2.0 INCINERATION

2.1 GENERAL DESCRIPTION OF TREATMENT TECHNOLOGY

Incineration is a process in which medical waste is burned, producing combustion gases and noncombustible residue (ash). The product combustion gases are vented directly to the air before or after treatment in an air pollution control device (APCD). The noncombusted ash residue is removed from the incinerator and disposed of in a landfill. Incineration greatly reduces the weight and volume of the solid waste, reduces the number of microorganisms in the waste, and meets the destruction criteria defined in the MWTA.

2.1.1 Operational Parameters

2.1.1.1 Incinerator Parameters

Several parameters influence the efficiency of incineration of all organic waste, including temperatures, negative pressure levels, oxygen levels, waste characteristics, and waste feed rate. Temperature and pressure drop as an indicator of incinerator draft are routinely monitored in many hospital incinerators. Other parameters such as carbon monoxide content and opacity of air emissions should be monitored to provide additional information that operators can use to maintain proper operation (EPA, 1989).

Parameters for proper operation of air pollution control devices also should be monitored. The pertinent operating parameters for wet scrubbers are pressure and pressure drop, scrubber liquid flow rate, scrubber liquid pH, and temperature. For fabric filters, the pertinent operating parameters are pressure drop across the bag and temperature (EPA, 1989).

2.1.1.2 Waste Characteristics

As indicated in Section 1.1 of this document all types of wastes may be treated by incineration.

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 3,400kJ/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.

2.1.1.3 Residuals

Incinerator residue (ash) is produced after every incineration cycle. Ash that has accumulated from prior burns must be removed before loading additional waste into an incinerator. Ash should be removed after the cooldown period which may be as long as 8 hours following the previous burn. For manual ash removal systems, the ash bin must be emptied on a regular schedule. For fully automated ash systems, the ash is routinely mechanically removed with a rake or conveyor from a water quench pit located at the end of the ash discharge chute.

2.1.2 Incinerator Types

Provided below are very brief descriptions of several of the more common types of incinerators used to treat medical waste. Detailed descriptions of these technologies can be found in the following references:

U.S. Environmental Protection Agency Control Technology Center. 1989. Hospital Incinerator Operator Training Course: Volume 1 and 2. EPA Document No. 450/3-89-003 and 004. Research Triangle Park, NC.

U.S. Environmental Protection Agency Control Technology Center. 1989. Operations and Maintenance of Hospital Medical Waste Incinerators. EPA Document No. 450/3-89-002.

2.1.2.1 Multiple Chamber Pathological Waste Incinerators

Multiple chamber pathological waste incinerators are often designed and used specifically for pathological wastes which have a 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.

2.1.2.2 Controlled Air Incinerators

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 ("controlled"). The combustion air is usually fed as underfire air. Three processes occur in the primary chamber. First, the moisture in the waste is volatilized. Second, the volatile fraction of the waste is vaporized, and the volatile gases are directed to the secondary chamber. Third, the fixed carbon remaining in the waste is combusted. The combustion gases containing the volatile

combustible materials from the primary chamber are directed to the secondary chamber. In the secondary chamber the combustion air is regulated to provide excess air, turbulence, and good mixing of the combustion gases and air. Complete combustion can be achieved by the high temperatures, excess air, and turbulence (EPA, 1989).

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.

2.1.2.3 Rotary Kilns

A rotary kiln incinerator also utilizes two-stage combustion with two combustion chambers. The primary combustion chamber is a rotating cylindrical chamber. The secondary chamber may be cylindrical or box-like in shape. Waste is fed to the higher end of the kiln by a mechanical feed system. Combustion air is usually provided in excess, but some units may be designed to operate with a substoichiometric atmosphere which reduces the amount of auxiliary fuel needed for the secondary chamber.

2.2 OPERATION EVALUATION

Appropriate incinerator design and operator training are essential for destruction of both infectious organisms and organic chemical waste. To demonstrate acceptable microbial destruction in specific units, effectiveness tests can be conducted. *B. stearothermophilus* ATCC 12980 spores are the organisms of choice for this testing. Bacterial spores are more heat resistant than most microbial pathogens, providing a significant challenge to the incinerator. Survival of a large number of indicator spores suggests that particular conditions may have allowed survival and release of at least a small number of pathogens. Spores can also be selectively cultured from treatment residuals (ash) allowing a relatively clean microbial trace. As the heat resistant spores used in equipment performance tests are non-pathogenic, health risks are minimized.

The EPA has supported the development and evaluation of appropriate methodology to evaluate the treatment effectiveness of incineration. This has been published recently (Segall et al., 1991).

2.2.1 Equipment/Materials/Reagents

For indicator spore flue gas sampling, a sampling train must be assembled. A diagram of the suggested sampling system is shown in Figure 2.1. Flue gas samples are extracted

through a quartz nozzle/probe system housed in a water cooled sheath. A smaller tube is located inside the sampling probe to deliver a buffered solution at the nozzle end of the probe. This allows the gas sample stream to be immediately buffered preventing acid condensate from killing viable spores. From the probe, the sample stream is delivered to a series of chilled impingers. The first two contain 200 mL and 100 mL, respectively, of phosphate buffered solution to collect indicator spores. The third impinger is empty and serves as a knock-out and the fourth flask contains silica gel. The remainder of the sampling train is identical to a Method 5 (EPA) air sampling train system.

The ash quality is measured by analyzing a sample of the incinerator ash. No special materials, reagents, or equipment are necessary for collecting ash samples. The necessary equipment includes 4 or 5 large containers (garbage cans), a shovel, plastic sampling thief, and sterilized amber glass bottles. All non-sterile equipment should be autoclaved or if the items are not autoclavable they should be treated with 2 percent glutaraldehyde according to manufacture's directions prior to use. This method should be used when the total microbial destruction is to be determined for that unit. Alternatively, if the operator is only interested in the number of organisms surviving the process in the ash, a second method can be used. It consists of a metal pipe containing indicator spores. A paper strip containing approximately 10^6 dry *B. stearothermophilus* spores should be obtained from a supplier. Each pipe sample uses one spore strip. The pipe is a short piece (2 to 4 inches) of 3/8 stainless steel tubing capped on both ends with Swagelock caps. This "inner container" is then placed in an "outer container" which is a 1.25 inch or 2 inch diameter steel pipe nipple about 4 to 6 inches long. Enough vermiculite or other thermal insulation surrounds the inner container to maintain its position in the center of the outer container and protect it from thermal shock. Both ends of the outer container are capped. A diagram of the pipe assembly is shown in Figure 2.2.

2.2.2 Test Organism Selection

Bacterial spores are recommended in order to provide a significant challenge to the incinerator. Various kinds of spores have been used in incinerator efficacy tests. *B. stearothermophilus* spores are recommended because, they are heat resistant , can be selectively isolated at a relatively high temperature, and are not normally found in a medical waste stream.

2.2.3 Test Organism Procurement

While small quantities of spores in suspension can be routinely obtained from commercial sources, the trial burn method that may be used for measuring viable spores in air emissions and incinerator ash requires 10^{12} spores for each test burn. Such spore suspensions can be

Sampling Train for Determination of Indicator Spore Emissions

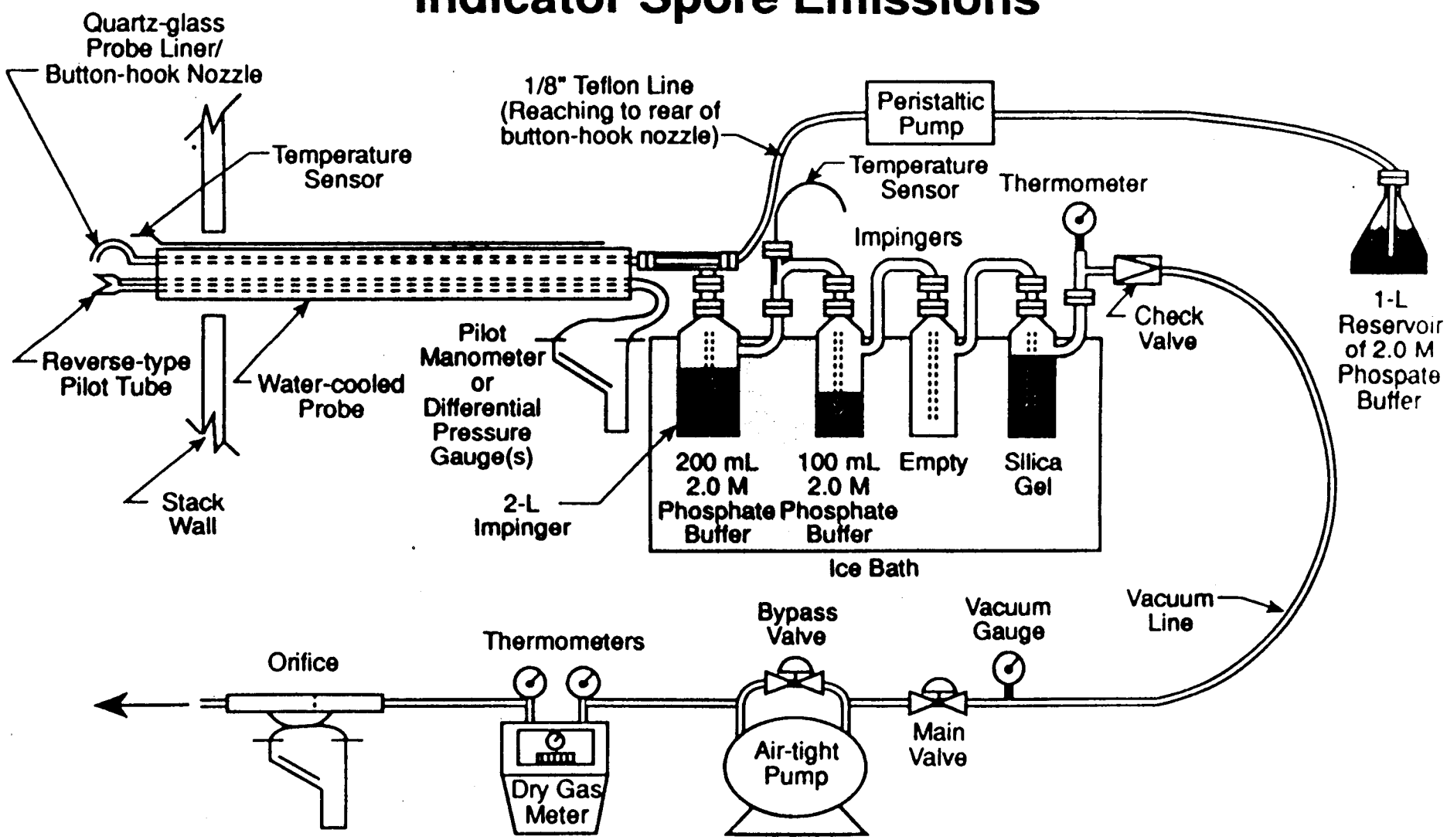

Figure 2.1 Sampling Train for Determination of Indicator Spore Emissions

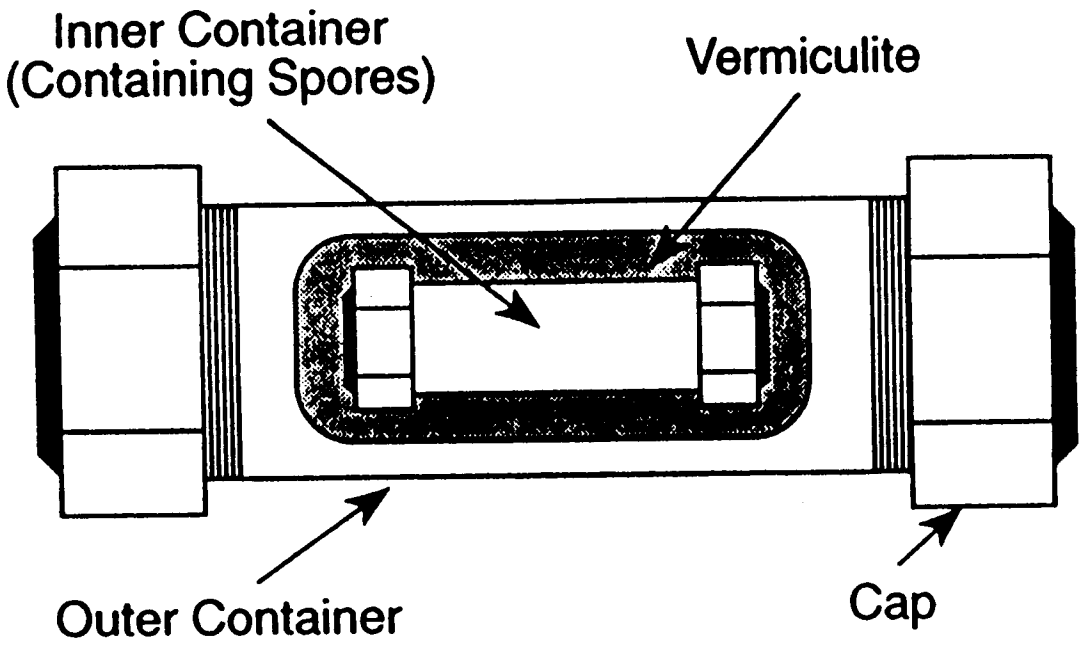

Figure 2.2. Ash quality pipe assemblies.

obtained from a number of specialized sources. Typically, a large fermenter is needed to produce the number of spores required for this test.

Dry *B. stearothermophilus* spores (10^6), used for the ash quality pipe test, can be acquired from routine commercial sources.

2.2.4 Test Organism Quantitation

The spores should be quantitated by standard colonial enumeration methods. This requires that appropriate dilutions of the source material be prepared, dilutions of aliquot samples placed on agar petri dishes, and the petri dishes incubated to allow development of colonies. For *B. stearothermophilus*, soybean-casein digest agar or equivalent is recommended (available from commercial sources), and petri dishes should be incubated at 55 °C in sealed plastic bags to prevent dehydration.

2.2.5 Test Load Preparation

The type of testing needed is determined by the type of results that are wanted. If the objective of the testing is to determine the total destruction of microorganisms then an analysis of indicator spores in the stack gases and ash is required. However, if the objective is to determine the level of indicator organisms surviving in the ash, then the pipe method could be used in lieu of analysis of ash samples. The pipe method cannot be used with air sampling to determine total destruction efficiency.

A known quantity of spores should be inoculated onto or into materials normally found in the medical waste stream (i.e.petri dishes, test tubes, gauze, etc.) and placed in a container that will be added to the normal incinerator charge. The spore solution is typically provided as a frozen slurry from the manufacturer. The total quantity for organisms should be divided into aliquots of equal size and added to the waste stream at equal intervals. For example, to spike the waste stream of a four cycle quality control test one could use four 500 mL aliquots containing 1×10^8 spores/mL to achieve a 2×10^{11} spores spike level total concentration or four 500 mL aliquots of 1×10^9 spores/mL to achieve a 2×10^{12} spike spore level.

The pipe test may be performed in addition to the waste spike test. To perform this test the inner container and caps should be cleaned and decontaminated before use. The pipes and caps should first be cleaned with detergent using a brush to scrub the inner pipe, rinsed thoroughly with distilled/deionized water, and allowed to dry. For decontamination, the clean dry pipe with caps loose may be placed in a steam autoclave (15 psi, 121 °C) for 30 minutes. Alternatively, the pipe end caps can be chemically treated by soaking in a 2 percent glutaraldehyde solution for 12 hours. After soaking in the antimicrobial solution, the pipes should be rinsed thoroughly with sterile distilled/deionized water and allowed to dry before addition of spores. A known quantity of dry spores ($\sim 10^6$) should be placed inside the inner container and sealed using the cleaned and disinfected end caps.

2.2.6 Test Load Exposure

The overall analysis should be performed under normal operating conditions. For each test burn, the liquid spores should be added in several fractions to challenge the incinerator with a total of ~10^{12} spores. Each spore fraction should be added to waste and then charged to the incinerator at equally spaced intervals.

Residue quality pipes also may be charged to the incinerator several times during the test operation. The pipe samples may be placed in the charging hopper at random locations. All equipment used for sampling and sample recovery, which come into contact with the sample, should be washed and disinfected before and after use. The nozzle/probe liner, impinger, impinger connections and the nozzle/probe brush should be washed using the same procedure as described for the pipes. Following washing, all components are disinfected with 2 percent glutaraldehyde. Metal, autoclavable plastic, and glass sample containers, should be sterilized by autoclaving.

2.2.7 Stack Sampling

The gas sampling train should be assembled by aseptically adding sterile buffer (2.0 M phosphate) to the first two impingers. Silica gel is added to the fourth impinger and the impinger train is connected to the meter box via an umbilical line. A pretest leakcheck on the impinger train is completed at approximately 15 inches Hg. Leakage rates in excess of 4 percent of the average sampling rate or 0.02 cfm, whichever is less, should be considered unacceptable.

Before inserting the probe into the stack, the nozzle cap should be removed and the alignment of the nozzle and pitot tube checked. The probe cooling water flow is started and adjusted. The buffering system pump is then started making sure that the probe is slightly inclined so that the buffer solution drains into the first impinger. The probe is inserted into the duct and located at the first sampling traverse point. Isokinetic sampling commences in accordance with Method 5 (EPA) guidelines. All sampling parameters (pressure, gas meter readings, stack temperature, meter temperature, meter vacuum, first impinger temperature, and silica gel impinger temperature) should be periodically monitored, adjusted, and recorded throughout the test run.

After completion of the test run, the probe may be removed from the stack and the flow of buffering solution turned off. The final meter reading should be recorded and the sample train is leakchecked. Posttest leak checks are complete at a vacuum equal to or greater than the maximum vacuum reached during the sampling run. Leakage rates in excess of 4 percent of the average sampling rate or 0.02 cfm, whichever is less, should be considered unacceptable, the same as previously mentioned for the pretest leak checks.

The probe nozzle tip is inspected for port scraping or any external matter near the tip and, if any is found, it should be removed. The probe then should be disconnected from the

impinger train and the probe buffer delivery tube rinsed and brushed with sterile buffer solution. All rinses should be collected in a sterile sample bottle.

The impingers should be weighed and the contents antiseptically transferred to the sample bottle containing the nozzle/probe rinsing. The pH of the sample should be adjusted if necessary to 6.0 to 7.5 with 1.0 N NaOH. The level of liquid in the sample bottle should be marked to determine later if leakage occurred during transport. The bottle should be packed in ice to maintain sample temperatures at or below 4 °C, for shipment to the laboratory.

2.2.8 Ash Sampling

The ash may be recovered from the incinerator when the ash has cooled. It should be completely removed from the incinerator bed and placed in four or five large containers (garbage cans) and weighed. A sampling thief is then used to collect several 50 g ash samples. The samples are placed in clean amber bottles for transport to the laboratory. In the laboratory three representative 1 g ash samples should be taken for analysis. The ash from the test cycle should be collected and weighed. Samples relatively free of unburned material should be taken using a clean plastic scoop. During each sampling run, three samples should be taken. Two of the samples should be used for spore analysis and the third sample used to determine the pH of the material.

2.2.9 Microbial Analysis

Microbial analyses procedures for impinger, ash and pipe samples are illustrated in Figures 2.3, 2.4, 2.5. Samples should be thoroughly mixed just prior to removal of aliquots for analysis.

2.2.10 Interpretation of Results

By comparing the number of viable spores spiked to the incinerator to the number of viable spores exiting the incinerator in both the stack gas and incinerator ash, an overall spore kill can be calculated. The total number of spores in the stack emissions (Se) is calculated using information collected during the test procedures.

$$Se = [Sx\ (Vf/Vx)]/Vm\ (Q)(T)$$

Where:
- Se = Number of viable spores in stack emissions
- Sx = Number of viable spores detected in sample aliquot
- Vf = Final volume of liquid sample (mL)
- Vx = Volume of sample aliquot filtered (mL)
- Vm = Volume of the sample gas (mL)
- Q = Dry volumetric flue gas flow rate at standard conditions (cm^3/min)
- T = Total sampling time (min)

The total number of viable spores in the ash (Sa) is calculated from the number of spores in the sample aliquot and the total weight of the ash from the incinerator test.

$$Sa = Sy \times Wt$$

Where: Sa = Number of viable spores in incinerator ash
Sy = Average number of spores in triplicate 1 g ash samples
Wt = Total weight of ash removed from incinerator.

The total number of viable spores spiked in the waste (Ss) are compared with the number of spores in the stack emissions (Se) and the number of spores in the ash (Sa) to calculate the overall spore log reductions.

$$K = [Ss] - [Se + Sa]$$

Where: K = spore kill
Ss = number of viable wet spores spiked in the waste feed

Alternatively the microbial survivability can be determined as follows:

$$MS = Se + Sa/Ss \times 100$$

MS = wet spore survivability

The relationship between the two measures of effectiveness is:

$$K = (100 - MS)/100$$

2.2.11 Quality Control Procedures

QA/QC procedures are summarized in Table 2.1. The spore count in the spore spike solution should be independently verified. Field blank samples should be prepared for the impingers, pipes and ash. Duplicate samples of impingers, pipes and ash should be analyzed for spores.