC Shimla, Year 2004

It is not necessary, however, that all three hospitals be considered for predicting waste load on CTF. There are other possible combinations of lesser number of representative hospitals that can be used to predict the amount of waste incinerated equally well. These possible combinations are presented in Table 7.3 along with the correction factor for Equation (6.2) to accommodate waste received from other sources and their respective RMS values. It is evident from this table that the predictions are better in cases when representative group comprise of hospitals of different specialty. Since IGMCH and DDUH are of similar nature, the RMS value of errors is considerably high when waste generated from these hospitals is used to predict load on CTF. Therefore only one of these two hospitals should be considered for the grouping of representative hospitals.

Table 7.3. Groups of Representative Hospitals

S.N.	**Representative Hospitals**	**Year**			
		2003		**2004**	
		Factor	**RMS (kg/day)**	**Factor**	**RMS (kg/day)**
1	IGMCH+KNH+DDUH	1.12	25.77	1.13	26.18
2	IGMCH+KNH	1.21	26.60	1.26	26.02
3	IGMCH+DDUH	1.68	35.71	1.76	24.84
4	KNH+DDUH	2.53	32.61	2.37	46.83
5	IGMCH	1.96	37.67	2.09	25.85
6	KNH	3.18	40.47	3.00	53.16
7	DDUH	11.89	31.30	11.25	37.45

Predictions based on various groups of representative hospitals are given in Figures 7.24 and 7.25 along with the waste incineration data on daily basis. Point values indicate monthly average (kg/day) of waste incinerated at CTF. Different curves correspond to predicted load on CTF using various representative groups of hospitals. Since the three hospitals considered contribute to almost 85% of total waste received at CTF, predictions based on waste generated from these three hospitals is reasonably close to the actual value. It is also evident from these figures that prediction based the three hospitals (dark line) and that based on IGMCH and KNH alone (green line) are almost coinciding for both the years. This indicates that IGMCH (a general hospital) and KNH (a female care hospital) form the representative group of all HCFs near Shimla town.

The waste of yellow bag category incinerated during the two years period (2003 and 2004) at CTF was coming largely from five major hospitals namely, IGMCH, KNH, DDUH, IH, and SS (as listed in Table 5.3). The total bed strength of three major hospitals considered in the present study (IGMCH, KNH, and DDUH) is 1018 beds, whereas bed strength of IH and SS combined is 150 which is 12.8% of the total bed strength of hospitals near Shimla. Perhaps due to this fact there is a difference of 12 and 13% in the total waste incinerated and the predictions based on bed occupancy of three major hospitals. The total waste load on CTF can be predicted equally well by considering only two hospitals viz., IGMCH and KNH. Although the rate of biomedical waste generation is significantly different for different health care facility, the group of two hospitals selected appears to be the representative of all HCFs in and around Shimla town (Figures 7.24 and 7.25). However, one must be careful while selecting group of representative hospitals. In the present case one of the hospitals in the group is a general hospital and other is a female care facility. Thus these two hospitals are the representative of all HCFs near Shimla town that contributes to the waste of yellow bag category to be incinerated.

Thus the proposed mathematical model, that can predict waste load on CTF in terms of bed occupancy, can prove to be a useful tool for waste planners in installation and maintenance of centralized treatment facility of optimum capacity. Such models can also serve authorities to set guidelines and regulations for handling of waste. The other benefits of the proposed model can be in resource planning, especially where waste has to be transported to a large distance for treatment.

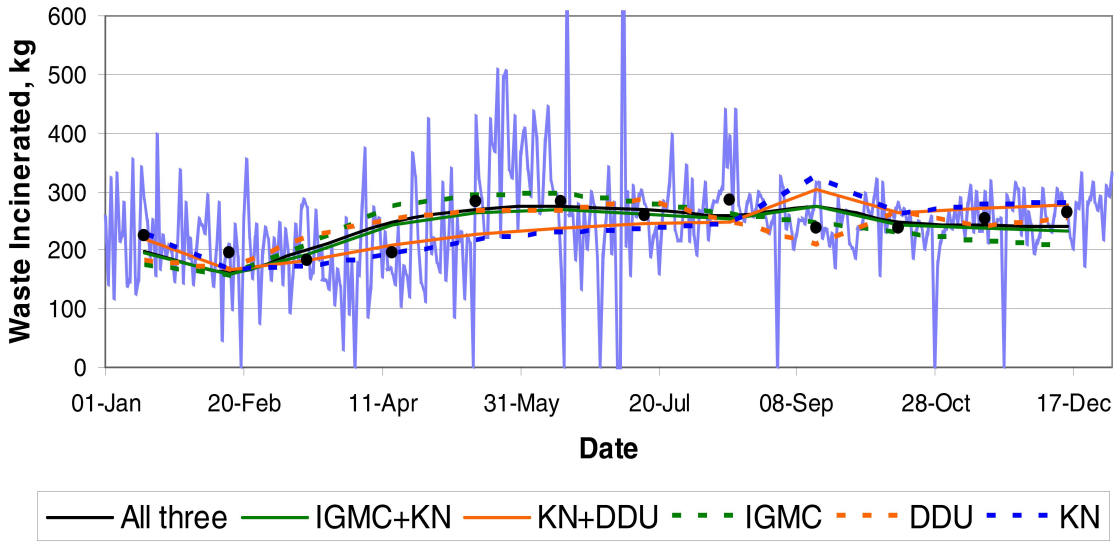


Figure 7.24. Biomedical Waste Incinerated and Predicted at CTF, Shimla (2003)

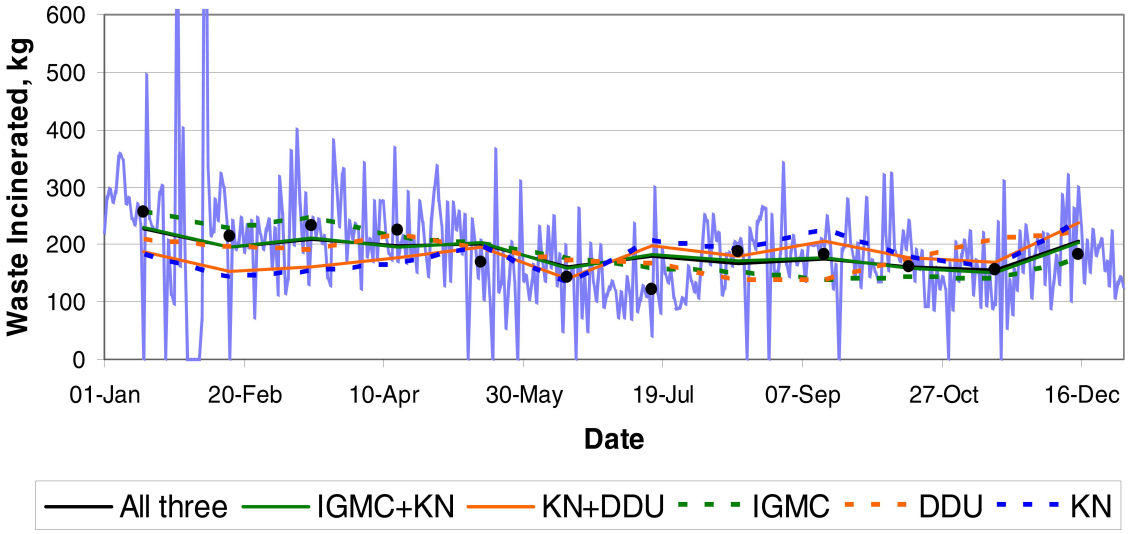


Figure 7.25. Biomedical Waste Incinerated and Predicted at CTF, Shimla (2004)

8. CONCLUSIONS

Medical wastes are classified according to their source, typology and risk factors associated with their handling, storage and ultimate disposal. The segregation of waste at source is the key step. Reduction, reuse and recycling should be considered in proper perspectives. Construction of a Medical waste Materials Recovery Facility (MED-MRF) will reduce the quantities of medical waste requiring landfill or incineration. Risk associated with the handling and disposal of Biomedical Waste, contaminated with body fluid, anatomical waste, etc., is very high.

Biomedical waste originating from, hospital, physicians' clinic, pathological laboratories, etc., is only 10-15% of the total solid waste, but highly dangerous. Safe disposal of these wastes is expensive; therefore small health care facilities cannot afford to handle these wastes. With this in view, Government of India has made clear guidelines for local administrations to provide central treatment facility for safe disposal of biomedical waste.

Incineration used to be the method of choice for most hazardous health care wastes and is still widely used. However, little is documented about the physical health of community members who live close to incinerators. Most hospitals (close to residential area) no longer operate their incinerators due to more stringent regulations regarding air pollution emissions. The use of proper APCDs during incineration would significantly reduce the carcinogenic potencies associated with PAH emissions from HWI/MWI to the residential area, which was not installed at the site of case study of CTF.

Health care professionals in hospitals have been concerned about the proper management of infectious waste because of aesthetic concerns, state regulations, and the fact that certain wastes have been associated with transmission of infection or injury. The purpose has been to rationalize waste management, reducing the amount of waste needing special treatment and lowering costs, while at the same time maintaining occupational safety and preventing environmental hazards.

The fundamental information for selecting and designing the most efficient treatment method of hospital waste is obtained by means of waste composition analysis. The final choice of treatment system should be made carefully, on the basis of various factors, many of which depend on local conditions including the amount and composition of waste generated, available space, regulatory approval, public acceptance, and cost.

There is a growing interest in the treatment of ash because of the potential toxicity of hazardous heavy metals. Solidification of fly ash coming from a biomedical waste incineration plant in cementitious matrices reduce the leachability of the heavy metals in this material so as to permit its disposal in a sanitary landfill requiring only a low degree of environmental protection. High temperature melting treatment of incinerated hospital waste ash produced stabilized product, which is proven to be non-hazardous.

Municipal Corporations, State Governments, and the Central Government need to plan and construct centralized facilities to recycle, treat, and dispose of biomedical waste. Large-scale enterprises should be encouraged to recycle, to treat, and to dispose of wastes by means of constructing facilities, and to have extra capacities available on a reasonable fee. Partnerships with health care organizations, energy service providers, equipment vendors and industry associations are required as the way to optimize energy use and reduce costs. The reduction of hospital waste, the control of polluting and toxic emissions, the avoidance of unnecessary disinfection procedures and disposables, and the implementation of energy and water saving technologies are practicable measures in hospital ecology.

For planning and construction of facilities, it is required to have a tool to estimate rate of biomedical waste generation. Present thesis embodies such a tool to predict biomedical waste generation throughout the year. The rate of biomedical waste generation depends strongly upon nature of illness of patients being admitted to hospitals, and nature of illness is affected by season of the year. This is why a definite trend in waste generation rate with seasonal variation as well as distinctive specialty of health care facility is observed.

After calculating seasonal variation, waste generation rate W (kg/day) was calculated for three hospitals (IGMCH, KNH, and DDUH) individually with their respective occupancy. It is observed that the sum of waste generated from these hospitals is between 10 to 15% less than the total waste incinerated at the CTF. This indicates that most of waste received is from these three hospitals and rest (nearly 15%) is from other two hospitals (IH & SS). The proposed model enables waste managers to make long term strategies by comparing among several waste management options and waste treatment technologies throughout the year for a given bed occupancy. It can be used either at a regional or national level for the purpose of setting guidelines for biomedical waste treatment. It can also be used at local level with the purpose of choosing a more environmentally beneficial strategy. The other benefits of the proposed model can be in reducing the risk in biomedical waste handling, especially where waste has to be transported to a large distance for incineration by proper planning during peak season.

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APPENDICES

Appendix 'A'
BIOMEDICAL WASTE GENERATION AT DIFFERENT HEALTH CARE FACILITIES.

TABLE A-1. BIOMEDICAL WASTE GENERATED AT IGMC HOSPITAL SHIMLA, YEAR 2003.

Number of Beds: 738.
Type of Waste: Yellow Bag.

Waste Generated (Kgs/Day)												
Year 2003												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	112	95	92	0	128	187	108	166	0	119	115	126
2	95	90	60	79	75	180	166	106	181	109	145	106
3	190	85	90	0	194	178	81	97	120	147	87	82
4	0	113	93	232	82	162	142	123	88	99	128	96
5	207	53	146	223	158	248	0	135	120	118	115	123
6	121	108	80	40	238	231	0	157	114	139	135	154
7	114	102	150	0	50	70	390	96	89	149	102	129
8	167	41	78	223	117	175	140	112	97	88	98	137
9	58	64	30	138	115	281	122	166	112	163	18	124
10	66	70	72	104	199	267	70	172	98	121	132	149
11	200	105	128	35	42	210	138	156	120	153	92	159
12	45	21	92	80	135	180	124	210	90	131	122	140
13	57	84	135	80	182	188	166	250	127	122	102	146
14	126	101	125	50	0	124	171	206	131	129	92	122
15	96	76	10	91	324	87	138	190	153	139	132	109
16	132	41	50	73	167	0	180	140	119	129	93	88
17	74	88	80	142	207	363	52	220	102	107	165	79
18	100	70	98	53	130	129	94	179	113	112	99	129
19	48	0	80	0	80	160	103	120	127	122	120	92
20	150	0	60	65	298	93	75	96	117	78	110	147
21	83	201	44	0	257	162	98	146	96	114	90	86
22	139	113	87	328	314	48	147	147	71	125	0	127
23	98	60	48	244	320	134	156	132	147	124	140	121
24	123	80	68	82	137	102	128	149	136	110	127	139
25	121	113	86	100	287	95	180	150	141	112	117	107
26	78	20	76	0	290	175	102	139	169	97	137	119
27	100	109	77	72	165	130	97	160	119	124	129	117
28	217	144	0	262	125	94	106	180	107	0	129	96
29	47	-	146	134	170	0	190	96	110	79	147	129
30	113	-	40	105	135	72	122	135	139	106	96	149
31	98	-	80	-	171	-	92	90	-	103	-	137
Sum	3375	2247	2501	3035	5292	4525	3878	4621	3453	3568	3314	3764
Avg	108.871	80.250	80.677	101.167	170.710	150.833	125.097	149.065	115.100	115.097	110.467	121.419

TABLE A-2. BIOMEDICAL WASTE GENERATED AT IGMC HOSPITAL SHIMLA, YEAR 2004.

Number of Beds: 738.

Type of Waste: Yellow Bag.

Waste Generated (Kgs/Day)												
Year 2004												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	88	0	94	112	138	43	79	57	63	83	88	64
2	137	0	103	0	78	75	78	79	50	67	71	93
3	139	0	0	208	135	116	61	76	60	48	85	51
4	120	0	189	78	68	58	68	114	65	0	82	75
5	139	0	149	107	146	132	60	110	50	63	89	58
6	156	538	45	82	127	123	85	116	58	120	75	56
7	186	185	0	129	123	68	72	94	45	64	48	48
8	170	90	247	79	59	180	0	60	25	48	76	70
9	96	96	88	141	136	148	178	56	85	125	58	139
10	114	128	135	149	0	140	69	62	65	54	24	78
11	137	108	109	89	67	101	42	65	103	71	93	153
12	117	179	88	88	140	89	82	77	130	57	52	54
13	133	98	132	89	85	30	85	88	46	95	59	98
14	127	101	73	162	90	96	90	79	113	55	33	74
15	0	0	129	83	115	116	0	71	123	95	36	149
16	270	117	124	90	40	65	158	36	133	36	124	105
17	132	90	117	94	92	93	71	72	65	50	0	52
18	137	137	98	84	59	0	58	0	52	67	119	86
19	103	102	108	143	0	160	68	91	90	60	28	65
20	123	82	119	93	180	41	47	96	0	80	65	109
21	149	92	65	79	42	76	67	64	85	19	34	67
22	147	78	0	75	75	48	72	63	0	25	75	76
23	0	103	279	143	141	140	35	129	137	76	61	85
24	0	0	139	123	11	87	32	137	67	36	110	65
25	0	140	182	94	97	52	42	98	62	70	45	71
26	0	119	149	73	70	116	52	75	67	39	120	47
27	740	109	221	124	120	107	56	80	72	100	76	94
28	0	115	86	158	0	54	48	35	55	52	41	42
29	288	133	112	165	175	56	65	0	67	0	28	48
30	119	-	102	130	63	65	62	0	147	70	97	55
31	0	-	95	-	72	-	72	290	-	35	-	54
Sum	4067	2940	3577	3264	2744	2675	2054	2470	2180	1860	1992	2381
Avg	131.194	101.379	115.387	108.800	88.516	89.167	66.258	79.677	72.667	60.000	66.400	76.806

TABLE A-3. BIOMEDICAL WASTE GENERATED AT K N HOSPITAL SHIMLA, YEAR 2003.

Number of Beds: 130.

Type of waste: Yellow Bag.

Waste Generated (Kgs/Day)												
Year 2003												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	122	80	53	0	0	150	66	96	0	67	68	86
2	40	17	35	54	78	147	112	72	110	90	72	80
3	128	80	50	85	67	75	60	58	140	120	102	61
4	35	83	36	0	46	65	89	88	96	102	92	71
5	75	60	42	106	25	125	0	55	86	79	80	49
6	60	48	20	20	56	96	0	110	72	97	98	94
7	84	77	40	72	0	120	208	61	79	136	109	82
8	80	54	60	0	92	60	90	92	89	47	81	49
9	67	63	37	86	80	80	135	72	87	106	103	59
10	60	75	65	0	0	122	42	72	92	69	116	73
11	100	95	42	104	50	65	108	92	80	62	88	94
12	36	14	50	103	48	25	85	45	130	102	113	87
13	60	30	71	35	19	64	70	129	90	91	88	97
14	148	50	107	45	0	72	80	96	102	104	102	90
15	136	50	95	35	58	40	106	160	124	98	109	99
16	166	40	65	58	79	0	44	90	92	67	72	72
17	80	89	0	52	40	175	97	145	72	112	96	66
18	110	73	127	0	34	66	78	75	91	96	82	90
19	68	0	40	152	102	52	86	102	93	106	70	125
20	148	107	47	55	58	38	46	122	61	64	91	124
21	46	74	79	68	42	58	68	92	86	86	113	44
22	47	70	39	37	12	36	96	96	65	71	0	97
23	35	50	38	0	115	96	66	86	90	70	97	96
24	52	80	45	71	40	42	140	75	70	47	103	112
25	40	57	0	0	132	120	170	120	90	78	87	117
26	40	25	53	105	165	40	92	102	61	109	109	94
27	62	42	32	20	98	87	84	70	54	79	120	102
28	71	55	0	65	112	40	66	122	71	0	45	72
29	60	-	87	49	106	0	45	90	49	49	113	106
30	100	-	20	91	55	74	166	75	62	65	66	90
31	45	-	58	-	120	-	79	120	-	85	-	134
Sum	2401	1638	1533	1568	1929	2230	2674	2880	2484	2554	2685	2712
Avg	77.452	58.500	49.452	52.267	62.226	74.333	86.258	92.903	82.800	82.387	89.500	87.484

TABLE A-4. BIOMEDICAL WASTE GENERATED AT K N HOSPITAL SHIMLA, YEAR 2004.

Number of Beds: 130.

Type of Waste: Yellow bag.

Waste Generated (Kgs/Day)												
Year 2004												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	72	0	31	63	76	47	37	38	70	42	49	72
2	87	0	79	67	38	59	40	64	66	48	29	76
3	100	0	69	82	110	36	0	132	98	37	52	53
4	96	0	72	50	48	28	32	96	70	83	64	91
5	102	0	61	74	98	83	0	33	63	33	48	30
6	144	485	35	47	86	33	58	98	46	147	84	45
7	113	98	88	91	114	56	27	76	85	82	32	65
8	127	85	68	37	96	38	55	103	65	64	39	0
9	120	78	50	82	98	0	48	38	48	135	45	95
10	110	92	138	59	0	96	0	42	72	70	50	81
11	49	88	80	76	95	20	62	36	65	68	69	102
12	66	88	60	42	67	83	27	42	42	60	23	35
13	100	137	98	42	103	18	27	47	88	71	48	107
14	66	95	28	142	40	83	28	57	67	78	22	47
15	0	0	68	46	77	22	0	86	60	80	24	104
16	137	69	74	50	50	83	123	108	85	84	65	80
17	67	75	59	67	80	46	28	47	76	39	0	45
18	52	27	99	43	38	0	0	0	74	54	128	67
19	69	96	59	97	0	52	96	66	58	48	26	48
20	54	68	39	42	152	30	63	88	0	63	34	64
21	82	98	40	62	60	58	52	82	63	32	32	52
22	97	68	78	38	41	0	0	127	135	50	42	69
23	0	97	57	79	35	62	55	68	124	62	37	74
24	121	48	120	66	42	32	112	80	48	28	62	49
25	67	70	0	67	0	48	38	112	84	40	54	52
26	59	59	122	33	134	18	43	59	42	48	70	58
27	52	42	67	72	0	80	33	99	66	0	57	73
28	69	45	48	83	0	27	52	87	37	36	27	45
29	58	69	88	121	103	37	36	87	58	0	82	39
30	63	-	62	99	56	42	40	128	80	43	74	43
31	0	-	86	-	55	-	24	40	-	28	-	44
Sum	2399	2177	2123	2019	1992	1317	1236	2266	2035	1753	1468	1905
Avg	77.387	75.069	68.484	67.300	64.258	43.900	39.871	73.097	67.833	56.548	48.933	61.452

TABLE A-5. BIOMEDICAL WASTE GENERATED AT DDU HOSPITAL SHIMLA, YEAR 2003.

Number of Beds: 150.

Type of Waste: Yellow Bag.

Waste Generated (Kgs/Day)												
Year 2003												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	7	19	20	0	14	35	24	32	0	22	23	22
2	0	13	20	5	8	39	28	22	19	26	18	25
3	5	10	25	0	18	34	26	16	24	11	24	21
4	0	17	10	14	0	31	13	26	28	28	19	20
5	19	15	30	16	10	29	0	40	21	29	22	21
6	14	30	15	5	14	9	0	28	23	29	25	29
7	15	70	10	5	10	30	196	26	21	19	18	17
8	11	38	10	16	17	19	26	28	21	12	19	22
9	0	11	5	5	0	8	12	20	24	22	26	17
10	0	20	10	25	10	27	22	15	28	19	28	11
11	29	39	20	0	10	7	22	25	27	21	22	24
12	23	11	10	8	12	5	26	25	29	16	29	20
13	9	11	12	15	5	10	28	40	21	20	23	24
14	16	13	14	15	0	25	26	20	19	12	18	20
15	14	18	10	0	17	18	18	20	21	12	26	23
16	24	11	7	0	0	0	24	15	29	18	19	22
17	12	27	10	0	10	42	18	35	26	24	23	22
18	10	18	10	0	20	17	28	17	19	18	28	31
19	14	0	20	5	12	18	31	20	16	11	24	33
20	20	70	40	10	25	29	23	14	14	15	19	28
21	6	40	7	11	38	17	27	21	18	11	21	12
22	7	9	8	0	19	16	23	27	16	24	0	18
23	7	20	20	29	40	13	29	22	27	21	27	31
24	8	30	15	17	11	22	26	27	14	18	18	28
25	0	0	0	10	37	14	28	14	9	17	27	21
26	12	10	4	10	0	48	22	25	21	20	29	24
27	30	12	0	8	27	29	17	29	19	23	16	35
28	0	14	6	41	42	16	21	29	7	0	18	19
29	5	-	0	0	118	0	20	23	14	19	21	29
30	28	-	10	14	19	12	28	19	17	19	20	24
31	15	-	7	-	35	-	22	26	-	15	-	14
Sum	360	596	385	284	598	619	854	746	592	571	650	707
Avg	11.613	21.286	12.419	9.467	19.290	20.633	27.548	24.065	19.733	18.419	21.667	22.806

TABLE A-6. BIOMEDICAL WASTE GENERATED AT DDU HOSPITAL SHIMLA, YEAR 2004.

Number of Beds: 150.

Type of Waste: Yellow Bag

Waste Generated (Kgs/Day)												
Year 2004												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	22	0	12	25	18	12	17	12	12	0	27	21
2	21	0	12	23	12	0	0	22	12	23	14	24
3	12	0	14	18	27	12	10	22	28	13	23	16
4	16	0	27	26	18	13	0	16	26	17	24	19
5	21	48	7	9	27	16	12	13	28	8	17	0
6	21	29	15	14	12	14	0	17	30	14	26	21
7	27	22	26	22	20	12	12	19	28	19	21	25
8	16	17	19	22	27	12	15	45	16	12	24	23
9	27	22	20	26	16	10	18	18	23	18	29	24
10	21	23	50	29	0	12	12	12	15	27	16	27
11	22	19	40	14	0	5	0	18	13	15	28	29
12	23	18	16	16	37	11	8	16	0	13	17	0
13	8	28	23	14	12	0	0	11	17	15	26	34
14	16	14	7	24	10	18	0	12	19	17	18	26
15	0	0	11	12	15	0	25	28	0	19	15	18
16	32	14	14	15	14	0	10	20	10	16	21	22
17	12	12	17	19	18	20	8	18	28	18	0	19
18	16	11	21	15	11	0	12	0	17	32	31	23
19	24	18	11	20	0	18	12	27	0	12	0	15
20	24	19	24	15	32	0	18	23	0	15	19	22
21	21	21	12	21	13	12	12	18	13	13	11	25
22	27	15	18	14	15	0	62	28	19	0	20	24
23	0	13	22	21	10	0	12	17	0	14	15	21
24	37	11	27	19	0	13	10	28	26	6	26	18
25	27	14	29	20	36	0	9	14	0	8	20	20
26	19	16	24	15	0	0	8	21	8	10	19	23
27	16	16	16	23	15	12	6	25	19	21	29	17
28	30	25	16	20	0	8	25	18	17	8	18	19
29	16	11	11	25	32	18	18	13	18	0	29	18
30	12	-	18	17	19	12	13	28	18	12	17	21
31	0	-	28	-	17	-	23	10	-	0	-	26
Sum	586	456	607	573	483	260	387	589	460	415	600	640
Avg	18.903	15.724	19.581	19.100	15.581	8.667	12.484	19.000	15.333	13.387	20.000	20.645

TABLE A-7. BIOMEDICAL WASTE GENERATED AT INDUS HOSPITAL SHIMLA, YEAR 2003.

Number of Beds: 100.

Type of Waste: Yellow Bag.

Waste Generated (Kgs/Day)												
Year 2003												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0	15	46	0	25	15	28	16	0	16	16	16
2	5	11	18	27	0	17	19	13	5	9	14	17
3	0	11	30	12	16	25	12	13	13	14	13	17
4	25	21	31	14	10	15	25	17	16	16	12	10
5	10	15	15	7	12	21	0	20	19	11	18	16
6	8	24	17	10	26	47	0	9	11	12	18	10
7	5	25	17	17	10	24	20	16	6	9	12	16
8	15	26	20	19	7	13	20	19	11	6	12	19
9	9	0	8	13	20	12	22	16	15	13	19	19
10	11	17	7	24	5	17	14	10	18	12	18	9
11	15	29	29	14	8	23	26	15	8	11	16	13
12	10	0	15	10	8	25	21	15	12	9	19	15
13	12	19	30	16	5	20	19	15	5	14	11	11
14	28	19	18	18	0	20	22	12	7	16	11	18
15	26	21	46	12	15	12	16	10	7	10	18	16
16	19	7	12	10	10	0	19	5	11	32	15	18
17	13	42	30	10	17	52	21	14	11	12	18	18
18	20	15	15	15	21	28	22	5	7	10	19	15
19	18	0	18	0	27	12	18	9	11	8	14	10
20	20	32	30	12	27	18	14	7	7	12	18	17
21	14	22	10	14	20	22	18	8	15	8	14	16
22	9	13	4	0	10	18	16	13	9	16	0	16
23	16	9	18	12	22	17	16	7	14	12	10	21
24	13	11	38	20	20	1	15	7	11	14	17	17
25	13	25	13	16	17	16	18	9	11	9	21	18
26	16	20	14	0	22	27	16	11	10	9	19	16
27	8	8	12	5	30	12	20	15	6	16	21	22
28	29	24	8	22	20	18	23	13	9	0	14	17
29	19	-	14	10	15	0	12	11	6	13	9	23
30	20	-	12	0	16	17	19	5	11	14	15	13
31	11	-	15	-	19	-	14	9	-	16	-	28
Sum	437	481	610	359	480	564	545	364	302	379	451	507
Avg	14.097	17.179	19.677	11.967	15.484	18.800	17.581	11.742	10.067	12.226	15.033	16.355

TABLE A-8. BIOMEDICAL WASTE GENERATED AT INDUS HOSPITAL SHIMLA, YEAR 2004.

Number of Beds: 100.

Type of Waste: Yellow Bag

Waste Generated (Kgs/Day)												
Year 2004												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	19	0	10	13	11	15	9	18	10	0	18	15
2	18	0	16	17	15	10	16	14	0	23	13	17
3	31	0	15	17	13	16	21	19	0	13	9	9
4	28	0	16	12	19	11	14	18	35	17	27	17
5	17	0	20	12	10	18	17	24	14	8	7	0
6	13	22	8	12	17	23	18	12	18	14	19	0
7	18	16	18	16	18	20	10	14	17	19	10	28
8	12	11	13	11	14	10	15	9	22	12	18	19
9	16	14	30	14	15	13	23	0	14	18	0	16
10	16	18	37	20	0	24	19	0	15	27	0	22
11	19	12	20	19	24	14	26	56	13	15	19	19
12	12	22	10	18	26	17	11	42	0	13	0	11
13	12	19	18	15	21	16	17	8	17	15	12	14
14	12	11	8	18	9	15	19	43	19	17	9	24
15	0	0	12	17	20	19	16	15	0	19	10	13
16	27	12	16	17	12	25	10	17	10	16	14	13
17	21	9	12	17	11	9	27	10	18	18	0	0
18	11	10	16	10	14	0	12	0	17	32	19	16
19	17	17	10	17	9	19	9	21	0	12	0	12
20	15	6	11	12	13	17	13	0	0	15	11	14
21	19	8	9	16	14	11	12	22	13	13	0	17
22	19	18	13	11	18	13	15	13	19	0	10	15
23	0	11	10	16	12	10	20	21	0	14	0	18
24	0	6	0	15	17	15	14	0	26	6	12	11
25	0	10	0	13	9	21	17	37	0	8	15	15
26	0	10	13	9	10	9	21	0	8	10	13	0
27	0	12	14	14	11	13	12	27	19	21	22	22
28	47	20	10	18	0	14	17	0	17	8	12	0
29	17	17	13	13	18	16	19	27	18	0	18	15
30	14	-	12	15	12	11	9	12	18	12	10	12
31	0	-	14	-	10	-	14	0	-	0	-	0
Sum	450	311	424	444	422	444	492	499	377	415	327	404
Avg	14.516	10.724	13.677	14.800	13.613	14.800	15.871	16.097	12.567	13.387	10.900	13.032

TABLE A-9. BIOMEDICAL WASTE GENERATED AT SANATORIUM SHIMLA, YEAR 2003.

Number of Beds: 50.

Type of Waste: Yellow Bag.

Waste Generated (Kgs/Day)												
Year 2003												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	15	11	8	0	10	15	22	9	0	12	12	14
2	0	9	15	12	0	22	17	11	9	11	15	15
3	0	13	25	60	20	23	14	7	9	5	8	13
4	35	16	8	15	10	19	10	12	8	20	16	17
5	20	0	14	21	18	14	0	15	12	16	12	14
6	13	17	9	10	5	12	0	11	9	10	12	17
7	7	19	18	42	15	17	20	19	7	8	8	12
8	7	20	25	15	20	10	31	15	7	4	13	16
9	7	0	12	0	0	5	8	10	12	10	12	11
10	9	18	0	41	15	11	8	5	15	8	14	17
11	10	11	24	0	5	22	16	10	12	7	13	14
12	11	0	12	29	21	16	0	10	10	3	16	17
13	10	22	27	20	0	15	11	5	7	10	8	19
14	24	14	18	42	0	30	14	8	11	8	9	14
15	13	38	12	20	10	11	18	15	9	19	14	15
16	11	0	10	0	63	0	22	15	13	16	13	19
17	8	28	40	35	15	58	9	25	9	11	14	15
18	10	11	18	34	18	20	12	13	6	7	14	12
19	9	0	25	15	5	19	17	8	6	14	12	12
20	8	37	27	13	15	25	16	10	6	16	14	14
21	11	22	5	27	23	18	13	12	12	12	17	13
22	20	13	10	0	12	14	20	11	7	12	0	21
23	28	9	8	39	10	22	19	9	9	10	19	16
24	10	11	41	20	15	16	14	9	9	11	15	19
25	25	25	8	18	22	17	15	5	12	11	14	16
26	0	20	19	15	29	10	8	13	7	7	17	14
27	5	8	17	7	15	17	18	11	10	14	18	16
28	18	24	15	32	24	21	19	9	10	0	19	14
29	13	-	8	0	20	0	8	7	5	17	13	21
30	19	-	9	16	8	16	8	11	9	8	12	14
31	15	-	17	-	20	-	6	13	-	12	-	17
Sum	391	416	504	598	463	515	413	343	267	329	393	478
Avg	12.613	14.857	16.258	19.933	14.935	17.167	13.323	11.065	8.900	10.613	13.100	15.419

TABLE A-10. BIOMEDICAL WASTE GENERATED AT SANATORIUM SHIMLA, YEAR 2004.

Number of Beds: 50.

Type of Waste: Yellow Bag.

Waste Generated (Kgs/Day)												
Year 2004												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	18	0	9	12	10	15	17	0	8	0	22	13
2	16	0	17	15	13	14	16	14	16	17	9	10
3	15	0	12	16	15	17	18	18	0	11	12	0
4	11	0	12	10	12	18	16	14	27	8	10	15
5	13	22	16	6	15	20	18	8	12	12	9	0
6	17	19	10	13	8	10	11	19	19	12	17	11
7	12	12	9	18	7	16	12	14	13	22	0	13
8	21	13	15	12	19	17	14	10	8	8	14	17
9	11	12	10	11	12	19	8	0	27	12	16	12
10	18	16	39	19	0	15	9	8	22	20	0	11
11	16	13	21	17	21	14	16	8	0	8	10	17
12	15	16	12	19	14	22	15	8	16	9	0	0
13	16	16	16	11	13	19	22	7	13	11	11	9
14	15	19	14	22	17	12	11	12	8	11	7	21
15	0	0	14	10	9	14	15	0	0	9	11	15
16	28	28	18	18	8	10	8	15	7	12	15	12
17	12	6	9	18	11	23	7	12	10	12	0	15
18	14	12	10	14	12	0	8	0	13	11	13	14
19	12	14	16	13	14	22	17	12	0	11	0	11
20	12	10	19	10	16	17	19	0	0	10	8	16
21	17	14	13	17	14	15	10	13	12	17	0	18
22	12	14	17	13	17	13	20	7	17	0	9	11
23	0	17	12	17	18	19	4	9	0	7	7	12
24	47	7	18	16	20	14	2	18	33	3	11	9
25	17	12	19	11	8	12	0	0	0	5	17	10
26	17	12	12	12	15	18	3	20	11	8	10	0
27	14	10	12	9	12	21	0	21	16	5	14	15
28	14	20	9	16	0	13	35	0	0	0	8	0
29	22	14	16	11	12	17	16	21	16	0	24	12
30	11	-	16	14	18	16	0	27	13	16	12	13
31	0	-	13	-	9	-	13	0	-	9	-	0
Sum	463	348	455	420	389	472	380	315	337	296	296	332
Avg	14.935	11.226	14.677	14.000	12.548	15.733	12.258	10.161	11.233	9.548	9.867	10.710

Appendix 'B'

BIOMEDICAL WASTE DAILY AVERAGE GENERATION RATE AT DIFFERENT HEALTH CARE FACILITIES

TABLE B-1. BIOMEDICAL WASTE DAILY AVERAGE GENERATION RATE AT IGMC HOSPITAL SHIMLA, YEAR 2003.

Number of Beds: 738. **Period:** Year 2003. **Type of Waste:** Yellow Bag

Month	Days	Average Waste Generated		Number of Patients Treated Monthly			Bed Occupancy		Waste Generation Rate	
		Kg/ Month	Kg/ Day	Indoor	Outdoor	Total	Percent	Number	Kg/Patient/Day	Kg/Bed/Day
January	31	3375	108.871	15555	15749	31304	67.99	502	0.108	0.217
February	28	2247	80.250	13423	13363	26786	64.96	479	0.084	0.167
March	31	2501	80.677	15673	19155	34828	68.51	506	0.072	0.160
April	30	3035	101.167	16704	19306	36010	75.45	557	0.084	0.182
May	31	5292	170.710	18055	22838	40893	78.92	582	0.129	0.293
June	30	4525	150.833	18136	22681	40817	81.92	605	0.111	0.250
July	31	3878	125.097	18510	24118	42628	80.91	597	0.091	0.210
August	31	4621	149.065	18546	23348	41894	81.06	598	0.110	0.249
September	30	3453	115.100	18488	23356	41844	83.50	616	0.083	0.187
October	31	3568	115.097	18532	18817	37349	81.00	598	0.096	0.193
November	30	3314	110.467	17062	17698	34760	77.06	569	0.095	0.194
December	31	3764	121.419	16883	17713	34596	73.80	545	0.109	0.223

TABLE B-2. BIOMEDICAL WASTE DAILY AVERAGE GENERATION RATE AT IGMC HOSPITAL SHIMLA, YEAR 2004.

Number of Beds: 738. **Period:** Year 2004. **Type of Waste:** Yellow Bag.

Month	Days	Average Waste Generated		Number of Patients Treated Monthly			Bed Occupancy		Waste Generation Rate	
		Kg/ Month	Kg/ Day	Indoor	Outdoor	Total	Percent	Number	Kg/Patient/Day	Kg/Bed/Day
January	31	4067	131.194	15973	14472	30445	69.82	515	0.134	0.255
February	29	2940	101.379	15764	14316	30080	73.66	544	0.098	0.187
March	31	3577	115.387	16838	20807	37645	73.60	543	0.095	0.212
April	30	3264	108.800	17254	20122	37376	77.93	575	0.087	0.189
May	31	2744	88.516	18167	21742	39909	79.41	586	0.069	0.151
June	30	2675	89.167	18526	23190	41716	83.68	618	0.064	0.144
July	31	2054	66.258	19979	23510	43489	87.33	644	0.047	0.103
August	31	2470	79.677	19417	23173	42590	84.87	626	0.058	0.127
September	30	2180	72.667	19437	21891	41328	87.79	648	0.053	0.112
October	31	1860	60.000	18756	16768	35524	81.98	605	0.052	0.099
November	30	1992	66.400	18145	16666	34811	81.96	605	0.057	0.110
December	31	2381	76.806	17606	18012	35618	76.96	568	0.067	0.135

TABLE B-3. BIOMEDICAL WASTE DAILY AVERAGE GENERATION RATE AT KN HOSPITAL SHIMLA, YEAR 2003.

Number of Beds: 130. **Period:** Year 2003. **Type of Waste:** Yellow Bag

Month	Days	Average Waste Generated		Number of Patients Treated Monthly			Bed Occupancy		Waste Generation Rate	
		Kg/ Month	Kg/ Day	Indoor	Outdoor	Total	Percent	Number	Kg/Patient/Day	Kg/Bed/Day
January	31	2401	77.452	4659	2587	7246	115.61	150	0.331	0.515
February	28	1638	58.500	4456	1772	6228	122.42	159	0.263	0.368
March	31	1533	49.452	5099	3433	8532	126.53	164	0.180	0.301
April	30	1568	52.267	4758	3572	8330	122.00	159	0.188	0.330
May	31	1929	62.226	4937	3062	7999	122.51	159	0.241	0.391
June	30	2230	74.333	4766	3381	8147	122.21	159	0.274	0.468
July	31	2674	86.258	4963	3206	8169	123.15	160	0.327	0.539
August	31	2880	92.903	5221	3040	8261	129.55	168	0.349	0.552
September	30	2484	82.800	5560	2744	8304	142.56	185	0.299	0.447
October	31	2554	82.387	4997	4373	9370	124.00	161	0.273	0.511
November	30	2685	89.500	4675	2593	7268	119.87	156	0.369	0.574
December	31	2712	87.484	5152	2652	7804	127.84	166	0.348	0.526

TABLE B-4. BIOMEDICAL WASTE DAILY AVERAGE GENERATION RATE AT KN HOSPITAL SHIMLA, 2004.

Number of Beds: 130. **Period:** Year 2004. **Type of Waste:** Yellow Bag

Month	Days	Average Waste Generated		Number of Patients Treated Monthly			Bed Occupancy		Waste Generation Rate	
		Kg/ Month	Kg/ Day	Indoor	Outdoor	Total	Percent	Number	Kg/Patient/Day	Kg/Bed/Day
January	31	2399	77.387	4570	3181	7751	113.40	147	0.310	0.525
February	29	2177	75.069	4334	2680	7014	114.96	149	0.310	0.502
March	31	2123	68.484	5008	3050	8058	124.27	162	0.263	0.424
April	30	2019	67.300	5045	2492	7537	129.36	168	0.268	0.400
May	31	1992	64.258	5006	3007	8013	124.22	161	0.249	0.398
June	30	1317	43.900	4058	3318	7376	104.05	135	0.179	0.325
July	31	1236	39.871	5160	4036	9196	128.04	166	0.134	0.240
August	31	2266	73.097	5324	3355	8679	132.11	172	0.261	0.426
September	30	2035	67.833	4796	3335	8131	122.97	160	0.250	0.424
October	31	1753	56.548	4298	3032	7330	106.65	139	0.239	0.408
November	30	1468	48.933	4055	2248	6303	103.97	135	0.233	0.362
December	31	1905	61.452	4690	2535	7225	116.38	151	0.264	0.406

TABLE B-5. BIOMEDICAL WASTE DAILY AVERAGE GENERATION RATE AT DDU HOSPITAL SHIMLA, YEAR 2003.

Number of Beds: 150. **Period:** Year 2003. **Type of Waste:** Yellow Bag

Month	Days	Average Waste Generated		Number of Patients Treated Monthly			Bed Occupancy		Waste Generation Rate	
		Kg/ Month	Kg/ Day	Indoor	Outdoor	Total	Percent	Number	Kg/Patient/Day	Kg/Bed/Day
January	31	360	11.613	2895	8595	11490	62.26	93	0.031	0.124
February	28	596	21.286	2992	7504	10496	71.24	107	0.057	0.199
March	31	385	12.419	3846	10578	14424	82.71	124	0.127	0.100
April	30	284	9.467	3769	12138	15907	83.76	126	0.018	0.075
May	31	598	19.290	3914	12191	16105	84.17	126	0.037	0.153
June	30	619	20.633	3800	15051	18851	84.44	127	0.033	0.163
July	31	854	27.548	4162	13397	17559	89.51	134	0.049	0.205
August	31	746	24.065	4046	12336	16382	87.01	131	0.046	0.184
September	30	592	19.733	3734	11350	15084	82.98	124	0.039	0.159
October	31	571	18.419	4242	9087	13329	91.23	137	0.043	0.135
November	30	650	21.667	3884	9458	13342	86.31	129	0.049	0.167
December	31	707	22.806	4002	7435	11437	86.06	129	0.062	0.177

TABLE B-6. BIOMEDICAL WASTE DAILY AVERAGE GENERATION RATE AT DDU HOSPITAL SHIMLA, 2004.

Number of Beds: 150. **Period:** Year 2004. **Type of Waste:** Yellow Bag

Month	Days	Average Waste Generated		Number of Patients Treated Monthly			Bed Occupancy		Waste Generation Rate	
		Kg/ Month	Kg/ Day	Indoor	Outdoor	Total	Percent	Number	Kg/Patient/Day	Kg/Bed/Day
January	31	586	18.903	3340	5753	9093	71.83	108	0.064	0.175
February	29	456	15.724	2952	7655	10607	67.86	102	0.043	0.154
March	31	607	19.581	4100	10103	14203	88.17	132	0.043	0.148
April	30	573	19.100	3891	9874	13765	86.47	130	0.042	0.147
May	31	483	15.581	4433	13124	17557	95.33	143	0.028	0.109
June	30	260	8.667	4433	10728	15161	98.51	148	0.017	0.059
July	31	387	12.484	4518	10383	14901	97.16	146	0.026	0.086
August	31	589	19.000	4678	12376	17054	100.60	151	0.035	0.126
September	30	460	15.333	4474	15256	19730	99.42	149	0.023	0.103
October	31	415	13.387	4173	9968	14141	89.74	135	0.029	0.099
November	30	600	20.000	3557	9508	13065	79.04	119	0.046	0.169
December	31	640	20.645	3683	6655	10338	79.20	119	0.062	0.174

Appendix 'C'
BIOMEDICAL WASTE COLLECTION IN COLOURED BAGS AT HCFs.

TABLE C-1. BIOMEDICAL WASTE COLLECTION IN COLOURED BAGS AT IGMCH SHIMLA, YEAR 2004

Number of Beds: 738

Type of Bag	Average Waste Collected (Kgs/day)											
	Year 2004											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yellow	131.20	101.40	115.40	108.80	88.52	89.17	66.26	79.68	72.67	60.00	66.40	76.81
Red	65.87	40.00	45.38	71.07	18.52	19.93	18.70	13.52	16.23	15.42	15.00	20.00

TABLE C-2. BIOMEDICAL WASTE COLLECTION IN COLOURED BAGS AT KNH SHIMLA, YEAR 2004

Number of Beds: 130

Type of Bag	Average Waste Collected (Kgs/day)											
	Year 2004											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yellow	77.39	75.07	68.48	67.30	64.26	43.00	39.87	73.10	67.83	56.55	48.93	61.45
Red	2.16	8.62	9.90	11.90	9.71	18.27	19.32	18.48	17.67	14.55	14.53	17.03

Appendix 'D'

INCINERATION OF YELLOW BAG AT CENTRALISED TREATMENT FACILITY

TABLE D-1. INCINERATION OF YELLOW BAG AT MC INCINERATOR SHIMLA, YEAR 2003

Name and Address of CTF: Municipal Corporation Biomedical Waste Incinerator
Near IGMC Hospital, SHIMLA (HP)

BMW Handling Capacity: 1000Kgs/Day

Average Waste Incinerated (Kgs/Day)												
Year 2003												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	256	220	219	0	177	402	248	319	0	236	234	264
2	140	141	148	177	161	405	342	224	324	245	264	243
3	323	199	220	157	315	335	193	191	306	297	234	194
4	115	250	178	275	148	292	279	266	236	265	267	214
5	331	243	247	373	223	437	0	265	258	257	247	223
6	216	227	141	85	339	395	0	315	229	287	288	304
7	225	293	235	136	85	261	834	218	202	320	249	256
8	280	179	193	273	253	275	207	266	225	157	223	243
9	141	138	92	242	215	386	299	284	250	314	278	230
10	146	200	154	254	229	444	156	284	251	229	308	259
11	354	279	243	153	115	317	310	298	247	254	231	304
12	125	46	179	230	224	296	256	305	271	261	299	279
13	148	166	275	166	211	297	294	439	250	257	232	297
14	342	197	282	170	0	271	299	342	270	269	232	264
15	285	209	273	158	428	168	278	395	314	278	299	262
16	252	99	154	141	319	0	267	265	314	262	212	219
17	187	244	160	239	289	690	188	439	220	266	316	200
18	250	187	268	102	223	260	222	275	236	243	242	277
19	157	0	183	172	223	261	238	259	235	261	240	272
20	396	256	204	155	423	183	158	249	205	185	252	330
21	166	354	151	120	380	277	211	279	227	231	255	171
22	224	220	148	365	367	132	282	294	169	248	0	279
23	184	150	132	324	507	272	267	256	287	237	293	285
24	206	219	207	210	223	200	309	267	240	200	280	315
25	199	242	107	144	495	262	396	298	263	226	266	279
26	146	75	166	130	506	300	232	290	268	242	311	267
27	205	195	138	112	335	276	218	285	208	256	304	292
28	335	237	29	422	323	189	216	253	204	0	225	218
29	144	-	255	193	429	0	275	227	184	177	303	308
30	280	-	91	220	233	191	343	245	238	212	209	290
31	184	-	177	-	365	-	213	258	-	231	-	330
Sum	6942	5465	5649	5898	8763	8474	8030	8850	7131	7403	7593	8168
Avg	223.94	195.18	182.23	196.60	282.68	282.47	259.03	285.48	237.70	238.80	253.10	263.48

TABLE D-2. INCINERATION OF YELLOW BAG AT MC INCINERATOR SHIMLA, YEAR 2004

Name and Address of CTF: Municipal Corporation Biomedical Waste Incinerator
Near IGMC Hospital, SHIMLA (HP)

BMW Handling Capacity: 1000Kgs/Day

Average Waste Incinerated (Kgs/Day)												
Year 2004												
Date	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	219	0	156	225	232	102	133	107	163	142	204	185
2	279	0	227	122	128	134	118	179	144	172	136	220
3	297	0	110	341	272	164	71	248	186	151	180	129
4	271	0	316	176	134	99	116	240	213	136	207	217
5	292	70	253	208	271	231	72	164	167	134	170	88
6	351	1093	113	168	225	170	143	250	171	321	221	133
7	356	333	141	276	257	136	111	208	188	214	111	179
8	346	216	362	171	182	230	70	217	136	152	171	129
9	270	222	198	274	250	158	234	112	197	322	148	286
10	279	277	399	276	0	248	81	124	201	189	90	219
11	243	240	270	215	162	126	104	183	198	179	219	320
12	234	323	186	183	244	183	127	185	201	168	92	100
13	269	298	287	171	200	48	112	161	176	222	156	262
14	236	240	130	368	140	197	118	203	210	191	89	192
15	0	0	234	168	207	138	40	200	195	241	96	299
16	494	240	246	200	104	148	299	206	249	182	239	232
17	244	192	214	215	190	159	114	169	197	135	0	131
18	230	197	244	166	108	0	78	0	122	191	310	205
19	225	247	204	290	0	261	193	227	165	157	54	151
20	228	185	212	172	364	71	147	207	0	188	137	225
21	288	233	139	205	115	146	133	189	191	92	77	180
22	302	193	126	151	131	48	154	238	196	92	156	195
23	0	241	380	276	186	202	106	244	278	180	120	210
24	205	72	304	239	53	132	86	263	197	85	221	152
25	111	246	230	185	133	100	89	261	177	159	151	168
26	95	216	320	142	204	134	106	0	141	122	232	128
27	822	189	330	242	135	199	95	252	201	144	198	221
28	160	225	169	295	0	89	160	140	123	121	106	106
29	401	244	240	335	310	111	135	148	194	0	181	132
30	219	-	210	275	138	124	115	185	280	167	210	144
31	0	-	236	-	144	-	132	340	-	84	-	124
Sum	7966	6232	7186	6730	5219	4288	3792	5850	5457	5033	4682	5662
Avg	256.97	214.89	231.81	224.33	168.35	142.93	122.32	188.71	181.9	162.35	156.07	182.64

__Appendix 'E'__

PROGRAMMING FOR NUMERCAL VALUES OF COEFFICIENTS OF EQUATIONS

```
*                      ***************************************
*                         NPSOL Version 4.06  January 1992.
*                      ***************************************

      PROGRAM EQNFIT

      IMPLICIT DOUBLE PRECISION(A-H,O-Z)

      PARAMETER (NCONST = 7,MAXDATA= 12)

* Lines in boxes are mandatory NPSOL statements
      PARAMETER( MAXN   =  NCONST,
     $           LDR    =  MAXN,
     $           LIWORK =  3*LDR,
     $           LWORK  = 20*LDR,
     $           LDA    =   1,
     $           LDCJAC =   1,
     $           MAXBND =  MAXN + LDA + LDCJAC)

      INTEGER      ISTATE(MAXBND)
      INTEGER      IWORK(LIWORK)
      DIMENSION    A(LDA,1)
      DIMENSION    C(LDCJAC), CJAC(LDCJAC,1), CLAMDA(MAXBND)
      DIMENSION    OBJGRD(MAXN), R(LDR,MAXN)
      DIMENSION    WORK(LWORK)

      DIMENSION    B(MAXN), BL(MAXBND), BU(MAXBND)

* Variable B is the parameters to be optimized
* BL and BU are lower and upper bounds of B


      DIMENSION   X(MAXDATA),Y(MAXDATA),Z(MAXDATA)
      COMMON      /DATA/   X,Y,Z

      EXTERNAL     OBJFN,  CONFN

* >>>>>>>>>> Initializing NPSOL Variables >>>>>>>>>
      N      = MAXN
      NCLIN  = 0
      NCNLN  = 0
      NBND   = N + NCLIN + NCNLN
* <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<

* >>>>>>>>>>>>>> Reading Waste Data >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
* FILE: YELLOW.TXT contains data for the
*                "Month", "kg Yellow Bags", and "Bed Occupancy"
*                  X(I)         Y(I)                 Z(I)
*                where I varies from 1 to MAXDATA (=12)
* ----------------------------------------------------------------
      OPEN(UNIT=1,FILE='YELLOW.TXT',STATUS='OLD')

      DO I=1,MAXDATA
          READ(1,*)X(I),Y(I),Z(I)
      ENDDO
      CLOSE (1)
* <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
```

```
* >>>>>>>>Reading Initial Guess
Values>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
*
*FILE: GUESS.TXT contains initial guess value of coefficients, B(I),
*                and lower and upper bounds of B(I),
*                i.e., BL(I) and BU(I), respectively,
*                in the order BL(I),B(I),BU(I)
* ---------------------------------------------------------------------
--

      OPEN(UNIT=2,FILE='GUESS.TXT', STATUS='OLD')

      DO I=1,MAXN
          READ(2,*)BL(I),B(I),BU(I)
      ENDDO
      CLOSE(2)
*
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
```

```
* >>>>>>>>>>>>>>>>>>> Reading NPSOL Options File >>>>>>>>>>>>>>>>>>
      NOUT=6
      IOPTNS = 10
      OPEN(IOPTNS, ERR = 190, FILE = 'NPMAIN.OPT',STATUS = 'OLD')
      CALL NPFILE( IOPTNS, INFORM )
      IF (INFORM .NE. 0) THEN
         WRITE (NOUT, 3000) INFORM
         CLOSE(IOPTNS)
         STOP
      END IF
      CLOSE(IOPTNS)
      GOTO 200
  190 CONTINUE
      STOP
  200 CONTINUE
* <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
```

```
* >>>>>>>>>>>>>>>>>>> Calling NPSOL Main Subroutine
>>>>>>>>>>>>>>>>>>>>>>
```

```
      CALL NPSOL ( N, NCLIN, NCNLN, LDA, LDCJAC, LDR,
     $             A, BL, BU,
     $             CONFN, OBJFN,
     $             INFORM, ITER, ISTATE,
     $             C, CJAC, CLAMDA, OBJF, OBJGRD, R, B,
     $             IWORK, LIWORK, WORK, LWORK )
```

```
*
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
*  NPSOL returns optimized values of "B(I)" along with the
*        final objective function value "OBJF"
```

```
        WRITE(*,*)' FINAL OBJECTIVE FN.=',OBJF
        WRITE(*,3031)B
        WRITE(*,*)' ++++++++++ UDATING FILE: FIT.TXT ++++++++++'

      OPEN(UNIT=2,FILE='FIT.TXT', STATUS='UNKNOWN')
      DO I=1,MAXN
        WRITE(2,3030)BL(I),B(I),BU(I)
      ENDDO
      CLOSE(2)


 3000 FORMAT(/ ' NPFILE TERMINATED WITH  INFORM =', I3)
 3010 FORMAT(/ ' NPSOL  TERMINATED WITH  INFORM =', I3)
 3020 FORMAT(/ ' COULD NOT FIND OPTIONS FILE: NPMAIN.OPT')
 3030 FORMAT(1X,5E15.7)
 3031 FORMAT(1X,20(1X,F10.4))

      END
```

```
* >>>>>>>>>>>>>>>>The Objective Function to be Minimized
>>>>>>>>>>>>>>>>
      SUBROUTINE OBJFN( MODE, N, B, OBJF, OBJGRD, NSTATE )

      IMPLICIT DOUBLE PRECISION(A-H,O-Z)

      PARAMETER (NCONST = 7,MAXDATA= 12)

      DIMENSION   B(N), OBJGRD(N)

      DIMENSION  X(MAXDATA),Y(MAXDATA),Z(MAXDATA)
      COMMON     /DATA/   X,Y,Z

       OBJF = 0.0
       DO I = 1, MAXDATA
          BB=4.0*B(1)+6.0*B(2)+7.2*B(3)
          CC=-(B(1)+B(2)+B(3))
          F=(B(5)+B(6)*Z(I)+B(7)*Z(I)**2)*(B(4)+BB*X(I)+CC*X(I)**2
     &     +B(1)/18.0*X(I)**3+B(2)/288.0*X(I)**4+B(3)/4320.0*X(I)**5)
        OBJF = OBJF + (F - Y(I))**2
      ENDDO

      RETURN
      END
* Note: To avoid bad behavior of iterations, parameters were scaled so
that
* the values are of the same order of magnitude. Accordingly,
necessary
* correlation in the equation to predict waste generation, "F", is
made.
* the scaling factors used for various parameters are as follow
*
* B(1)=d*18
* B(2)=e*288
* B(3)=f*4321
* B(4)=a
* B(5)=k1
* B(6)=k2
* B(7)=k3
*
<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<



* NPSOL is a constrained optimization package.
* Although in the present case no constraints are imposed, however,
* following empty subroutine has to be present in the program
      SUBROUTINE CONFN( MODE, NCNLN, N, LDCJAC,
     $                  NEEDC, X, C, CJAC, NSTATE )

      IMPLICIT           DOUBLE PRECISION(A-H,O-Z)
      INTEGER            NEEDC(1)
      DIMENSION   X(1), C(1), CJAC(LDCJAC,1)

      RETURN
      END
```

Publications from Research Work

Surjit Singh Katoch and Vineet Kumar. (2007). Prediction of Biomedical Waste Load at Centralized Treatment Facility. Chemical Product and Process Modeling, Vol. 2, No. 2, Article 4, 01-12.

Surjit S Katoch and Vineet Kumar. (2007). Modeling Seasonal Variation in Biomedical Waste Generation at Health Care Facilities. Waste Management & Research. [MS#WMR-1369-1]

Surjit S Katoch, Vineet Kumar, and Susheel K. Mittal. Biomedical Solid Waste and Prevailing Treatment Strategies. (Manuscript under preparation).