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Technical Guidance Document:

QUALITY ASSURANCE AND QUALITY CONTROL FOR WASTE CONTAINMENT FACILITIES

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DISCLAIMER

The information in the document has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement number CR-815546-01-0. It has been subject to the Agency's peer and administrative review and has been approved for publication as a U.S. EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document contains numerous references to various procedures for performing tests as part of the process of quality control and quality assurance. Standards published by the American Society for Testing and Materials (ASTM) are referenced wherever possible because ASTM procedures represent consensus standards. Other testing procedures referenced in this document were generally developed by an individual or a small group of individuals and, therefore, do not represent consensus standards. The mention of non-consensus standards does not constitute their endorsement.

The reader is cautioned against using this document for the direct preparation of site specific quality assurance plans or related documents without giving proper consideration to the site- and project-specific requirements. To do so would ignore the educational context of the accompanying text, innovations made since the publication of the document, and the prevailing unique and site-specific aspects of all waste containment facilities.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The United States Environmental Protection Agency (U.S. EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the U.S. EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the U.S. EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This document provides information needed to develop comprehensive quality assurance plans and to carry out quality control procedures at waste containment sites. It discusses quality assurance and quality control issues for compacted soil liners, soil drainage systems, geosynthetic drainage systems, vertical cutoff walls, ancillary materials, and appurtenances.

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Director
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ABSTRACT

This Technical Guidance Document provides comprehensive guidance on procedures for quality assurance and quality control for waste containment facilities. The document includes a discussion of principles and concepts, compacted soil liners, soil drainage systems, geosynthetic drainage systems, vertical cutoff walls, ancillary materials, appurtenances, and other details. The guidance document outlines critical quality assurance (QA) and quality control (QC) issues for each major segment and recommends specific procedures, observations, tests, corrective actions, and record keeping requirements. For geosynthetics, QA and QC practices for both manufacturing and construction are suggested.

The main body of the text details recommended procedures for quality assurance and control. Appendices include a list of acronyms, glossary, and index. A companion document was under development by the American Society for Testing and Materials (ASTM) at the time of this writing that will contain all of the ASTM standards referenced in this guidance document as well as most, if not all, of the other test procedures that are referenced in this guidance document.

This report was submitted in fulfillment of CR-815546 by the University of Texas, Austin, under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 1991 to July 1993, and work was completed as of August 1993.

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Chapter 1

Manufacturing Quality Assurance (MQA) and Construction Quality Assurance (CQA) Concepts and Overview

1.1 Introduction

As a prelude to description of the detailed components of a waste containment facility, some introductory comments are felt to be necessary. These comments are meant to clearly define the role of the various parties associated with the manufacture, installation and inspection of all components of a total liner and/or closure system for landfills, surface impoundments and waste piles.

1.1.1 Scope

Construction quality assurance (CQA) and construction quality control (CQC) are widely recognized as critically important factors in overall quality management for waste containment facilities. The best of designs and regulatory requirements will not necessarily translate to waste containment facilities that are protective of human health and the environment unless the waste containment and closure facilities are properly constructed. Additionally, for geosynthetic materials, manufacturing quality assurance (MQA) and manufacturing quality control (MQC) of the manufactured product is equally important. Geosynthetics refer to factory fabricated polymeric materials like geomembranes, geotextiles, geonets, geogrids, geosynthetic clay liners, etc.

The purpose of this document is to provide detailed guidance for proper MQA and CQA procedures for waste containment facilities. (The document also is applicable to MQC and CQC programs on the part of the manufacturer and contractor). Although facility designs are different, MQA and CQA procedures are the same. In this document, no distinction is made concerning the type of waste to be contained (e.g., hazardous or nonhazardous waste) because the MQA and CQA procedures needed to inspect quality lining systems, fluid collection and removal systems, and final cover systems are the same regardless of the waste type. This technical guidance document has been written to apply to all types of waste disposal facilities, including new hazardous waste landfills and impoundments, new municipal solid waste landfills, nonhazardous waste liquid impoundments, and final covers for new facilities and site remediation projects.

This document is intended to aid those who are preparing MQA/CQA plans, reviewing MQA/CQA plans, performing MQA/CQA observations and tests, and reviewing field MQC/CQC and MQA/CQA procedures. Permitting agencies may use this document as a technical resource to aid in the review of site-specific MQA/CQA plans and to help in identification of any deficiencies in the MQA/CQA plan. Owner/operators and their MQA/CQA consultants may consult this document for guidance on the plan, the process, and the final certification report. Field inspectors may use this document and the references herein as a guide to field MQA/CQA procedures. Geosynthetic manufacturers may use the document to help in establishing appropriate MQC procedures and as a technical resource to explain the reasoning behind MQA procedures. Construction personnel may use this document to help in establishing appropriate CQC procedures and as a technical resource to explain the reasoning behind CQA procedures.

This technical guidance document is intended to update and expand EPA's Technical Guidance Document, "Construction Quality Assurance for Hazardous Waste Land Disposal

Facilities," (EPA, 1986). The scope of this document includes all natural and geosynthetic components that might normally be used in waste containment facilities, e.g., in liner systems, fluid collection and removal systems, and cover systems.

This document draws heavily upon information presented in three EPA Technical Guidance Documents: "Design, Construction, and Evaluation of Clay Liners for Waste Management Facilities" (EPA, 1988a), "Lining of Waste Containment and Other Impoundment Facilities" (1988b), and "Inspection Techniques for the Fabrication of Geomembrane Field Seams" (EPA, 1991a). In addition, general technical backup information concerning many of the principles involved in construction of liner and cover systems for waste containment facilities is provided in two additional EPA documents: "Requirements for Hazardous Waste Landfill Design, Construction, and Closure" (EPA, 1989) and "Design and Construction of RCRA/CERCLA Final Covers" (EPA, 1991b). Additionally, there are numerous books and technical papers in the open literature which form a large data base from which information and reference will be drawn in the appropriate sections.

1.1.2 Definitions

It is critical to define and understand the differences between MQC and MQA and between CQC and CQA and to counterpoint where the different activities contrast and/or complement one another. The following definitions are made.

- *Manufacturing Quality Control (MQC):* A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factory originated. MQC is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract plans.

- *Manufacturing Quality Assurance (MQA):* A planned system of activities that provides assurance that the materials were constructed as specified in the certification documents and contract plans. MQA includes manufacturing facility inspections, verifications, audits and evaluation of the raw materials and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if the manufacturer is in compliance with the product certification and contract plans for a project.

- *Construction Quality Control (CQC)*: A planned system of inspections that is used to directly monitor and control the quality of a construction project (EPA, 1986). Construction quality control is normally performed by the geosynthetics installer, or for natural soil materials by the earthwork contractor, and is necessary to achieve quality in the constructed or installed system. Construction quality control (CQC) refers to measures taken by the installer or contractor to determine compliance with the requirements for materials and workmanship as stated in the plans and specifications for the project.

- *Construction Quality Assurance (CQA)*: A planned system of activities that provides the owner and permitting agency assurance that the facility was constructed as specified in the design (EPA, 1986). Construction quality assurance includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility. Construction quality

assurance (CQA) refers to measures taken by the CQA organization to assess if the installer or contractor is in compliance with the plans and specifications for a project.

MQA and CQA are performed independently from MQC and CQC. Although MQA/CQA and MQC/CQC are separate activities, they have similar objectives and, in a smoothly running construction project, the processes will complement one another. Conversely, an effective MQA/CQA program can lead to identification of deficiencies in the MQC/CQC process, but a MQA/CQA program by itself (in complete absence of a MQC/CQC program) is unlikely to lead to acceptable quality management. Quality is best ensured with effective MQC/CQC and MQA/CQA programs. See Fig. 1.1 for the usual interaction of the various elements in a total inspection program.

1.2 Responsibility and Authority

Many individuals are involved directly or indirectly in MQC/CQC and MQA/CQA activities. The individuals, their affiliation, and their responsibilities and authority are discussed below.

The principal organizations and individuals involved in designing, permitting, constructing, and inspecting a waste containment facility are:

- *Permitting Agency.* The permitting agency is often a state regulatory agency but may include local or regional agencies and/or the federal U. S. Environmental Protection Agency (EPA). Other federal agencies, such as the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, the U.S. Bureau of Mines, etc., or their regional or state affiliates are sometimes also involved. It is the responsibility of the permitting agency to review the owner/operator's permit application, including the site-specific MQA/CQA plan, for compliance with the agency's regulations and to make a decision to issue or deny a permit based on this review. The permitting agency also has the responsibility to review all MQA/CQA documentation during or after construction of a facility, possibly including visits to the manufacturing facility and construction site to observe the MQC/CQC and MQA/CQA practices, to confirm that the approved MQA/CQA plan was followed and that the facility was constructed as specified in the design.

- *Owner/Operator.* This is the organization that will own and operate the disposal unit. The owner/operator is responsible for the design, construction, and operation of the waste disposal unit. This responsibility includes complying with the requirements of the permitting agency, the submission of MQA/CQA documentation, and assuring the permitting agency that the facility was constructed as specified in the construction plans and specifications and as approved by the permitting agency. The owner/operator has the authority to select and dismiss organizations charged with design, construction, and MQA/CQA. If the owner and operator of a facility are different organizations, the owner is ultimately responsible for these activities. Often the owner/operator, or owner, will be a municipality rather than a private corporation. The interaction of a state office regulating another state or local organization should have absolutely no impact on procedures, intensity of effort and ultimate decisions of the MQA/CQA or MQC/CQC process as described herein.

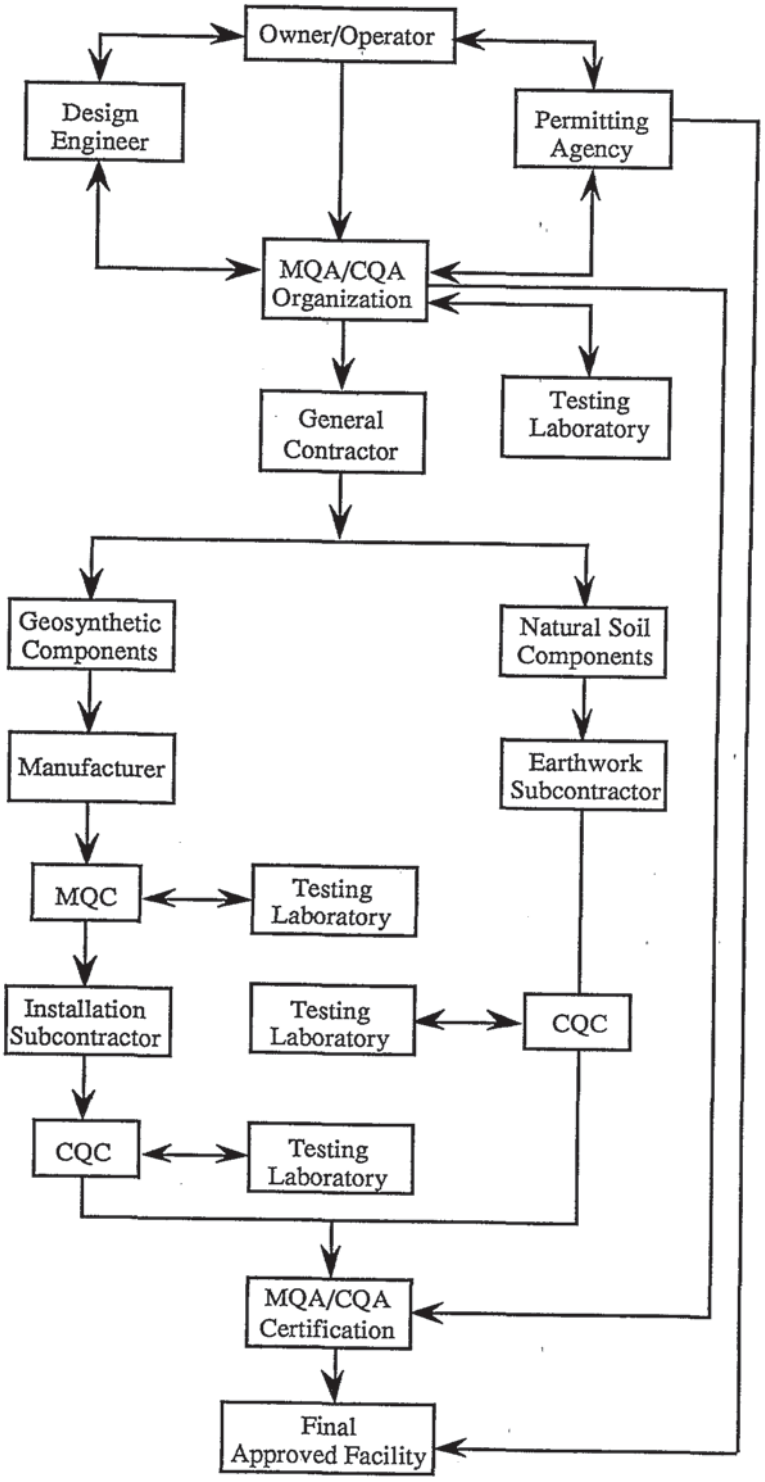

Figure 1.1 - Organizational Structure of MQA/CQA Inspection Activities

- *Owner's Representative.* The owner/operator usually has an official representative who is responsible for coordinating schedules, meetings, and field activities. This responsibility includes communications to other members in the owner/operator's organization, owner's representative, permitting agency, material suppliers, general contractor, specialty subcontractors or installers, and MQA/CQA engineer.

- *Design Engineer.* The design engineer's primary responsibility is to design a waste containment facility that fulfills the operational requirements of the owner/operator, complies with accepted design practices for waste containment facilities, and meets or exceeds the minimum requirements of the permitting agency. The design engineer may be an employee of the owner/operator or a design consultant hired by the owner/operator. The design engineer may be requested to change some aspects of the design if unexpected conditions are encountered during construction (e.g., a change in site conditions, unanticipated logistical problems during construction, or lack of availability of certain materials). Because design changes during construction are not uncommon, the design engineer is often involved in the MQA/CQA process. The plans and specifications referred to in this manual will generally be the product of the Design Engineer. They are a major and essential part of the permit application process and the subsequently constructed facility.

- *Manufacturer.* Many components, including all geosynthetics, of a waste containment facility are manufactured materials. The manufacturer is responsible for the manufacture of its materials and for quality control during manufacture, i.e., MQC. The minimum or maximum (when appropriate) characteristics of acceptable materials should be specified in the permit application. The manufacturer is responsible for certifying that its materials conform to those specifications and any more stringent requirements or specifications included in the contract of sale to the owner/operator or its agent. The quality control steps taken by a manufacturer are critical to overall quality management in construction of waste containment facilities. Such activities often take the form of process quality control, computer-aided quality control and the like. All efforts at producing better quality materials are highly encouraged. If requested, the manufacturer should provide information to the owner/operator, permitting agency, design engineer, fabricator, installer, or MQA engineer that describes the quality control (MQC) steps that are taken during the manufacturing of the product. In addition, the manufacturer should be willing to allow the owner/operator, permitting agency, design engineer, fabricator, installer, and MQA engineer to observe the manufacturing process and quality control procedures if they so desire. Such visits should be able to be made on an announced or unannounced basis. However, such visits might be coordinated with the manufacturer to assure that the appropriate people are present to conduct the tour and that the proper geosynthetic is scheduled for that date so as to obtain the most information from the visit. The manufacturer should have a designated individual who is in charge of the MQC program and to whom questions can be directed and/or through whom visits can be arranged. Random samples of materials should be able to be taken for subsequent analysis and/or archiving. However, the manufacturer should retain the right to insist that any proprietary information concerning the manufacturing of a product be held confidential. Signed agreements of confidentiality are at the option of the manufacturer. The owner/operator, permitting agency, design engineer, fabricator, installer, or MQA engineer may request that they be allowed to observe the manufacture and quality control of some or all of the raw materials and final product to be utilized on a particular job; the manufacturer should be willing to accommodate such requests. Note that these same comments apply to marketing organizations which represent a manufactured product made by others, as well as the manufacturing organization itself.

- *Fabricator*. Some materials are fabricated from manufactured components. For example, certain geomembranes are fabricated by seaming together smaller, manufactured geomembrane sheets at the fabricator's facility. The minimum characteristics of acceptable fabricated materials are specified in the permit application. The fabricator is responsible for certifying that its materials conform to those specifications and any more stringent requirements or specifications included in the fabrication contract with the owner/operator or its agent. The quality control steps taken by a fabricator are critical to overall quality in construction of waste containment facilities. If requested, the fabricator should provide information to the owner/operator, permitting agency, design engineer, installer, or MQA engineer that describes the quality control steps that are taken during the fabrication of the product. In addition, the fabricator should be willing to allow the owner/operator, permitting agency, design engineer, installer, or MQA engineer to observe the fabrication process and quality control procedures if they so desire. Such visits may be made on an announced or unannounced basis. However, such visits might be coordinated with the fabricator to assure that the appropriate people are present to conduct the tour and that the proper geosynthetic is scheduled for that date so as to obtain the most information from the visit. Random samples of materials should be able to be taken for subsequent analysis and/or archiving. However, the fabricator should retain the right to insist that any proprietary information concerning the fabrication of a product be held confidential. Signed agreements of confidentiality are at the option of the fabricator. The owner/operator, permitting agency, design engineer, or MQA engineer may request that they be allowed to observe the fabrication process and quality control of some or all fabricated materials to be utilized on a particular job; the fabricator should be willing to accommodate such a requests.

- *General Contractor*. The general contractor has overall responsibility for construction of a waste containment facility and for CQC during construction. The general contractor arranges for purchase of materials that meet specifications, enters into a contract with one or more fabricators (if fabricated materials are needed) to supply those materials, contracts with an installer (if separate from the general contractor's organization), and has overall control over the construction operations, including scheduling and CQC. The general contractor has the primary responsibility for ensuring that a facility is constructed in accord with the plans and specifications that have been developed by the design engineer and approved by the permitting agency. The general contractor is also responsible for informing the owner/operator and the MQA/CQA engineer of the scheduling and occurrence of all construction activities. Occasionally, a waste containment facility may be constructed without a general contractor. For example, an owner/operator may arrange for all the necessary material, fabrication, and installation contracts. In such cases, the owner/operator's representative will serve the same function as the general contractor.

- *Installation Contractor*. Manufactured products (such as geosynthetics) are placed and installed in the field by an installation contractor who is the general contractor, a subcontractor to the general contractor, or is a specialty contractor hired directly by the owner/operator. The installer's personnel may be employees of the owner/operator, manufacturer, or fabricator, or they may work for an independent installation company hired by the general contractor or by the owner/operator directly. The installer is responsible for handling, storage, placement, and installation of manufactured and/or fabricated materials. The installer should have a CQC plan to detail the proper manner that materials are handled, stored, placed, and installed. The installer is also responsible for informing the owner/operator and the MQA/CQA engineer of the scheduling and

occurrence of all geosynthetic construction activities.

- *Earthwork Contractor.* The earthwork contractor is responsible for grading the site to elevations and grades shown on the plans and for constructing earthen components of the waste containment facility, e.g., compacted clay liners and granular drainage layers according to the specifications. The earthwork contractor may be hired by the general contractor or if the owner/operator serves as the general contractor, by the owner/operator directly. In some cases, the general contractor's personnel may serve as the earthwork contractor. The earthwork contractor is responsible not only for grading the site to proper elevations but also for obtaining suitable earthen materials, transport and storage of those materials, preprocessing of materials (if necessary), placement and compaction of materials, and protection of materials during and (in some cases) after placement. If a test pad is required, the earthwork contractor is usually responsible for construction of the test pad. It is highly suggested that the same earthwork contractor that constructs the test fill also construct the waste containment facility compacted clay liner so that the experience gained from the test fill process will not be lost. Earthwork functions must be carried out in accord with plans and specifications approved by the permitting agency. The earthwork contractor should have a CQC plan (or agree to one written by others) and is responsible for CQC operations aimed at controlling materials and placement of those materials to conform with project specifications. The earthwork contractor is also responsible for informing the owner/operator and the CQA engineer of the scheduling and occurrence of all earthwork construction activities.

- *CQC Personnel.* Construction quality control personnel are individuals who work for the general contractor, installation contractor, or earthwork contractor and whose job it is to ensure that construction is taking place in accord with the plans and specifications approved by the permitting agency. In some cases, CQC personnel, perhaps even a separate company, may also be part of the installation or construction crews. In other cases, supervisory personnel provide CQC or, for large projects, separate CQC personnel, perhaps even a separate company, may be utilized. It is recommended that a certain portion of the CQC staff should be certified* as per the implementation schedule of Table 1.1. The examinations have been available as of October, 1992.

- *MQA/CQA Engineer.* The MQA/CQA engineer has overall responsibility for manufacturing quality assurance and construction quality assurance. The engineer is usually an individual experienced in a variety of activities although particular specialists in soil placement, polymeric materials and geosynthetic placement will invariably be involved in a project. The MQA/CQA engineer is responsible for reviewing the MQA/CQA plan as well as general plans and specifications for the project so that the MQA/CQA plan can be implemented with no contradictions or unresolved discrepancies. Other responsibilities of the MQA/CQA engineer include education of inspection personnel on MQA/CQA requirements and procedures and special steps that are needed on a particular project, scheduling and coordinating of MQA/CQA inspection activities, ensuring that proper procedures are followed, ensuring that testing laboratories are conforming to MQA/CQA requirements and procedures, ensuring that sample custody procedures are followed, confirming that test data are accurately reported and that test data are maintained for later reporting, and preparation of periodic reports. The most important duty of the MQA/CQA engineer is overall responsibility for confirming that the facility was constructed in accord with plans and specifications approved by the

* A certification program is available from the National Institute for Certification of Engineering Technologies (NICET); 1420 King Street; Alexandria, Virginia 22314 (phone: 703-684-2835)

permitting agency. In the event of nonconformance with the project specifications or CQA Plan, the MQA/CQA engineer should notify the owner/operator as to the details and, if appropriate, recommend work stoppage and possibly remedial actions. The MQA/CQA engineer is normally hired by the owner/operator and functions separately of the contractors and owner/operator. The MQA/CQA engineer must be a registered professional engineer who has shown competency and experience in similar projects and is considered qualified by the permitting agency. It is recommended that the person's resume and record on like facilities must be submitted in writing and accordingly accepted by the permitting agency before activities commence. The permitting agency may request additional information from the prospective MQA/CQA engineer and his/her associated organization including experience record, education, registry and ownership details. The permitting agency may accept or deny the MQA/CQA engineer's qualifications based on such data and revelations. If the permitting agency requests additional information or denies the MQA/CQA engineer's qualifications it should be done prior to construction, so that alternatives can be made which do not negatively impact on the progress of the work. The MQA/CQA engineer is usually required to be at the construction site during all major construction operations to oversee MQA/CQA personnel. The MQA/CQA engineer is usually the MQA/CQA certification engineer who certifies the completed project.

Table 1.1 - Recommended Impentation Program for Construction Quality Control (CQC) for Geosynthetics* (Beginning January 1, 1993)

No. of Field Crews** At Each Site	End of 18 Months (i.e., June 30, 1994)	End of 36 Months (i.e., January 1, 1996)
1-4	1 - Level II	1 - Level III***
≥ 5	1 - Level II	1 - Level III***
	2 - Level I	1 - Level I

*Certification for natural materials is under development as of this writing
**Performing a Critical Operation; Typically 4 to 6 People/Crew
***Or PE with applicable experience

- *MQA/CQA Personnel.* Manufacturing quality assurance and construction quality assurance personnel are responsible for making observations and performing field tests to ensure that a facility is constructed in accord with the plans and specifications approved by the permitting agency. MQA/CQA personnel normally are employed by the same firm as the MQA/CQA engineer, or by a firm hired by the firm employing the MQA/CQA engineer. Construction MQA/CQA personnel report to the MQA/CQA engineer. A relatively large proportion (if not the entire group) of the MQA/CQA staff should be certified. Table 1.2 gives the currently recommended implementation schedule. As mentioned previously, certification examinations have been available as of October, 1992, from the National Institute for Certification of Engineering Technologies in Alexandria, Virginia.

- *Testing Laboratory.* Many MQC/CQC and MQA/CQA tests are performed by commercial laboratories. The testing laboratory should have its own internal QC plan to ensure that laboratory procedures conform to the appropriate American Society for Testing and Materials (ASTM) standards or other applicable testing standards. The testing laboratory is responsible for ensuring that tests are performed in accordance with applicable methods and standards, for following internal QC procedures, for maintaining sample chain-of-custody records, and for reporting data. The testing laboratory must be willing to allow the owner/operator, permitting agency, design engineer, installer, or MQA/CQA engineer to observe the sample preparation and testing procedures, or record-keeping procedures, if they so desire. The owner/operator, permitting agency, design engineer, or MQA/CQA engineer may request that they be allowed to observe some or all tests on a particular job at any time, either announced or unannounced. The testing laboratory personnel must be willing to accommodate such a request, but the observer should not interfere with the testing or slow the testing process.

Table 1.2 - Recommended Implementation Program for Construction Quality Assurance (CQA) for Geosynthetics* (Beginning January 1, 1993)

No. of Field Crews** At Each Site	End of 18 Months (i.e., June 30, 1994)	End of 36 Months (i.e., January 1, 1996)
1-2	1 - Level II	1 - Level III***
3-4	1 - Level II 1 - Level I	1 - Level III*** 1 - Level I
≥ 5	1 - Level II 2 - Level I	1 - Level III*** 1 - Level II 1 - Level I

*Certification for natural materials is under development as of this writing
**Performing a Critical Operation; Typically 4 to 6 People/Crew
***Or PE with applicable experience

- *MQA/CQA Certifying Engineer.* The MQA/CQA certifying engineer is responsible for certifying to the owner/operator and permitting agency that, in his or her opinion, the facility has been constructed in accord with plans and specifications and MQA/CQA document approved by the permitting agency. The certification statement is normally accompanied by a final MQA/CQA report that contains all the appropriate documentation, including daily observation reports, sampling locations, test results, drawings of record or sketches, and other relevant data. The MQA/CQA certifying engineer may be the MQA/CQA engineer or someone else in the MQA/CQA engineer's organization who is a registered professional engineer with experience and competency in certifying like installations.

1.3 Personnel Qualifications

The key individuals involved in MQA/CQA and their minimum recommended qualifications are listed in Table 1.3.

Table 1.3 - Recommended Personnel Qualifications

Individual	Minimum Recommended Qualifications
Design Engineer	Registered Professional Engineer
Owner's Representative	The specific individual designated by the owner with knowledge of the project, its plans, specifications and QC/QA documents.
Manufacturer/Fabricator	Experience in manufacturing, or fabricating, at least 1,000,000 m^2 (10,000,000 ft^2) of similar geosynthetic materials.
MQC Personnel	Manufacturer, or fabricator, trained personnel in charge of quality control of the geosynthetic materials to be used in the specific waste containment facility.
MQC Officer	The individual specifically designated by a manufacturer or fabricator, in charge of geosynthetic material quality control.
Geosynthetic Installer's Representative	Experience installing at least 1,000,000 m^2 (10,000,000 ft^2) of similar geosynthetic materials.
CQC Personnel	Employed by the general contractor, installation contractor or earthwork contractor involved in waste containment facilities; certified to the extent shown in Table 1.1.
CQA Personnel	Employed by an organization that operates separately from the contractor and the owner/operator; certified to the extent shown in Table 1.2.
MQA/CQA Engineer	Employed by an organization that operates separately from the contractor and owner/operator; registered Professional Engineer and approved by permitting agency.
MQA/CQA Certifying Engineer	Employed by an organization that operates separately from the contractor and owner/operator; registered Professional Engineer in the state in which the waste containment facility is constructed and approved by the appropriate permitting agency.

1.4 Written MQA/CQA Plan

Quality assurance begins with a quality assurance plan. This includes both MQA and CQA. These activities are never ad hoc processes that are developed while they are being implemented. A written MQA/CQA plan must precede any field construction activities.

The MQA/CQA plan is the owner/operator's written plan for MQA/CQA activities. The MQA/CQA plan should include a detailed description of all MQA/CQA activities that will be used during materials manufacturing and construction to manage the installed quality of the facility. The MQA/CQA plan should be tailored to the specific facility to be constructed and be completely integrated into the project plans and specifications. Differences should be settled before any construction work commences.

Most state and federal regulatory agencies require that a MQA/CQA plan be submitted by the owner/operator and be approved by that agency prior to construction. The MQA/CQA plan is usually part of the permit application.

A copy of the site-specific plans and specifications, MQA/CQA plan, and MQA/CQA documentation reports should be retained at the facility by the owner/operator or the MQA/CQA engineer. The plans, specifications, and MQA/CQA documents may be reviewed during a site inspection by the permitting agency and will be the chief means for the facility owner/operator to demonstrate to the permitting agency that MQA/CQA objectives for a project are being met.

Written MQA/CQA plans vary greatly from project to project. No general outline or suggested list of topics is applicable to all projects or all regulatory agencies. The elements covered in this document provides guidance on topics that should be addressed in the written MQA/CQA plan.

1.5 Documentation

A major purpose of the MQA/CQA process is to provide documentation for those individuals who were unable to observe the entire construction process (e.g., representatives of the permitting agency) so that those individuals can make informed judgments about the quality of construction for a project. MQA/CQA procedures and results must be thoroughly documented.

1.5.1 Daily Inspection Reports

Routine daily reporting and documentation procedures should be required. Inspectors should prepare daily written inspection reports that may ultimately be included in the final MQA/CQA document. Copies of these reports should be available from the MQA/CQA engineer. The daily reports should include information about work that was accomplished, tests and observations that were made, and descriptions of the adequacy of the work that was performed.

1.5.2 Daily Summary Reports

A daily written summary report should be prepared by the MQA/CQA engineer. This report provides a chronological framework for identifying and recording all other reports and aids in tracking what was done and by whom. As a minimum, the daily summary reports should contain the following (modified from Spigolon and Kelly, 1984, and EPA, 1986):

- Date, project name, location, waste containment unit under construction, personnel involved in major activities and other relevant identification information;
- Description of weather conditions, including temperature, cloud cover, and precipitation;
- Summaries of any meetings held and actions recommended or taken;
- Specific work units and locations of construction underway during that particular day;
- Equipment and personnel being utilized in each work task, including subcontractors;
- Identification of areas or units of work being inspected;
- Unique identifying sheet number of geomembranes for cross referencing and document control;
- Description of off-site materials received, including any quality control data provided by the supplier;
- Calibrations or recalibrations of test equipment, including actions taken as a result of recalibration;
- Decisions made regarding approval of units of material or of work, and/or corrective actions to be taken in instances of substandard or suspect quality;
- Unique identifying sheet numbers of inspection data sheets and/or problem reporting and corrective measures used to substantiate any MQA/CQA decisions described in the previous item;
- Signature of the MQA/CQA engineer.

1.5.3 Inspection and Testing Reports

All observations, results of field tests, and results of laboratory tests performed on site or off site should be recorded on a suitable data sheet. Recorded observations may take the form of notes, charts, sketches, photographs, or any combination of these. Where possible, a checklist may be useful to ensure that pertinent factors are not overlooked.

As a minimum, the inspection data sheets should include the following information (modified from Spigolon and Kelly, 1984, and EPA, 1986):

- Description or title of the inspection activity;
- Location of the inspection activity or location from which the sample was obtained;
- Type of inspection activity and procedure used (reference to standard method when appropriate or specific method described in MQA/CQA plan);
- Unique identifying geomembrane sheet number for cross referencing and document control;

- Recorded observation or test data;
- Results of the inspection activity (e.g., pass/fail); comparison with specification requirements;
- Personnel involved in the inspection besides the individual preparing the data sheet;
- Signature of the MQA/CQA inspector and review signature by the MQA/CQA engineer.

1.5.4 Problem Identification and Corrective Measures Reports

A problem is defined as material or workmanship that does not meet the requirements of the plans, specifications or MQA/CQA plan for a project or any obvious defect in material or workmanship, even if there is conformance with plans, specifications and the MQA/CQA plan. As a minimum, problem identification and corrective measures reports should contain the following information (modified from EPA, 1986):

- Location of the problem;
- Description of the problem (in sufficient detail and with supporting sketches or photographic information where appropriate) to adequately describe the problem;
- Unique identifying geomembrane sheet number for cross referencing and document control;
- Probable cause;
- How and when the problem was located (reference to inspection data sheet or daily summary report by inspector);
- Where relevant, estimation of how long the problem has existed;
- Any disagreement noted by the inspector between the inspector and contractor about whether or not a problem exists or the cause of the problem;
- Suggested corrective measure(s);
- Documentation of correction if corrective action was taken and completed prior to finalization of the problem and corrective measures report (reference to inspection data sheet, where applicable);
- Where applicable, suggested methods to prevent similar problems;
- Signature of the MQA/CQA inspector and review signature of MQA/CQA engineer.

1.5.5 Drawings of Record

Drawings of record (also called "as-built" drawings) should be prepared to document the actual lines and grades and conditions of each component of the disposal unit. For soil components, the record drawings shall include survey data that show bottom and top elevations of a particular component, the plan dimensions of the component, and locations of all destructive test samples. For geosynthetic components, the record drawings often show the dimensions of all

geomembrane field panels, the location of each panel, identification of all seams and panels with appropriate identification numbering or lettering, location of all patches and repairs, and location of all destructive test samples. Separate drawings are often needed to show record cross sections and special features such as sump areas.

1.5.6 Final Documentation and Certification

At the completion of a project, or a component of a large project, the owner/operator should submit a final report to the permitting agency. This report may include all of the daily inspection reports, the daily MQA/CQA engineer's summary reports, inspection data sheets, problem identification and corrective measures reports, and other documentation such as quality control data provided by manufacturers or fabricators, laboratory test results, photographs, as-built drawings, internal MQA/CQA memoranda or reports with data interpretation or analyses, and design changes made by the design engineer during construction. The document should be certified correct by the MQA/CQA certifying engineer.

The final documentation should emphasize that areas of responsibility and lines of authority were clearly defined, understood, and accepted by all parties involved in the project (assuming that this was the case). Signatures of the owner/operator's representative, design engineer, MQA/CQA engineer, general contractor's representative, specialty subcontractor's representative, and MQA/CQA certifying engineer may be included as confirmation that each party understood and accepted the areas of responsibility and lines of authority outlined in the MQA/CQA plan.

1.5.7 Document Control

The MQA/CQA documents which have been agreed upon should be maintained under a document control procedure. Any portion of the document(s) which are modified must be communicated to and agreed upon by all parties involved. An indexing procedure should be developed for convenient replacement of pages in the MQA/CQA plan, should modifications become necessary, with revision status indicated on appropriate pages.

A control scheme should be implemented to organize and index all MQA/CQA documents. This scheme should be designed to allow easy access to all MQA/CQA documents and should enable a reviewer to identify and retrieve original inspection reports or data sheets for any completed work element.

1.5.8 Storage of Records

During construction, the MQA/CQA engineer should be responsible for all MQA/CQA documents. This includes a copy of the design criteria, plans, specifications, MQA/CQA plan, and originals of all data sheets and reports. Duplicate records should be kept at another location to avoid loss of this valuable information if the originals are destroyed.

Once construction is complete, the document originals should be stored by the owner/operator in a manner that will allow for easy access while still protecting them from damage. An additional copy should be kept at the facility if this is in a different location from the owner/operator's main files. A final copy should be kept by the permitting agency. All documentation should be maintained through the operating and post-closure monitoring periods of the facility by the owner/operator and the permitting agency in an agreed upon format (paper hard copy, microfiche, electronic medium, etc.).

1.6 Meetings

Communication is extremely important to quality management. Quality construction is easiest to achieve when all parties involved understand clearly their responsibility and authority. Meetings can be very helpful to make sure that responsibility and authority of each organization is clearly understood. During construction, meetings can help to resolve problems or misunderstandings and to find solutions to unanticipated problems that have developed.

1.6.1 Pre-Bid Meeting

The first meeting is held to discuss the MQA/CQA plan and to resolve differences of opinion before the project is let for bidding. The pre-bid meeting is held after the permitting agency has issued a permit for a waste containment facility and before a construction contract has been awarded. The pre-bid meeting is held before construction bids are prepared so that the companies bidding on the construction will better understand the level of MQA/CQA to be employed on the project. Also, if the bidders identify problems with the MQA/CQA plan, this affords the owner/operator an opportunity to rectify those problems early in the process.

1.6.2 Resolution Meeting

The objectives of the resolution meeting are to establish lines of communication, review construction plans and specifications, emphasize the critical aspects of a project necessary to ensure proper quality, begin planning and coordination of tasks, and anticipate any problems that might cause difficulties or delays in construction. The meeting should be attended by the owner/operator's representative, design engineer, representatives of the general contractor and/or major subcontractors, the MQA/CQA engineer, and the MQA/CQA certifying engineer.

The resolution meeting normally involves the following activities:

- An individual is assigned to take minutes (usually a representative of the owner/operator or of the MQA/CQA engineer's organization);
- Individuals are introduced to one another and their responsibilities (or potential responsibilities) are identified;
- Copies of the project plans and specifications are made available for discussion;
- The MQA/CQA plan is distributed;
- Copies of any special permit restrictions that are relevant to construction or MQA/CQA are distributed;
- The plans and specifications are described, any unique design features are discussed (so the contractors will understand the rationale behind the general design), any potential construction problems are identified and discussed, and questions from any of the parties concerning the construction are discussed;
- The MQA/CQA plan is reviewed and discussed, with the MQA/CQA engineer and MQA/CQA certifying engineer identifying their expectations and identifying the most critical components;

- Procedures for MQC/CQC proposed by installers and contractors are reviewed and discussed;
- Corrective actions to resolve potential construction problems are discussed;
- Procedures for documentation and distribution of documents are discussed;
- Each organization's responsibility, authority, and lines of communication are discussed;
- Suggested modifications to the MQA/CQA plan that would improve quality management on the project are solicited; and
- Construction variables (e.g., precipitation, wind, temperature) and schedule are discussed.

It is very important that the procedures for inspection and testing be known to all, that the criteria for pass/fail decisions be clearly defined (including the resolution of test data outliers), that all parties understand the key problems that the MQA/CQA personnel will be particularly careful to identify, that each individual's responsibilities and authority be understood, and that procedures regarding resolution of problems be understood. The resolution meeting may be held in conjunction with either the pre-bid meeting (rarely) or the pre-construction meeting (often).

1.6.3 Pre-construction Meeting

The pre-construction meeting is held after a general construction contract has been awarded and the major subcontractors and material suppliers are established. It is usually held concurrent with the initiation of construction. The purpose of this meeting is to review the details of the MQA/CQA plan, to make sure that the responsibility and authority of each individual is clearly understood, to agree on procedures to resolve construction problems, and to establish a foundation of cooperation in quality management. The pre-construction meeting should be attended by the owner/operator's representative, design engineer, representatives of the general contractor and major subcontractors, the MQA/CQA engineer, the MQA/CQA certifying engineer, and a representative from the permitting agency, if that agency expects to visit the site during construction or independently observe MQA/CQA procedures.

The pre-construction meeting should include the following activities:

- Assign an individual (usually representative of MQA/CQA engineer) to take minutes;
- Introduce parties and identify their responsibility and authority;
- Distribute the MQA/CQA plan, identify any revisions made after the resolution meeting, and answer any questions about the MQA/CQA plan, procedures, or documentation;
- Discuss responsibilities and lines of communication;
- Discuss reporting procedures, distribution of documents, schedule for any regular meetings, and resolution of construction problems;
- Review site requirements and logistics, including safety procedures;

- Review the design, discuss the most critical aspects of the construction, and discuss scheduling and sequencing issues;
- Discuss MQC procedures that the geosynthetics manufacturer(s) will employ;
- Discuss CQC procedures that the installer or contractor will employ, for example, establish and agree on geomembrane repair procedures;
- Make a list of action items that require resolution and assign responsibilities for these items.

1.6.4 Progress Meetings

Weekly progress meetings should be held. Weekly meetings can be helpful in maintaining lines of communication, resolving problems, identifying action items, and improving overall quality management. When numerous critical work elements are being performed, the frequency of these meetings can be increased to biweekly, or even daily. Persons who should attend this meeting are those involved in the specific issues being discussed. At all times the MQA/CQA engineer, or designated representative, should be present.

1.7 Sample Custody

All samples shall be identified as described in the MQA/CQA plan. Whenever a sample is taken, a chain of custody record should be made for that sample. If the sample is transferred to another individual or laboratory, records shall be kept of the transfer so that chain of custody can be traced. The purpose of keeping a record of sample custody is to assist in tracing the cause of anomalous test results or other testing problem, and to help prevent accidental loss of test samples.

Soil samples are usually discarded after testing. Destructive testing samples of geosynthetic materials are often taken in triplicate, with one sample tested by CQC personnel, one tested by CQA personnel, and the third retained in storage as prescribed in the CQA plan.

1.8 Weather

Weather can play a critical role in the construction of waste containment facilities. Installation of all geosynthetic materials (including geosynthetic clay liners) and natural clay liners is particularly sensitive to weather conditions, including temperature, wind, humidity, and precipitation. The contractor or installer is responsible for complying with the contract plans and specifications (along with the MQC/CQC plans for the various components of the system). Included in this information should be details which restrict the weather conditions in which certain activities can take place. It is the responsibility of the contractor or installer to make sure that these weather restrictions are observed during construction.

1.9 Work Stoppages

Unexpected work stoppages can occur due to a variety of causes, including labor strikes, contractual disputes, weather, QC/QA problems, etc. The MQA/CQA engineer should be particularly careful during such stoppages to determine (1) whether in-place materials are covered and protected from damage (e.g., lifting of a geomembrane by wind or premature hydration of geosynthetic clay liners); (2) whether partially covered materials are protected from damage (e.g., desiccation of a compacted clay liners); and (3) whether manufactured materials are properly stored and properly or adequately protected (e.g., whether geotextiles are protected from ultraviolet

exposure). The cessation of construction should not mean the cessation of MQA/CQA inspection and documentation.

1.10 References

Spigolon, S.J., and M.F. Kelly (1984), "Geotechnical Assurance of Construction of Disposal Facilities," U. S. Environmental Protection Agency, EPA 600/2-84-040, Cincinnati, Ohio.

U.S. Environmental Protection Agency (1986), "Technical Guidance Document, Construction Quality Assurance for Hazardous Waste Land Disposal Facilities," EPA/530-SW-86-031, Cincinnati, Ohio, 88 p.

U.S. Environmental Protection Agency (1988a), "Design, Construction, and Evaluation of Clay Liners for Waste Management Facilities," EPA/530-SW-86-007F, Cincinnati, Ohio.

U.S. Environmental Protection Agency (1988b), "Lining of Waste Containment and Other Impoundment Facilities," EPA/600/2-88/052, Cincinnati, Ohio.

U. S. Environmental Protection Agency (1989), "Requirements for Hazardous Waste Landfill Design, Construction, and Closure," EPA/625/4-89/022, Cincinnati, Ohio.

U.S. Environmental Protection Agency (1991a), "Inspection Techniques for the Fabrication of Geomembrane Field Seams," EPA/530/SW-91/051, Cincinnati, Ohio.

U. S. Environmental Protection Agency (1991b), "Design and Construction of RCRA/CERCLA Final Covers," EPA/625/4-91/025, Cincinnati, Ohio.