June 14, 2012

Mr. Joseph T. Martella II – Senior Engineer
RIDEM / Office of Waste Management
235 Promenade Street
Providence, RI 02908

RE: Response to May 10, 2012 Comments
Rhode Island Department of Environmental Management
Draft Remedial Action Work Plan
Former Gorham Manufacturing Facility – Park Parcel (a.k.a. Parcel C-1)
333 Adelaide Avenue, Providence, RI
Case No. 200-059 (Associated with Case No. 97-030)

Dear Mr. Martella:

These response to comments address both RIDEM's comments dated May 10, 2012 and the Environmental Justice League of Rhode Island's comments on the February 2012 Draft RAWP. Please note that any changes made to the construction drawings and specifications Appendices A and B of the Remedial Action Work Plan (RAWP) have been shown in red-line strikeout.

RIDEM's Draft RAWP Review Comments

COMMENT 1: Regarding Section 3.1.1 (Western Shoreline Soil Excavation), and Section 3.1.2 (Former Slag Area Removal and Testing) – The descriptions of the excavation activities should specify that all confirmatory soil samples will be grab samples, and should also list the specific laboratory analytical methods to be performed on each collected sample as applicable. In addition, the specific soil management details for all excavated regulated soils (i.e., how it will be managed from the time it is excavated to the time it is placed under a cap or disposed of off-site at a licensed disposal facility), should also be described.

RESPONSE: *The RAWP has been amended to state that all confirmatory soil samples will be grab samples, and the list of laboratory analytical methods are included for each collected sample. Also, specific soil management details were added for all excavated soils as follows: soil from the western shoreline excavation will be placed in a dump truck for immediate disposal under the soil cover system, or it will be placed in a roll-off container, covered, and disposed under the soil cover system later in the construction sequence; and excavated soil from the former slag area will be directly loaded into dump trucks or roll-off containers, and covered, for transportation and off-site disposal at a permitted facility.*

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COMMENT 2: Section 3.3 (Preferred Remedial Alternative) indicates that *"Stormwater management will be included with the construction of the cap to maintain its integrity and recharge stormwater runoff into the buffer zone, wetlands, and Cove."*

a) Please provide a brief but comprehensive description of the proposed plans for storm water management.

RESPONSE: *Section 3.6 Stormwater Management has been added to the RAWP to summarize the engineering controls used during the Phase I Cap construction to manage surface water runoff. Storm water management includes the installation of hay bales, silt fence, stabilized construction entrance, erosion control matting on the cap surface and maintenance of the turbidity curtain in the Inner Cove. Surface water run-off from the adjacent retail and high school parcels upslope from the cap will drain to the adjacent detention basin. The potential surface water runoff from Parcel C will be contained on property for infiltration prior to entering Parcel C-1 capped area. The cap has been designed to address limited surface water runoff within the capped area for flow into the Mashapaug Cove. The response to this comment is discussed further in the response to EJLRI Comment No. 1.*

b) Regarding the Rhode Island Pollutant Discharge Elimination System (RIPDES) Program review of the RAWP – It is the OWM's understanding that discussions are ongoing between Textron/Amec and the Department's Office of Customer and Technical Assistance (OC&TA) concerning RIPDES Program requirements.

RESPONSE: *AMEC has had discussions with OC&TA regarding the submittal of a notice of intent (NOI) and preparation of a Storm Water Pollution Prevention Plan (SWP3) for the Phase I capping activities. The SWP3 will be prepared following the selection and coordination with the construction contractor. This SWP3 will be retained on site throughout the construction period and will include the inspection and maintenance of the erosion control measures. The NOI will be submitted to OC&TA approximately two weeks prior to the start of construction for review and comment.*

c) In its responses to the July 12, 2011 Phase I Park Parcel Public Meeting, specifically Comment 11, Textron indicated *"The design details for storm water management will be included in the construction drawings and specifications for review by RIDEM prior to construction."* Please provide a site figure detailing the proposed design details for storm water management.

RESPONSE: *The locations of storm water management controls are shown on contract drawings C-102, C-103, and C-104. The details of the proposed storm water management controls are shown on contract drawing C-501. These updated construction drawings have been included with the Final RAWP.*

COMMENT 3: Regarding Section 3.4 (Installation of Monitoring Wells) - The Department concurs that the future groundwater monitoring program for the Gorham Site will be developed as part of the comprehensive Site wide groundwater RAWP.

RESPONSE: *Agreed. The construction details for the two new monitoring wells have been included on contract drawing C-503 and Specification Section 02522, included with the Final RAWP.*

COMMENT 4: Regarding Section 6.0 (Contractors and/or Consultants) - The Department acknowledges that selection of the analytical laboratory and some of the project contractors will be conducted through a bidding process, and when contracts are awarded, Amec will notify the Department. Please clarify whether the construction contractor and the earthworks contractor will be a single contractor, or two individual contractors. Also, please clarify whether there are any other potential contractors that still need to be selected.

RESPONSE: *The general contractor will be selected through a bidding process. The general contractor will subcontract with other trades (i.e., transporter, disposal facility, landscaper) as necessary. AMEC will contract with the analytical laboratory supporting the confirmatory soil analyses. A list of the contractors and subcontractors roles and responsibilities will be provided to RIDEM prior to the start of construction.*

COMMENT 5: Regarding Section 8.0 (Set Up Plans), which references Specification Section 01110 "Summary of Work"(Appendix B):

a) Do the proposed erosion and sedimentation controls include hay bales and silt fencing?

RESPONSE: *Yes, as shown on contract drawing C-501 and Specification Section 02370.*

b) Please provide a site figure detailing the locations and types of proposed erosion and sedimentation controls.

RESPONSE: *The locations of stormwater management controls are shown on contract drawings C-102, C-103, and C-104. The details of the proposed stormwater management controls are shown on contract drawing C-501.*

COMMENT 6: Section 9.0 (Effluent Disposal), indicates that waste handling and disposal will be in accordance with the requirements of Specification Section 02110 (Waste Excavation, Removal, and Handling) and Section 02120 (Off-Site Transportation and Disposal), however neither of these Sections appear to be included in the RAWP.

RESPONSE: *These sections have been included in the Final RAWP.*

COMMENT 7: Regarding Section 10.0 (Contingency Plan/Health and Safety Plan):

a) The Department acknowledges Amec's statement that its Contingency Plans are documented within the Amec Health and Safety Plan (HASP) for Phase 1 Parcel C-1 Soil Capping, and will be available on site at all times during the implementation and operations of the Phase 1 remedial action. In accordance with Rule 9.13 of the Remediation Regulations, a copy of the Contingency Plan should be included in the RAWP, so therefore the Department requests that the Amec HASP be included as an attachment or Appendix to the RAWP.

RESPONSE: *The AMEC HASP has been included in the Final RAWP as Appendix E. The general contractor will prepare their own HASP and will provide a copy to AMEC to be available for RIDEM review, if requested.*

b) Regarding the second paragraph on page 10-1, it appears that the citation for Specification Section 01350 (Safety, Health, and Emergency Response) is incorrect and should be revised to 01351.

RESPONSE: *The citation has been revised to 01351.*

c) Appendix B (Specifications), Section 01110 (Summary of Work) and Section 01351 (Safety, Health, and Emergency Response), both indicate that the "Contractor" shall prepare and submit a Site HASP. It is presumed that the "Contractor" referenced in these Sections is not Amec, and the Amec HASP referenced in comment 7.a above is not the same as the "Contractor" HASP(s) referenced here. How many individual "Contractor" HASPs are anticipated to be generated?

RESPONSE: *AMEC has a site specific HASP and the general contractor will be required to submit their own site specific HASP. Subcontractors will be expected to read and comply with the general contractor's HASP.*

d) The RAWP states that dust monitoring will be performed in the work zone using hand held real-time continuous air monitoring instruments and at the work area perimeter using monitoring instruments to measure aerosol dust and automatically store data for subsequent retrieval.

RESPONSE: *Potential risks from prolonged exposure to respirable dust are related to the presence of lead, chromium, arsenic and silver that have previously been detected in some prior site soil samples. Tasks that could generate dust require fixed perimeter air monitoring stations, one station located upwind of the site activities and three locations located at the other sides of the work activities. These stations will be set within the adult breathing zone or approximately 5-feet above the ground surface. This monitoring data will be collected on a daily basis and* *sent to an off-site laboratory for analysis of particulate matter and metals. This monitoring program will also include visual monitoring and a handheld mini-RAM device for real time measurement of dust. These measurements will be collected immediately downwind of the construction activities and will be logged every two hours of the work day. These logs will include notations regarding ongoing construction activities being monitored, engineering controls being implemented, the results and any required corrective actions. At the end of each week these logs will be scanned and pdf files provided to RIDEM via email the following Monday for upload to the project website.*

Construction activity will be stopped and corrective actions implemented if these results exceed the action level of 0.29 mg/m3 which is protective of worker health under the OSHA lead standard and given the known concentrations in Site soils. This action level is also based on the actual measured site data during the July 2006 slag removal action conducted at the site. More details regarding the general contractors responsibilities is presented in specification 01560 and has been included in AMEC's existing HASP, and will be included in the general contractors HASP. Table 4-1 of the AMEC HASP lists the contaminants of concern and their threshold values (Appendix E, Section 4). Section 10 of the RAWP has been updated to respond to all eight of the specific comments below:

i) What are the proposed plans for measuring and monitoring dust concentrations at the property line?

ii) Are dust concentrations proposed to be measured in the breathing zone, and how is the breathing zone being defined?

iii) What are the maximum detected concentrations of the contaminants of concern that could be present in dust generated during work activities at the site?

iv) What concentration of each contaminant measured in respirable dust could present a risk to on-site workers and off-site student or residential populations?

v) What were the sources of these risk based concentrations (i.e., published regulatory standards, etc.) and/or how were these concentrations derived/calculated? Please provide references and documentation.

vi) Since the air monitoring instruments measure particulate dust concentrations, but not specific contaminants in dust, how have the individual contaminant risk concentrations referenced in item iv above, been translated into conservative risk-based protective dust concentrations for the work zone, work perimeter and property line areas?

vii) What are the proposed action levels for instrument measured dust concentrations that will trigger required responses in the work zone, work perimeter and property line areas, and what are the proposed action level threshold duration periods at each zone before responses are implemented (i.e., immediate response upon action level exceedance, response after sustained action level exceedance for minimum of 5 minutes, response after X number of short duration exceedances, etc.)?

viii) What are the proposed required responses in the work zone, work perimeter and property line areas, in the event of an action level exceedance (i.e., temporary work stoppage, implementation of dust suppression methods, etc.)?

e) Will the dust monitoring instruments be equipped with an alarm to alert on-site workers if an exceedance of an action level is measured?

RESPONSE: *Yes, the mini-RAM will be set with an alarm to trigger the exceedance of established site criteria. This will be operated by AMEC as part of the construction oversight activities.*

f) Is any real-time volatile organic compound (VOC) monitoring or screening proposed during work activities? If so, please provide details such as proposed monitoring devices, monitoring locations, proposed action levels that trigger required responses, and proposed responses.

RESPONSE: *Yes, a PID will be used to monitor the ambient air during the grading, soil excavation and soil sampling activities. Please note that based on the proposed scope of work and investigation activities to date, it is not anticipated that VOC-impacted soils of concern will be encountered.*

g) Since elevated levels of methane gas have been documented in subsurface fill at certain locations on the Gorham site, are there any plans to field screen or monitor for methane or combustible gas with a combustible gas meter (CGI) during planned intrusive work in areas where fill is either known to exist or may be present in the subsurface?

RESPONSE: *Methane gas has only been detected in limited concentrations in the center of Parcel C and nowhere else on Site. The fill found on Parcel C-1 is industrial and does not include municipal waste, the primary source of methane gas. Cuts and fills required for site grading have been minimized typically to the top few feet to balance the site and limit as much as possible the movement of the existing fill material. Therefore, monitoring for methane will not be included with the proposed construction monitoring activities.*

COMMENT 8: Regarding Appendix B (Specifications), Section 01340 (Submittal Schedule Attachment) - Why do the references to Section 02101 (Clearing and Grubbing) and Section

02370 (Erosion and Sedimentation Control) indicate (No submittals required), when they are both cited as references in other Sections of the RAWP?

RESPONSE: *Please refer to updated Section 01330 (Submittal Procedures), Section 02231 (Clearing and Grubbing), and Section 02370 (Erosion and Sedimentation Control)*

COMMENT 9: Regarding Appendix B (Specifications), Section 01510 (Temporary Facilities and Controls):

a) Part 1, item 101.A.2.e - Soil Stockpile Areas, indicates *(see Section 02300, "earthwork", for information).* Section 02300 (Earthwork) 3.07.B.2.a, indicates that *"Stockpiles shall be constructed in accordance with Section 02110 - Waste Excavation, Removal, and Handling."* As previously indicated, Section 02110 is not included in the RAWP.

RESPONSE: *Section 02110 has been included in the Final RAWP*

b) Regarding Part 1, item 101.A.2.f – Decontamination pad – Please provide additional details about the decontamination pad, including its planned dimensions, construction details (i.e., liner specifications, secondary containment and/or runoff controls, etc.), and proposed location.

RESPONSE: *Specification Section 01354 includes details for the decontamination pad.*

COMMENT 10: Regarding Appendix B (Specifications), Section 02300 (Earthwork):

a) In Part 1.02 (Related Work Specified Elsewhere), 7 of the 12 listed Sections do not appear to be included anywhere in Appendix B. Several of these Sections are specifically referenced numerous times throughout the main body of the RAWP and also in many of the individual Specification Sections of Appendix B. Please clarify whether these Sections were omitted from the submittal intentionally, and if so, where the referenced details are discussed in the RAWP, otherwise, please provide these Sections.

RESPONSE: *The revised contract specifications are now complete and have been included within Appendix B of the Final RAWP.*

b) In Part 3.07 (Handling and Temporary On-Site Storage of Excavated Materials), reference is made to the *"designated Waste Staging and Storage Area as shown on the Drawings."* Please provide additional details about the designated Waste Staging and Storage Area including its proposed location (text description and site figure), construction details, a list of what items may be stored there, material management specifications (i.e., plans for material segregation and tracking, proposed usage of polyethylene liners and covers, storage containers [i.e., rolloffs, drums, and/or live loading of trucks], applicable dust, erosion and sedimentation controls, etc.), and final area decommissioning plans.

RESPONSE: *The lay down areas for waste staging and storage areas are located on Sheet C-101. See Sheet G-001 and Specification Section 02110 (Waste Excavation, Removal and Handling) for stockpiling and on-site management of materials and Specification Section 02120 (Off-Site Transportation and Disposal) for off-site material handling.*

c) Part 3.07 (Handling and Temporary On-Site Storage of Excavated Materials), and Part 3.08 (Sampling, Analysis, and Characterization), both reference Section 02110 (Waste Excavation, Removal, and Handling), but as noted in comments 6 and 10.a above, this important Section does not appear to be included in Appendix B.

RESPONSE: *Section 02110 has been included in the Final RAWP.*

COMMENT 11: In accordance with Rule 11.09 (Closure and Post Closure) of the Remediation Regulations, compliance with the Remedial Action Approval shall be documented in a Closure Report submitted to the Department for review and approval. The RAWP should include a statement indicating that a Remedial Action Closure Report will be prepared and submitted to the Department documenting the work performed and including at a minimum the following items:

a) A post remediation survey of the entire Phase I Park Parcel Site with as-built plans demarcating the exact location (e.g., vertical and horizontal extent and type) of the installed engineered controls, including: geotextile material, clean fill, and as applicable any utilities, structures, basins, swales, storm water management features, and current groundwater monitoring locations.

b) Analytical results and summary of all air and dust monitoring and/or sampling performed throughout the project.

c) All original laboratory analytical data results from the remedial activities, compliance and confirmation sampling, as applicable.

d) Documentation that all excess regulated soil, solid waste, remediation waste, etc. was properly disposed of off-site at an appropriately licensed facility in accordance with all applicable laws.

RESPONSE: *Agreed, the Final RAWP includes a statement indicating that a Remedial Action Closure Report will be prepared and submitted to the Department with the minimum requirements listed.*

COMMENT 12: The Department has not completed its review of the draft ELUR and will be supplying comments on that document separately. Please resubmit a track changes version of the proposed ELUR in electronic format and showing all text changes (additions and deletions) that have been made from the Department's boilerplate ELUR, for the purpose of facilitating its review by the Department's Office of Legal Services.

RESPONSE: *Textron provided an electronic comparison of the draft ELUR for Parcel C-1 and RIDEM ELUR boiler plate language to RIDEM on May 8, 2012 for review and comment. Please note that any changes to the submitted draft ELUR will need to be approved by representatives of the City of Providence. Textron would be happy to facilitate discussions between the RIDEM and the City of Providence regarding this document.*

COMMENT 13: Regarding the draft SMP:

a) The Department acknowledges that the draft SMP is intended to be a component of the final ELUR for Phase I of the Park Parcel, and is intended to address the handling, stockpiling, and tracking of impacted soils should they require management as part of potential future activities following post remediation closure of Phase I of the Park Parcel. Therefore, the comments that follow are made with the understanding that the intent of the SMP is limited to post remedial disturbances of regulated soil or the engineered control caps.

RESPONSE: *Agreed, the SMP is related to post remediation activities on Parcel C-1.*

b) Page A-1, fifth paragraph - Please add dioxin to the list of potential contaminants that exceeded the applicable direct exposure criteria at several locations.

RESPONSE: *Dioxin has been added to the list of potential contaminants.*

c) Page A-1, last paragraph- Please add maintenance of the engineered control cap to the list of anticipated site activities that may require soil management.

RESPONSE: *Text has been revised as requested.*

d) Regarding Section 2 (Responsibilities), the third paragraph on page A-2- It appears that the citation should be for Paragraph 5.2.2, not Paragraph 7.2.2.

RESPONSE: *The citation has been corrected to Paragraph 5.2.2.*

e) Page A-2, Section 5.1 (Stockpile Criteria) – Please clarify that regulated soils shall be placed upon polyethylene sheeting and covered with polyethylene sheeting.

RESPONSE: *The text has been revised as requested.*

f) Regarding Paragraphs 5.2 (Air Monitoring), 5.2.1 (Breathing-Zone Monitoring), 5.2.2 (Perimeter Monitoring), and 5.2.3 (Construction Control Measures) - The final action levels and response action protocols worked out in comment 7.d above should also be utilized in the post closure SMP.

RESPONSE: *The response action levels and response actions (e.g., engineering controls) have been included within this section of the SMP.*

g) Regarding Paragraph 5.2.1 (Breathing-Zone Monitoring), the fourth paragraph on page A-3 – It appears that the citation should be for Paragraph 5.2.3, not Paragraph 7.2.3.

RESPONSE: *The citation has been corrected to Paragraph 5.2.3.*

h) Regarding Section 5.2.2 (Perimeter Monitoring) – Ambient air action levels at the property line should be based upon US Environmental Protection Agency (EPA) ambient air levels.

RESPONSE: *The air and dust action levels have been developed based on OSHA standards to protect the construction workers and the abutting residential neighborhood. The EPA ambient air levels are based on long term rolling averages for fixed emission points where this is a short term construction project that will last approximately 3 to 4 months. Documentation from the July 2006 slag removal operations did not indicate that there were any exceedances of the proposed thresholds (Appendix E HASP, Table 4-1). This included the personal monitoring devices on the construction workers in the slag area and the use of engineering control measures such as water spray to keep the dust down.*

i) Please add the following language to the post closure SMP:

RESPONSE: *Text shown below has been added to the SMP as requested.*

i) This SMP serves to supplement, and will be initiated by, the RIDEM notification requirement established by the Environmental Land Use Restriction (ELUR) for the property.

ii) As part of the RIDEM notification, the site owner will provide a brief written description of the anticipated site activity involving soil excavation. The description will include an estimate of the volume of soil to be excavated, the duration of the construction project, and the proposed location of the temporary storage of the soil.

iii) During site work, the appropriate precautions will be taken to restrict unauthorized access to the property.

iv) The excavated soils will either be re-entered to their original location (returned to the excavation) the same day of the removal and will be placed below the applicable engineered control cap, or will be properly stored in a secured location of the site.

v) To the extent it is necessary during excavation activities, the clean fill material of the engineered cap will be segregated from the regulated soil beneath the cap and stored separately and securely on and under polyethylene sheeting. Best management practices will be utilized to minimize and control generation of dust during excavation, movement or storage of regulated soils. Any regulated soil being re-entered will be placed below a RIDEM approved engineered control cap.

vi) If the soil cannot be returned to the excavation the same day, then the segregated soils will either be stockpiled separately on polyethylene sheeting, or stored separately in roll-off type containers. In either case, the segregated material in storage will be covered with secured polyethylene sheeting at the end of each workday. Stockpiled materials will be maintained with appropriate controls and best management practices to limit the loss of the cover and protect against stormwater or wind erosion.

vii) Any portion of the geosynthetic liner (geomembrane, geocomposite, geotextile, etc.) that is damaged during excavation, maintenance and/or related activities will either be repaired or replaced in a timely manner with a section of new gcosynthetic liner in accordance with the approved engineered control specifications.

viii) If the regulated soil cannot be returned to the original location, then a qualified environmental professional will collect samples of the excavated soils (either during excavation or from stockpiles) for laboratory testing. In the event that regulated soils are generated for which the only effective method of management is off-site disposal, then the testing program will also address the data requirements of the anticipated disposal facility.

ix) In the event that certain soils on regulated portions of the site were not previously characterized, these soils are presumed to be regulated until such time that it is demonstrated to the Department, through sampling and laboratory analysis that they are not regulated.

ix) Excavated soils will be staged and temporarily stored in a designated area of the property. Within reason, the storage location will be selected to limit the unauthorized access to the materials (i.e., away from public roadways/walkways). No regulated soil will be stockpiled on-site for greater than 60 days without prior Department approval.

x) In the event that stockpiled soils pose a risk or threat of leaching hazardous materials, a proper leak-proof container (i.e., drum or lined roll-off) or secondary containment will be utilized.

xi) Soils excavated from the site may not be re-used as fill on residential property.

xiii) Site soils, which are to be disposed of off-site, must be done so at a licensed facility in accordance with all local, state, and federal laws. Copies of the material shipping records associated with the disposal of the material shall be maintained by the site owner and included in the annual inspection report for the site.

xiv) Best soil management practices should be employed at all times and regulated soils should be segregated into separate piles (or cells or containers) as appropriate based upon the results of analytical testing, when multiple reuse options are planned (i.e., reuse on-site or disposal at a Department approved licensed facility).

xv) All non-disposable equipment used during the soil disturbance activities will be properly decontaminated as appropriate prior to removal from the site. All disposable equipment used during the soil disturbance activities will be properly containerized and disposed of following completion of the work. All vehicles utilized during the work shall be properly decontaminated as appropriate prior to leaving the site.

xvi) At the completion of site work, all exposed soils are required to be recapped with Department approved engineered controls consistent or better than the site surface conditions prior to the work that took place. These measures must also be consistent with the Department approved ELUR recorded on the property.

xvii) In accordance with Section A iii of the ELUR **(this reference is based upon the Department boilerplate ELUR language and may need to be revised depending upon the language of the final Department approved version of the ELUR)**, no soil at the property is to be disturbed in any manner without prior written permission of the Department's Office of Waste Management, except for minor inspections, maintenance, and landscaping activities that do not disturb the contaminated soil at the Site. As part of the notification process, the site owner shall provide a brief written description of the anticipated site activity involving soil excavation. The notification should be submitted to the Department no later than 60 days prior to the proposed initiation of the start of site activities. The description shall include an estimate of the volume of soil to be excavated, a list of the known and anticipated contaminants of concern, a site figure clearly identifying the proposed areas to be excavated/disturbed, the duration of the project and the proposed disposal location of the soil.

xviii) Following written Notification, the Department will determine the post closure reporting requirements. Significant disturbances of regulated soil will require submission of a Closure Report for Department review and approval documenting that the activities were performed in accordance with this SMP and the Department approved ELUR. Minor disturbances of regulated soil may be documented through the annual certification submitted in accordance with Section H (Inspection & Non- Compliance) of the Department approved ELUR. The Department will also make a determination regarding the necessity of performing Public Notice to abutting property owners/tenants concerning the proposed activities. Work associated with the Notification will not commence until written Department approval has been issued. Once Department approval has been issued, the Department will be notified a minimum of two (2) days prior to the start of activities at the site. Shall any significant alterations to the Department approved plan be necessary, a written description of the proposed deviation, will be submitted to the Department for review and approval prior to initiating such changes.

COMMENT 14: In addition to the post closure SMP to be recorded with the ELUR for Phase I of the Park Parcel, the RAWP should also contain either a standalone RAWP specific SMP, included as an attachment or Appendix, or alternatively a dedicated section specifically outlining the comprehensive procedures and protocols that must be followed when managing regulated soils on the site. This RAWP specific SMP should include at a minimum information about how all regulated soils will be managed on-site, where contaminated soil may be stockpiled, procedures governing reuse and off-site disposal of soil, the construction details of the soil stockpile management area, how the regulated and non-regulated soil in the stockpile area will be stored, segregated and tracked, how dust and odors will be monitored and controlled, etc. Many of the additional language elements requested in the post closure SMP (see comment 13 above) may also be applicable and should be included as appropriate.

RESPONSE: *Soil management requirements during the construction related activities are included within the construction specifications section 02110, 02120, 02300 and 02370. The breathing zone and perimeter air monitoring requirements are included within Section 5.2 of the SMP.*

COMMENT 15: Regarding previously listed document 4, the ELJRI's Comments and Questions on the RAWP:

a) It is the Department's understanding that the EJLRI's comments will be addressed along with the Department's comments in Textron and Amec's written response to this comment letter.

RESPONSE: *Agreed.*

b) It is also the Department's understanding, based upon a conversation with a representative of Textron, that Textron is willing to produce weekly status update reports documenting the real-time dust monitoring and other air monitoring and/or sampling events that are conducted during remedial work activities at the site, and which will be submitted electronically in a format (i.e., PDF) that is suitable for posting on the Gorham web page, located on the Department's web site.

RESPONSE: *Please see the response to RIDEM Comment No. 7d.*

COMMENT 16: The following comments are specific to Textron's responses to the July 12, 2011 Phase I Park Parcel Public Meeting:

a) Regarding Comment 9, Textron stated that *"Depending on additional inquiries on the proposed approach for capping Phase I of Parcel D, Textron is receptive to an additional pubic information session focusing on the construction methods and anticipated controls to be implemented while the work is occurring."* Has Textron received any additional inquiries on Phase I of the Park Parcel or requests for a public Information Session or Meeting?

RESPONSE: *Textron will continue to support and attend meetings with the stakeholders regarding ongoing activities at the former Gorham Site. Textron has not received any additional requests for additional information on the proposed remediation for Phase I of the Park Parcel.*

b) Regarding Comments 13 and 34 concerning signage at the site, please provide an update regarding Textron's discussions with the City of Providence about installation and maintenance of informational signs at the site.

RESPONSE: *Textron will work with the City of Providence to replace and maintain signage on the perimeter fence following the relocation of the fence at the completion of the Phase I Cap construction. Consistent with discussions at the May 25th stakeholders meeting, Textron will establish a project bulletin board at a safe, convenient location at the site that will contain information about ongoing remediation activities for the Phase I work.*

b) Regarding Comment 16, questioning the life expectancy of the geotextile material liner, Textron noted that *"with respect to life expectancy of the liner material, according to the Geosynthetic Research Institute, an IIPDE liner proposed to be* *covered with soil is expected to last well over 100 years. Product requirements have been included in the specifications section of the Remedial Action Work Plan."*

According to Appendix B (Specifications), Section 02072 (Geomembrane), the chosen material has a Manufacturer warranty of 20 years. Please provide documentation and an explanation supporting the proposition that if the selected geomembrane is installed correctly as proposed it will be expected to last over 100 years.

RESPONSE: *Based on the availability of warranties from the geomembrane manufacturers, the contractor is limited to a 10-year warranty on the geomembrane. However, geomembranes have been installed as soil covers since the 1980's. Industry research indicates that with a soil cover, as proposed for the former slag area of the Phase I cap, and proper maintenance, the geomembrane will continue to meet the remediation objectives well over 30 years. The Geosynthetic Research Institute recently updated their study on "Geomembrane Lifetime Predictions", dated February 8, 2011 (attached herein). Based on 10 years of research, covered geomembranes have a predicted lifetime of 446 years with an average ambient temperature of 68 degrees Fahrenheit. Warmer temperatures will reduce the predicted life of the geomembrane. Providence, RI has an average ambient temperature of 50.4 degrees Fahrenheit supporting the estimated duration of the former slag area cap for over 100 years.*

All correspondence regarding this Site should be sent to the attention of:

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EJLRI Draft RAWP Review Comments

COMMENT 1: Pg. 3-2 Last sentence at bottom of Section 3-3 "Preferred Remedial Alternative": "Stormwater management will be included with the construction of the cap to maintain its integrity and recharge stormwater runoff into the buffer zone, wetlands, and Cove."

Could Textron explain more about how the drainage from the parking lot will be monitored over time through the slag pile? Also, more about how pollution from the parking lots and road surfaces will be managed to reduce additional impacts on the pond after the Phase I cap is put into place? While recognizing that surface runoff is a lesser concern than the groundwater contamination and slag pile, at least in terms of toxicity, I would appreciate more explanation of how stormwater will be handled over time to create opportunities for infiltration of that stormwater rather than simply allowing it to go into the pond cove. I also recognize that the slag pile cap is designed to avoid any infiltration into the cap (though this needs to be monitored over time to ensure it stays that way) so that the slag pollutants aren't carried into the pond, but that seems to mean that stormwater will simply be able to go directly into the pond without any other infiltration or retention. And while there is a wetland buffer zone on either side of the slag pile cap, there isn't a wetland buffer at the base of the slag pile cap that could serve as a place for stormwater retention. How will all stormwater be directed to those buffer areas, if that is Textron's plan?

RESPONSE: *Drainage from the parking lots will not infiltrate through the former slag pile location;, rather stormwater runoff from the retail and high school lots is routed via catch basins and existing piping to the detention basin behind the retail building for infiltration and discharge to the Mashapaug Inner Cove. An impermeable liner will be installed over the former slag pile location and covered with clean soils. This liner will prevent infiltration from occurring through the former slag pile location. The surface water runoff on Parcel C is currently infiltrating through the ground surface. The City has proposed the construction of a parking lot along Adelaide Avenue so the surface water runoff will discharge into either Adelaide Avenue or the detention basin storm water system. Surface water runoff from the future grass field on Parcel C will be managed on property by infiltration. The Phase I cap has been designed to support surface water runoff from Parcel C-1 into the Mashapaug Inner Cove. An important point to note here is that the entire C-1 parcel will be vegetated and thus designed for water infiltration and not run-off. The exception to this statement to a certain extent is the former slag pile area, but even this area will be vegetated and thus be capable of capturing precipitation that falls on the area.*

COMMENT 2: Pg. 3-5 Invasive Species Management: Are there any other methods other than using chemical herbicides to kill invasives? Can Textron confirm that the herbicides will be applied to individual plant roots rather than broadcast spraying, which seems better, but are there any other possibilities?

RESPONSE: *The construction specifications require the application of the chemical to the individual plant roots. There will not be any broadcast spraying of herbicides. The contractors are also considering the use of mechanical removal of the root mass for off-site disposal.*

COMMENT 3: pg 8-1 Set Up Plans: Is the bulleted list boilerplate language and/or could something like "To ensure abutting properties and residents are not impacted by site-related contaminants or waste and emissions generated during construction activities" be added? Or is there mention of minimizing impact to abutters and the surrounding community in another part of the RAWP?

RESPONSE: *The Site access for equipment is restricted to the traffic light on Reservoir Avenue entering into the City property. The contractor will not be using Adelaide Avenue or Crescent Street for access. Gated access will be through the existing gate at Parcel C and High School intersection, behind the retail building and in the northeast corner behind the detention* *basin. Laydown areas are designated on the construction drawings for the northern portions of Parcel C and on the northeast corner of the property behind the detention basin. Vehicles leaving these areas must pass through a truck cleaning area and tire pad to restrict soil from getting out on the parking lot and roads. Dust monitoring and engineering controls are also a key part of the construction documents so not to impact the school or neighborhood.*

COMMENT 4: Pg 9-1 Effluent Disposal: I did not see anything in the RAWP about employing methods to eliminate potential for tracking contaminated soil off-site. Though Textron does mention they will be following RIDEM regs concerning all effluent disposal. Could Textron spell this out in the RAWP more so that residents know what specific precautions will be taken? Will it include a truck-washing station, an “anti-tracking” pad to get dirt off the truck wheels, and a requirement that the trucks will be covered? Or something else?

Also, there have been a number of successful efforts to reduce diesel pollution in Rhode Island, including an anti-idling law, which states that all diesel vehicles may not idle for more than 5 minutes anywhere in the state. Would Textron be willing to add this into the specs for the contractor in order to set that expectation?

There are also laws in RI that require construction equipment and diesel vehicles used in projects paid for with any public money to be retrofitted with diesel filters to reduce emissions. Since no public money is being used here, it’s not required by law, but I would be interested in hearing from Textron about whether this could be included in the contract when it’s put out to bid, and therefore any contractors with these retrofitted vehicles would be favored in the selection process.

RESPONSE: *Effluent disposal will include an anti-tracking pad at both the Parcel C entrance gate and the detention basin gate. Truck washing is required within the contract specifications and will be conducted inside these areas before exiting onto the parking lot and road way of the retail building and high school. The construction documents do include the no idling provision to reduce potential air pollution. We have asked the contractors bidding the project about retrofitted vehicles being used on the site, but it was not required within the bid documents to maintain a level playing field for the bidders.*

COMMENT 5: Pg. 10-1 Contingency Plan: It is good to see the real-time dust monitoring, though the plan doesn’t specify what would be done if the real-time monitors detect an exceedance—though it does say the area will be watered down if it seems too dusty from a visual inspection. Could Textron please clarify? Could Textron also specify what would be done if the dust exceedances continue after wetting down the area?

If live feed of the air monitoring results to a website is not practicable, could another way of doing this be through the operating log which is going to track the perimeter air monitoring dust readings—if that could be updated daily and done electronically?

RESPONSE: *Details of the dust and air monitoring program are presented in Section 10 Contingency Plan/Health and Safety Plan. This includes perimeter air monitoring for dust and lead at fixed locations and real time monitoring that will be summarized in a daily log. Readings will be taken approximately every two hours and recorded into the field log book and a separate log form to include the results, ongoing activities, engineering controls being implemented and any corrective actions taken, if necessary. These will be scanned and emailed to RIDEM at the end of every week for uploading to the RIDEM project website for public access.*

COMMENT 6: Pg 12-1 Security Procedures: "Areas where fencing is removed will be gated and/or properly secured with temporary fencing and signage. Signage will be in English and Spanish and will include a site contact phone number and other pertinent information.

Could Textron post signage along the entire fence at regular intervals as well as on the gates, not just where temporary fencing has been put up? I've seen this at the National Grid/Tidewater Site and think it is very important. In the past there has been a division of responsibility between the City and Textron for which entity puts up signs where—with the City only taking responsibility for the school property. Since Textron will be conducting remedial work directly along the school property it would make sense and be important to post signage along all of the fences separating the school from Parcel D. Could Textron clarify this or broaden the scope of where it will post signs in order to ensure proper public notification?

RESPONSE: *Some signs still remain on the fence or have been found on the ground and will be reinstalled on the existing fence. Textron and the City of Providence will coordinate the installation of new signs on the relocated fence at the completion of the Phase I cap and along the fence adjacent to the High School and retail driveway. These will be installed approximately every 200 feet, will be in English and Spanish and will include a point of contact and phone number for RIDEM if any questions regarding the site activities.*

Please feel free to contact Greg Simpson, Textron, at (401) 457-2635 or me if you have any questions regarding these response to comments or the RAWP.

Sincerely
AMEC Environment & Infrastructure, Inc.

David E. Heislein
Principal Project Manager

cc: G. Simpson, Textron, Inc.
AMEC Project File
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GRI White Paper #6

- on -

Geomembrane Lifetime Prediction:
Unexposed and Exposed Conditions

by

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Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions

1.0 Introduction

Without any hesitation the most frequently asked question we have had over the past thirty years' is "how long will a particular geomembrane last".* The two-part answer to the question, largely depends on whether the geomembrane is covered in a timely manner or left exposed to the site-specific environment. Before starting, however, recognize that the answer to either covered or exposed geomembrane lifetime prediction is neither easy, nor quick, to obtain. Further complicating the answer is the fact that all geomembranes are formulated materials consisting of (at the minimum), (i) the resin from which the name derives, (ii) carbon black or colorants, (iii) short-term processing stabilizers, and (iv) long-term antioxidants. If the formulation changes (particularly the additives), the predicted lifetime will also change. See Table 1 for the most common types of geomembranes and their approximate formulations.

Table 1 - Types of commonly used geomembranes and their approximate formulations (based on weight percentage)

Type	Resin	Plasticizer	Fillers	Carbon Black	Additives
HDPE	95-98	0	0	2-3	0.25-1
LLDPE	94-96	0	0	2-3	0.25-3
fPP	85-98	0	0-13	2-4	0.25-2
PVC	50-70	25-35	0-10	2-5	2-5
CSPE	40-60	0	40-50	5-10	5-15
EPDM	25-30	0	20-40	20-40	1-5

HDPE = high density polyethylene
LLDPE = linear low density polyethylene
fPP = flexible polypropylene
PVC = polyvinyl chloride (plasticized)
CSPE = chlorsulfonated polyethylene
EPDM = ethylene propylene diene terpolymer

* More recently, the same question has arisen but focused on geotextiles, geogrids, geopipe, turf reinforcement mats, fibers of GCLs, etc. This White Paper, however, is focused completely on geomembranes due to the tremendous time and expense of providing such information for all types of geosynthetics.

The possible variations being obvious, one must also address the degradation mechanisms which might occur. They are as follows accompanied by some generalized commentary.

- Ultraviolet Light - This occurs only when the geosynthetic is exposed; it will be the focus of the second part of this communication.
- Oxidation - This occurs in all polymers and is the major mechanism in polyolefins (polyethylene and polypropylene) under all conditions.
- Ozone - This occurs in all polymers that are exposed to the environment. The site-specific environment is critical in this regard.
- Hydrolysis - This is the primary mechanism in polyesters and polyamides.
- Chemical - Can occur in all polymers and can vary from water (least aggressive) to organic solvents (most aggressive).
- Radioactivity - This is not a factor unless the geomembrane is exposed to radioactive materials of sufficiently high intensity to cause chain scission, e.g., high level radioactive waste materials.
- Biological - This is generally not a factor unless biologically sensitive additives (such as low molecular weight plasticizers) are included in the formulation.
- Stress State – This is a complicating factor which is site-specific and should be appropriately modeled in the incubation process but, for long-term testing, is very difficult and expensive to acheive.
- Temperature - Clearly, the higher the temperature the more rapid the degradation of all of the above mechanisms; temperature is critical to lifetime and furthermore is the key to

time-temperature-superposition which is the basis of the laboratory incubation methods which will be followed.

2.0 Lifetime Prediction: Unexposed Conditions

Lifetime prediction studies at GRI began at Drexel University under U. S. EPA contract from 1991 to 1997 and was continued under GSI consortium funding until ca. 2002. Focus to date has been on HDPE geomembranes placed beneath solid waste landfills due to its common use in this particular challenging application. Incubation of the coupons has been in landfill simulation cells (see Figure 1) maintained at 85, 75, 65 and 55°C. The specific conditions within these cells are oxidation beneath, chemical (water) from above, and the equivalent of 50 m of solid waste mobilizing compressive stress. Results have been forthcoming over the years insofar as three distinct lifetime stages; see Figure 2.

Stage A - Antioxidant Depletion Time

Stage B - Induction Time to the Onset of Degradation

Stage C - Time to Reach 50% Degradation (i.e., the Halflife)

2.1 Stage A - Antioxidant Depletion Time

The dual purposes of antioxidants are to (i) prevent polymer degradation during processing, and (ii) prevent oxidation reactions from taking place during Stage A of service life, respectively. Obviously, there can only be a given amount of antioxidants in any formulation. Once the antioxidants are depleted, additional oxygen diffusing into the geomembrane will begin to attack the polymer chains, leading to subsequent stages as shown in Figure 2. The duration of the antioxidant depletion stage depends on both the type and amount of the various antioxidants, i.e., the precise formulation.

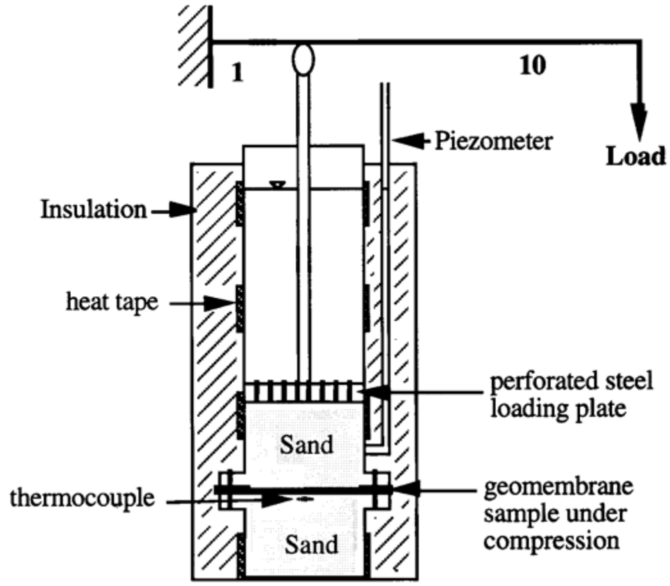


Figure 1. Incubation schematic and photograph of multiple cells maintained at various constant temperatures.

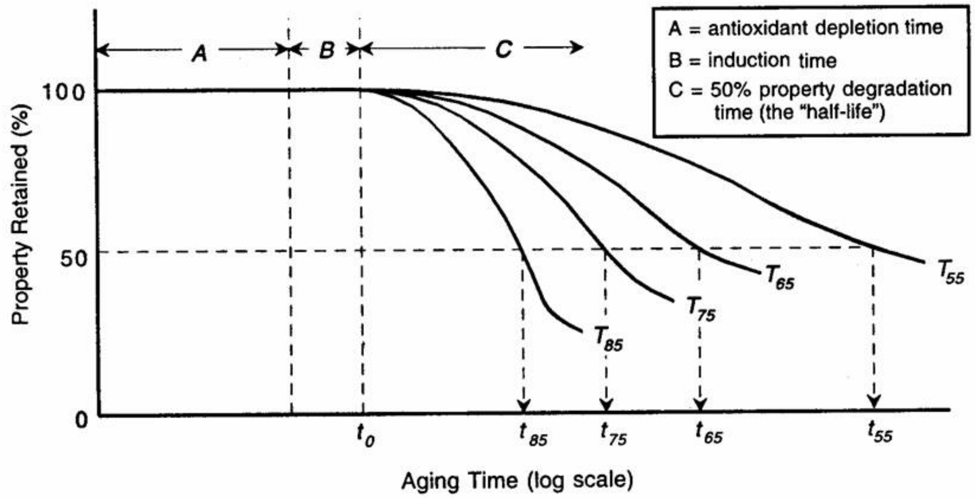


Figure 2. Three individual stages in the aging of most geomembranes.

The depletion of antioxidants is the consequence of two processes: (i) chemical reactions with the oxygen diffusing into the geomembrane, and (ii) physical loss of antioxidants from the geomembrane. The chemical process involves two main functions; the scavenging of free radicals converting them into stable molecules, and the reaction with unstable hydroperoxide (ROOH) forming a more stable substance. Regarding physical loss, the process involves the distribution of antioxidants in the geomembrane and their volatility and extractability to the site-specific environment.

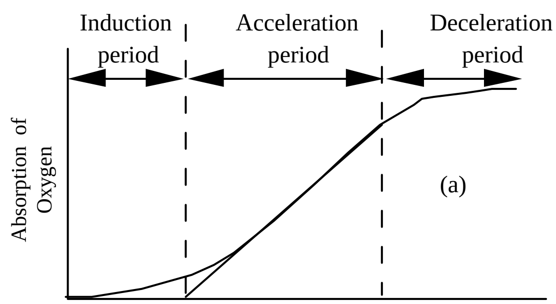
Hence, the rate of depletion of antioxidants is related to the type and amount of antioxidants, the service temperature, and the nature of the site-specific environment. See Hsuan and Koerner (1998) for additional details.

2.2 Stage B - Induction Time to Onset of Degradation

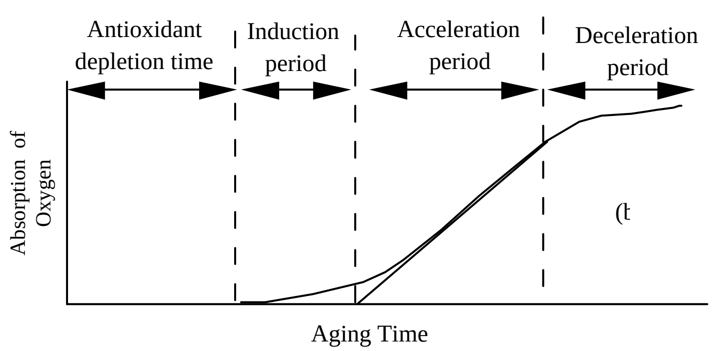
In a pure polyolefin resin, i.e., one without carbon black and antioxidants, oxidation occurs extremely slowly at the beginning, often at an immeasurable rate. Eventually, oxidation occurs more rapidly. The reaction eventually decelerates and once again becomes very slow.

This progression is illustrated by the S-shaped curve of Figure 3(a). The initial portion of the curve (before measurable degradation takes place) is called the induction period (or induction time) of the polymer. In the induction period, the polymer reacts with oxygen forming hydroperoxide (ROOH), as indicated in Equations (1)-(3). However, the amount of ROOH in this stage is very small and the hydroperoxide does not further decompose into other free radicals which inhibits the onset of the acceleration stage.

In a stabilized polymer such as one with antioxidants, the accelerated oxidation stage takes an even longer time to be reached. The antioxidants create an additional depletion time stage prior to the onset of the induction time, as shown in Figure 3(b).



(a) Pure unstabilized polyethylene



(b) Stabilized polyethylene

Figure 3. Curves illustrating various stages of oxidation.

$$RH \rightarrow R \bullet + H \bullet \tag{1}$$

(aided by energy or catalyst residues in the polymer)

$$R \bullet + O2 \rightarrow ROO \bullet \tag{2}$$

$$ROO \bullet + RH \rightarrow ROOH + R \bullet \tag{3}$$

In the above, RH represents the polyethylene polymer chains; and the symbol "•" represents free radicals, which are highly reactive molecules.

2.3 Stage C - Time to Reach 50% Degradation (Halflife)

As oxidation continues, additional ROOH molecules are being formed. Once the concentration of ROOH reaches a critical level, decomposition of ROOH begins, leading to a substantial increase in the amount of free radicals, as indicated in Equations (4) to (6). The additional free radicals rapidly attack other polymer chains, resulting in an accelerated chain reaction, signifying the end of the induction period, Rapopport and Zaikov (1986). This indicates that the concentration of ROOH has a critical control on the duration of the induction period.

$$ROOH \rightarrow RO \bullet OH \bullet \text{ (aided by energy)} \tag{4}$$

$$RO \bullet + RH \rightarrow ROH + R \bullet \tag{5}$$

$$OH \bullet + RH \rightarrow H2O + R \bullet \tag{6}$$

A series of oxidation reactions produces a substantial amount of free radical polymer chains (R•), called alkyl radicals, which can proceed to further reactions leading to either cross-linking or chain scission in the polymer. As the degradation of polymer continues, the physical and mechanical properties of the polymer start to change. The most noticeable change in physical properties is the melt index, since it relates to the molecular weight of the polymer. As for mechanical properties, both tensile break stress (strength) and break strain (elongation) decrease.

Ultimately, the degradation becomes so severe that all tensile properties start to change (tear, puncture, burst, etc.) and the engineering performance is jeopardized. This signifies the end of the so-called “service life” of the geomembrane.

Although quite arbitrary, the limit of service life of polymeric materials is often selected as a 50% reduction in a specific design property. This is commonly referred to as the halflife time, or simply the “halflife”. It should be noted that even at halflife, the material still exists and can function, albeit at a decreased performance level with a factor-of-safety lower than the initial design value.

2.4 Summary of Lifetime Research-to-Date

Stage A, that of antioxidant depletion for HDPE geomembranes as required in the GRI-GM13 Specification, has been well established by our own research and corroborated by others, e.g., Sangram and Rowe (2004). The GRI data for standard and high pressure Oxidative Induction Time (OIT) is given in Table 2. The values are quite close to one another. Also, as expected, the lifetime is strongly dependent on the service temperature; with the higher the temperature the shorter the lifetime.

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage “A” (years)			Stage “B”	Stage “C”	Total Prediction* (years)
	Standard OIT	High Press. OIT	Average OIT	(years)	(years)	
20	200	215	208	30	208	446
25	135	144	140	25	100	265
30	95	98	97	20	49	166
35	65	67	66	15	25	106
40	45	47	46	10	13	69

*Total = Stage A (average) + Stage B + Stage C

Stage “B”, that of induction time, has been obtained by comparing 30-year old polyethylene water and milk containers (containing no long-term antioxidants) with currently produced containers. The data shows that degradation is just beginning to occur as evidenced by slight changes in break strength and elongation, but not in yield strength and elongation. The lifetime for this stage is also given in Table 2.

Stage “C”, the time for 50% change of mechanical properties is given in Table 2 as well. The data depends on the activation energy, or slope of the Arrhenius curve, which is very sensitive to material and experimental techniques. The data is from Gedde, et al. (1994) which is typical of the HDPE resin used for gas pipelines and is similar to Martin and Gardner (1983).

Summarizing Stages A, B, and C, it is seen in Table 2 that the halflife of covered HDPE geomembranes (formulated according to the current GRI-GM13 Specification) is estimated to be 449-years at 20°C. This, of course, brings into question the actual temperature for a covered geomembrane such as beneath a solid waste landfill. Figure 4 presents multiple thermocouple monitoring data of a municipal waste landfill liner in Pennsylvania for over 10-years, Koerner and Koerner (2005). Note that for 6-years the temperature was approximately 20°C. At that time and for the subsequent 4-years the temperature increased to approximately 30°C. Thus, the halflife of this geomembrane is predicted to be from 166 to 446 years within this temperature range. The site is still being monitored, see Koerner and Koerner (2005).

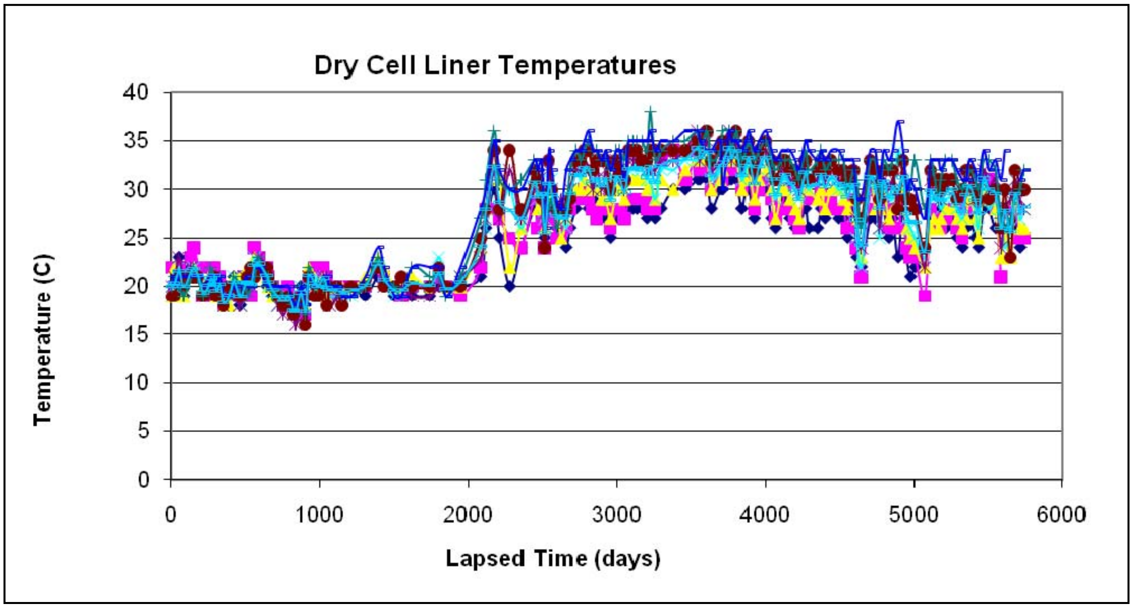


Figure 4. Long-term monitoring of an HDPE liner beneath a municipal solid waste landfill in Pennsylvania.

2.5 Lifetime of Other Covered Geomembranes

By virtue of its widespread use as liners for solid waste landfills, HDPE is by far the widest studied type of geomembrane. Note that in most countries (other than the U.S.), HDPE is the required geomembrane type for solid waste containment. Some commentary on other-than HDPE geomembranes (recall Table 1) follows:

2.5.1 Linear Low Density Polyethylene (LLDPE) geomembranes

The nature of the LLDPE resin and its formulation is very similar to HDPE. The fundamental difference is that LLDPE is a lower density, hence lower crystallinity, than HDPE; e.g., 10% versus 50%. This has the effect of allowing oxygen to diffuse into the polymer structure quicker, and likely decreases Stages A and C. How much is uncertain since no data is available, but it is felt that the lifetime of LLDPE will be somewhat reduced with respect to HDPE.

2.5.2 Plasticizer migration in PVC geomembranes

Since PVC geomembranes necessarily have plasticizers in their formulations so as to provide flexibility, the migration behavior must be addressed for this material. In PVC the plasticizer bonds to the resin and the strength of this bonding versus liquid-to-resin bonding is significant. One of the key parameters of a stable long-lasting plasticizer is its molecular weight. The higher the molecular weight of the plasticizer in a PVC formulation, the more durable will be the material. Conversely, low molecular weight plasticizers have resulted in field failures even under covered conditions. See Miller, et al. (1991), Hammon, et al. (1993), and Giroud and Tisinger (1994) for more detail in this regard. At present there is a considerable difference (and cost) between PVC geomembranes made in North America versus Europe. This will be apparent in the exposed study of durability in the second part of this White Paper.

2.5.3 Crosslinking in EPDM and CSPE geomembrnaes

The EPDM geomembranes mentioned in Table 1 are crosslinked thermoset materials. The oxidation degradation of EPDM takes place in either ethylene or propylene fraction of the co-polymer via free radical reactions, as expressed in Figure 5, which are described similarly by Equations (4) to (6).

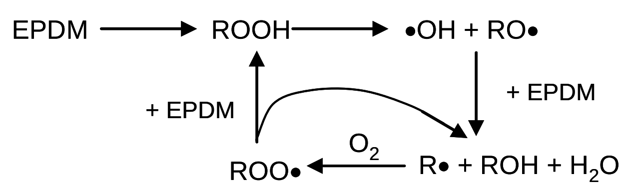


Figure 5. Oxidative degradation of crosslinked EPDM geomembranes, (Wang and Qu, 2003).

For CSPE geomembranes, the degradation mechanism is dehydrochlorination by losing chlorine and generating carbon-carbon double bonds in the main polymer chain, as shown in Figure 6.

The carbon-carbon double bonds become the preferred sites for further thermodegradation or cross-linking in the polymer, leading to eventual brittleness of the geomembrane.

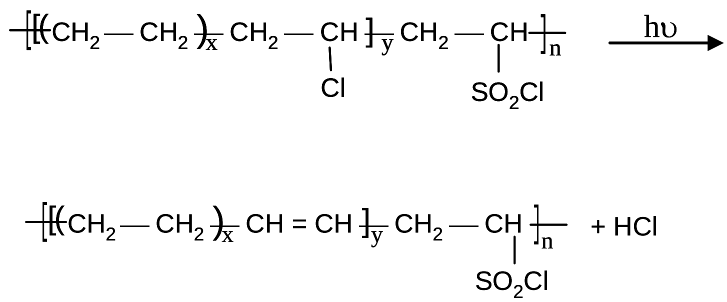


Figure 6. Dechlorination degradation of crosslinked CSPE geomembranes (Chailan, et al., 1995).

Neither EPDM nor CSPE has had a focused laboratory study of the type described for HDPE reported in the open literature. Most of lifetime data for these geomembranes is antidotal by virtue of actual field performance. Under covered conditions, as being considered in this section, there have been no reported failures by either of these thermoset polymers to our knowledge.

3.0 <u>Lifetime Prediction: Exposed Conditions</u>

Lifetime prediction of exposed geomembranes have taken two very different pathways; (i) prediction from anecdotal feedback and field performance, and (ii) from laboratory weathering device predictions.

3.1 Field Performance

There is a large body of anecdotal information available on field feedback of exposed geomembranes. It comes form two quite different sources, i.e., dams in Europe and flat roofs in the USA.

Regarding exposed geomembranes in dams in Europe, the original trials were using 2.0 mm thick polyisobutylene bonded directly to the face of the dam. There were numerous problems encountered as described by Scuero (1990). Similar experiences followed using PVC geomembranes. In 1980, a geocomposite was first used at Lago Nero which had a 200 g/m^2 nonwoven geotextile bonded to the PVC geomembrane. This proved quite successful and led to the now-accepted strategy of requiring drainage behind the geomembrane. In addition to thick nonwoven geotextiles, geonets, and geonet composites have been successful. Currently over 50 concrete and masonry dams have been rehabilitated in this manner and are proving successful for over 30-years of service life. The particular type of PVC plasticized geomembranes used for these dams is proving to be quite durable. Tests by the dam owners on residual properties show only nominal changes in properties, Cazzuffi (1998). As indicated in Miller, et al. (1991) and Hammond, et al. (1993), however, different PVC materials and formulations result in very different behavior; the choice of plasticizer and the material's thickness both being of paramount importance. An excellent overview of field performance is recently available in which 250 dams which have been waterproofed by geomembranes is available from ICOLD (2010).

Regarding exposed geomembranes in flat roofs, past practice in the USA is almost all with EPDM and CSPE and, more recently, with fPP. Manufacturers of these geomembranes regularly warranty their products for 20-years and such warrants appear to be justified. EPDM and CSPE, being thermoset or elastomeric polymers, can be used in dams without the necessity of having seams by using vertical attachments spaced at 2 to 4 m centers, see Scuero and Vaschetti (1996). Conversely, fPP can be seamed by a number of thermal fusion methods. All of these geomembrane types have good conformability to rough substrates as is typical of concrete and masonry dam rehabilitation. It appears as though experiences (both positive and negative) with geomembranes in flat roofs should be transferred to all types of waterproofing in civil engineering applications.

3.2 Laboratory Weatherometer Predictions

For an accelerated simulation of direct ultraviolet light, high temperature, and moisture using a laboratory weatherometer one usually considers a worst-case situation which is the solar maximum condition. This condition consists of global, noon sunlight, on the summer solstice, at normal incidence. It should be recognized that the UV-A range is the target spectrum for a laboratory device to simulate the naturally occurring phenomenon, see Hsuan and Koerner (1993), and Suits and Hsuan (2001).

The Xenon Arc weathering device (ASTM D4355) was introduced in Germany in 1954. There are two important features; the type of filters and the irradiance settings. Using a quartz inner and borosilicate outer filter (quartz/boro) results in excessive low frequency wavelength degradation. The more common borosilicate inner and outer filters (boro/boro) shows a good correlation with solar maximum conditions, although there is an excess of energy below 300 nm wavelength. Irradiance settings are important adjustments in shifting the response although they do not eliminate the portion of the spectrum below 300 nm frequency. Nevertheless, the Xenon Arc device is commonly used method for exposed lifetime prediction of all types of geosynthetics.

UV Fluorescent devices (ASTM D7238) are an alternative type of accelerated laboratory test device which became available in the early 1970's. They reproduce the ultraviolet portion of the sunlight spectrum but not the full spectrum as in Xenon Arc weatherometers. Earlier FS-40 and UVB-313 lamps give reasonable short wavelength output in comparison to solar maximum. The UVA-340 lamp was introduced in 1987 and its response is seen to reproduce ultraviolet light quite well. This device (as well as other types of weatherometers) can handle elevated temperature and programmed moisture on the test specimens.

Research at the Geosynthetic Institute (GSI) has actively pursued both Xenon and UV Fluorescent devices on a wide range of geomembranes. Table 3 gives the geomembranes that were incubated and the number of hours of exposure as of 12 July 2005.

Table 5 - Details of the GSI laboratory exposed weatherometer study on various types of geomembranes

Geomembrane Type	Thickness (mm)	UV Fluorescent Exposure*	Xenon Exposure*	Comment
1. HDPE (GM13)	1.50	8000 hrs.	6600 hrs.	Basis of GRI-GM13 Spec
2. LLDPE (GM17)	1.00	8000	6600	Basis of GRI-GM-17 Spec
3. PVC (No. Amer.)	0.75	8000	6600	Low Mol. Wt. Plasticizer
4. PVC (Europe)	2.50	7500	6600	High Mol. Wt. Plasticizer
5. fPP (BuRec)	1.00	2745**	4416**	Field Failure at 26 mos.
6. fPP-R (Texas)	0.91	100	100	Field Failure at 8 years
7. fPP (No. Amer.)	1.00	7500	6600	Expected Good Performance

*As of 12 July 2005 exposure is ongoing
**Light time to reach halflife of break and elongation

3.3 Laboratory Weatherometer Acceleration Factors

The key to validation of any laboratory study is to correlate results to actual field performance. For the nonexposed geomembranes of Section 2 such correlations will take hundreds of years for properly formulated products. For the exposed geomembranes of Section 3, however, the lifetimes are significantly shorter and such correlations are possible. In particular, Geomembrane #5 (flexible polypropylene) of Table 3 was an admittedly poor geomembrane formulation which failed in 26 months of exposure at El Paso, Texas, USA. The reporting of this failure is available in the literature, Comer, et al. (1998). Note that for both UV Fluorescent and Xenon Arc laboratory incubation of this material, failure (halflife to 50% reduction in strength and elongation) occurred at 2745 and 4416 hours, respectively. The comparative analysis of laboratory and field for this case history allows for the obtaining of acceleration factors for the two incubation devices.

3.3.1 Comparison between field and UV Fluorescent weathering

The light source used in the UV fluorescent weathering device is UVA with wavelengths from 295-400 nm. In addition, the intensity of the radiation is controlled by the Solar Eye irradiance control system. The UV energy output throughout the test is 68.25 W/m^2.

The time of exposure to reach 50% elongation at break was as follows:

= 2745 hr. of light
= 9,882,000 seconds

Total energy in MJ/m^2 = 68.25 W/m^2 $\times$ 9,882,000
= 674.4 MJ/m^2

The field site was located at El Paso, Texas. The UVA radiation energy (295-400 nm) at this site is estimated based on data collected by the South Florida Testing Lab in Arizona (which is a similar atmospheric location). For 26 months of exposure, the accumulated UV radiation energy is 724 MJ/m^2 which is very close to that generated from the UV fluorescent weatherometer. Therefore, direct comparison of the exposure time between field and UV fluorescent is acceptable.

Field time vs. Fluorescent UV light time: **Thus, the acceleration factor is 6.8.**
= 26 Months = 3.8 Months

3.3.2 Comparison between field and Xenon Arc weathering

The light source of the Xenon Arc weathering device simulates almost the entire sunlight spectrum from 250 to 800 nm. Depending of the age of the light source and filter, the solar energy ranges from 340.2 to 695.4 W/m^2, with the average value being 517.8 W/m^2.

The time of exposure to reach 50% elongation at break

= 4416 hr. of light
= 15,897,600 seconds

Total energy in MJ/m^2 = 517.8 W/m^2 $\times$ 15,897,600
= 8232 MJ/m^2

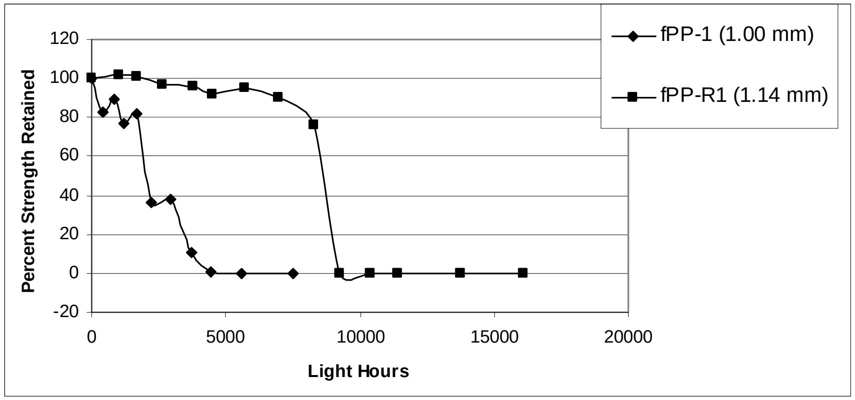
The solar energy in the field is again estimated based on data collected by the South Florida Testing Lab in Arizona. For 26 months of exposure, the accumulated solar energy (295-800 nm) is 15,800 MJ/m^2, which is much higher than that from the UV Fluorescent device. Therefore, direct comparison of halflives obtained from the field and Xenon Arc device is not anticipated to be very accurate. However, for illustration purposes the acceleration factor based on Xenon Arc device would be as follows:

Field = 26 Months	vs.	Xenon Arc = 6.1 Months	:	**Thus, the acceleration factor is 4.3.**

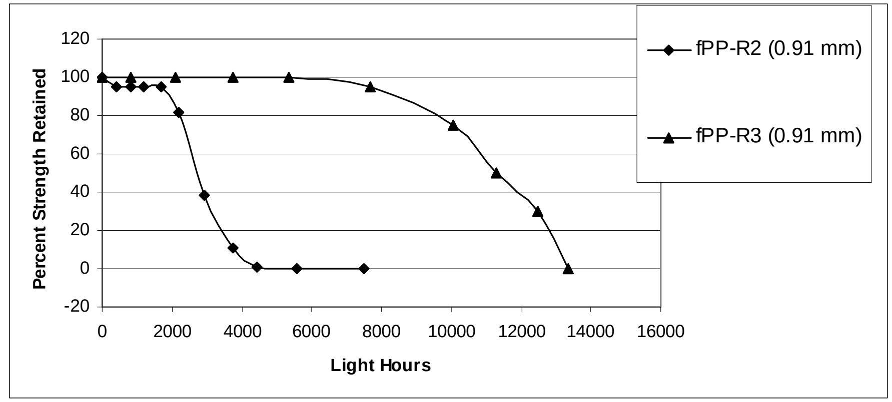
The resulting conclusion of this comparison of weathering devices is that the UV Fluorescent device is certainly reasonable to use for long-term incubations. When considering the low cost of the device, its low maintenance, its inexpensive bulbs, and ease of repair it (the UV Fluorescent device) will be used exclusively by GSI for long-term incubation studies.

3.3.3 Update of exposed lifetime predictions

There are presently (2011) four field failures of flexible polypropylene geomembranes and using unexposed archived samples from these sites their responses in laboratory UV Fluorescent devices per ASTM D7328 at 70°C are shown in Figure 5. From this information we deduce that the average correlation factor is approximately *1200 light hours $\underset{\sim}{}$~ one-year in a hot climate.* This value will be used accordingly for other geomembranes.



(a) Two Sites in West Texas



(b) Two Sites in So. Calif.

Lab-to-Field Correlation Factors
(ASTM D7238 @ 70°C)

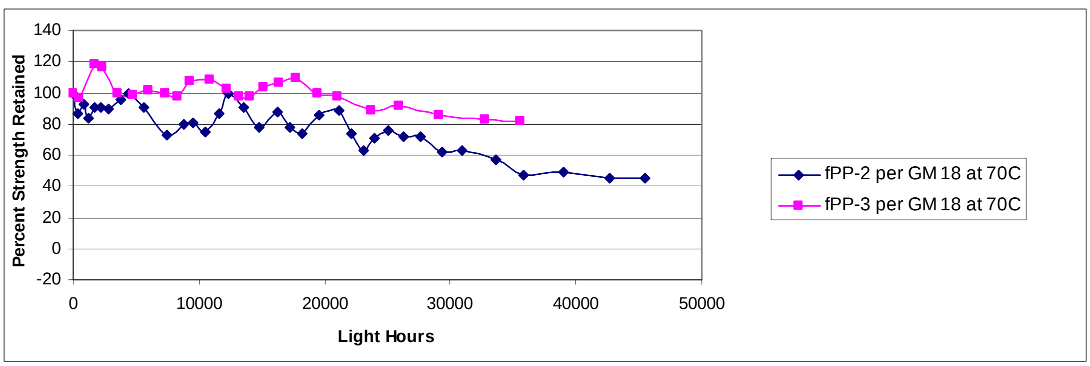
Method	Thickness (mm)	Field (yrs.)	Location	Lab (lt. hr.)	Factor (lt. hrs./1.0 yr.)
fPP-1	1.00	$\simeq$ 2	W. Texas	1800	900
fPP-R1	1.14	$\simeq$ 8	W. Texas	8200	1025
fPP-R2	0.91	$\simeq$ 2	So. Calif.	2500	1250
fPP-R3	0.91	$\simeq$ 8	So. Calif.	11200	1400
					1140*

*Use 1200 lt. hr. = 1.0 year in hot climates

Figure 5. Four field failures of fPP and fPP-R exposed geomembranes.

Exposure of a number of different types of geomembranes in laboratory UV Fluorescent devices per ASTM D7238 at 70°C has been ongoing for the six years (between 2005 and 2011) since this White Paper was first released. Included are the following geomembranes:

- Two black 1.0 mm (4.0 mil) unreinforced flexible polypropylene geomembranes formulated per GRI-GM18 Specification; see Figure 6a.
- Two black unreinforced polyethylene geomembranes, one 1.5 mm (60 mil) high density per GRI-GM13 Specification and the other 1.0 mm (40 mil) linear low density per GRI-GM17 Specification; see Figure 6b.
- One 1.0 (40 mil) black ethylene polypropylene diene terpolymer geomembrane per GRI-GM21 Specification; see Figure 6c.
- Two polyvinyl chloride geomembranes, one black 1.0 mm (40 mil) formulated in North America and the other grey 1.5 mm (60 mil) formulated in Europe; see Figure 6d.



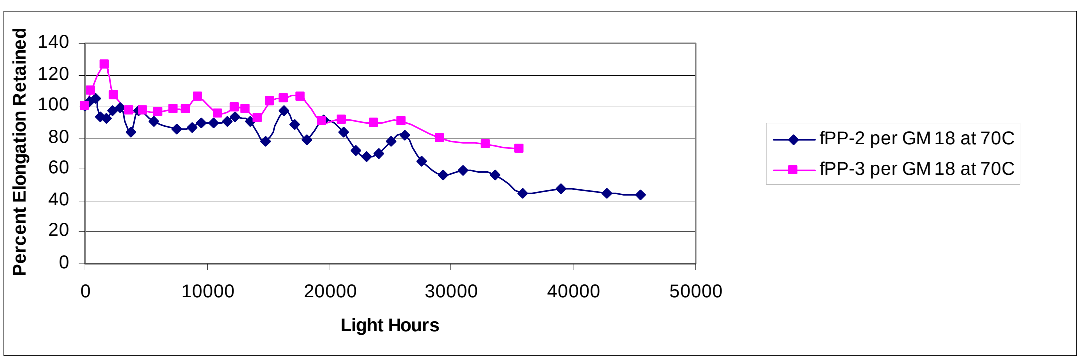
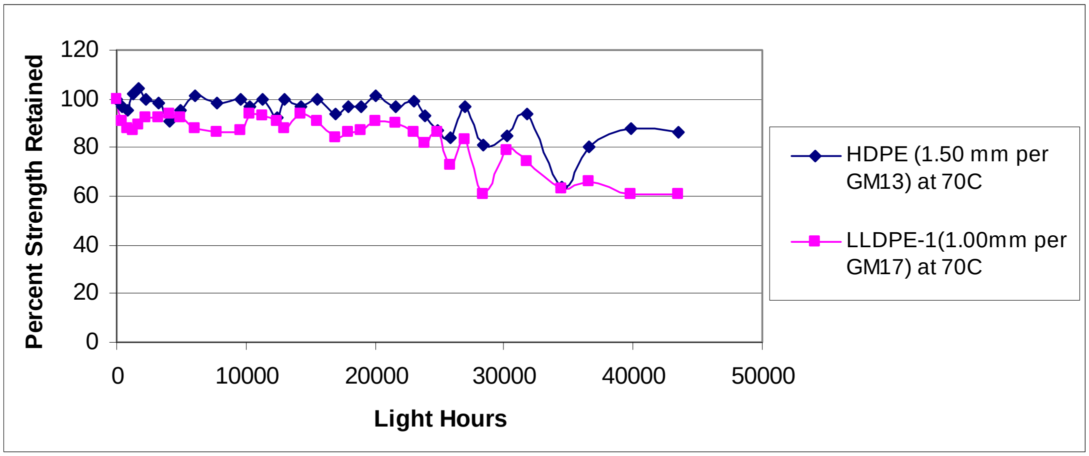


Figure 6a. Flexible polyethylene (fPP) geomembrane behavior.



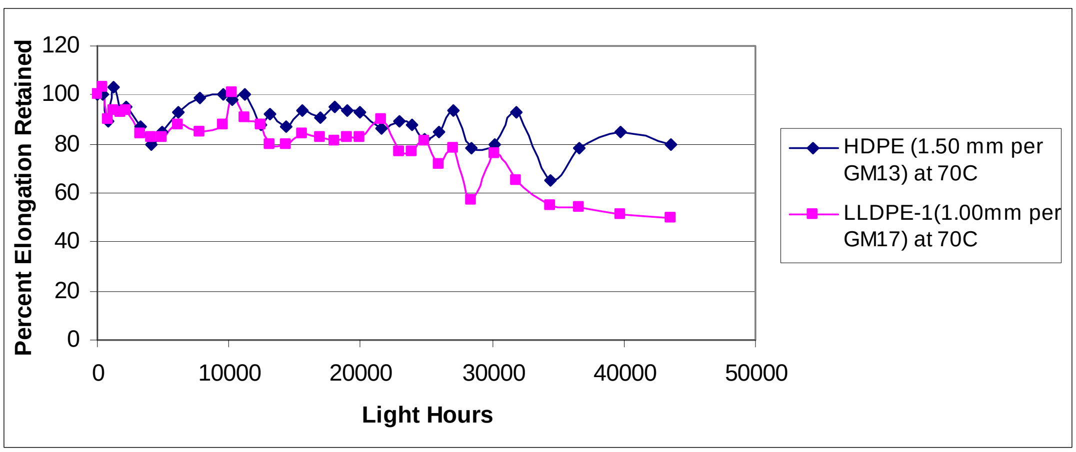
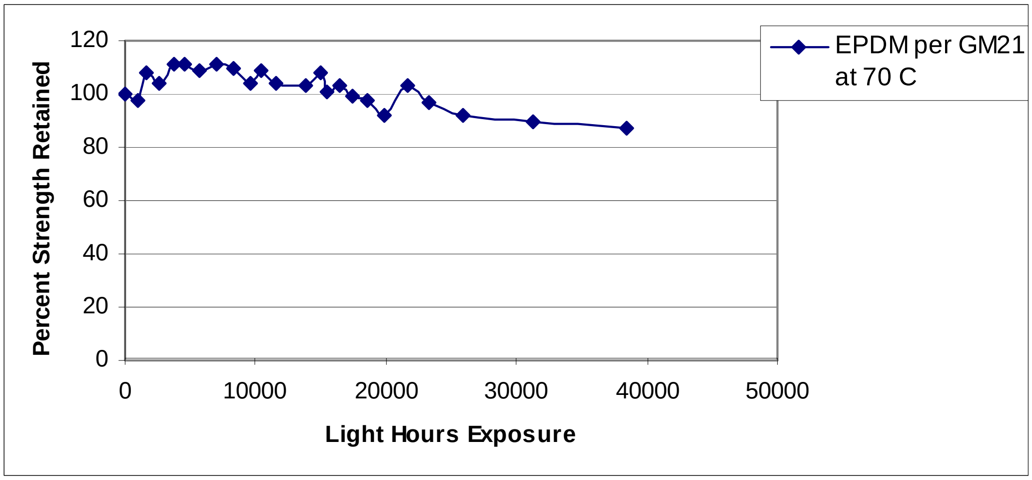


Figure 6b. Polyethylene (HDPE and LLDPE) geomembrane behavior.



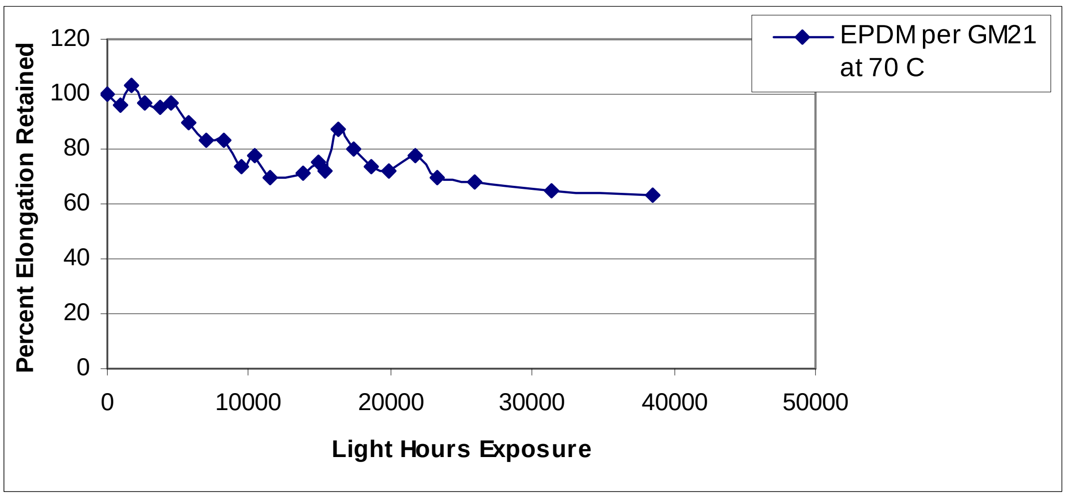


Figure 6c. Ethylene polypropylene diene terpolymer (EPDM) geomembrane.

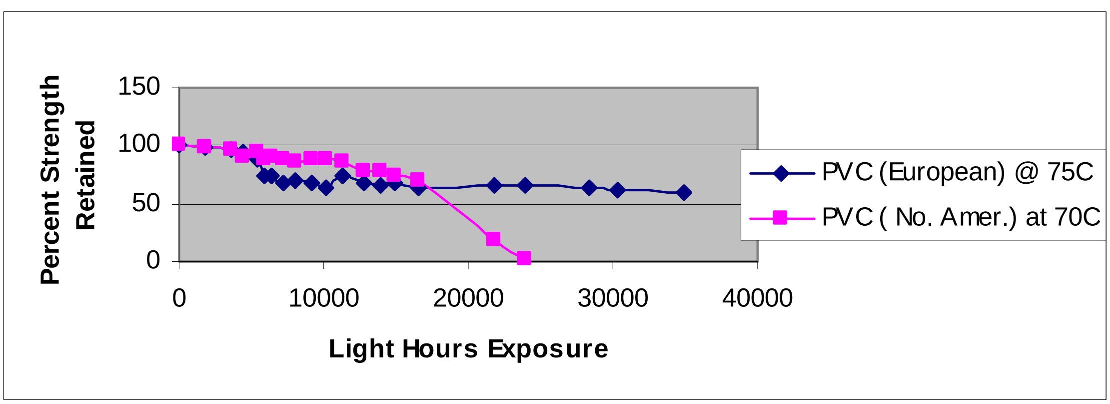


Figure 6d. Polyvinyl chloride (PVC) geomembranes.

From the response curves of the various geomembranes shown in Figure 6a-d, the 50% reduction value in strength or elongation (usually elongation) was taken as being the "halflife". This value is customarily used by the polymer industry as being the materials lifetime prediction value. We have done likewise to develop Table 6 which is our predicted values for the designated exposed geomembrane lifetimes to date.

Table 6 – Exposed lifetime prediction results of selected geomembranes to date

Type	Specification	Prediction Lifetime in a Dry and Arid Climate
HDPE	GRI-GM13	> 36 years (ongoing)
LLDPE	GRI-GM17	~ 36 years (halflife)
EPDM	GRI-GM21	> 27 years (ongoing)
fPP-2	GRI-GM18	~ 30 years (halflife)
fPP-3	GRI-GM18	> 27 years (ongoing)
PVC-N.A.	(see FGI)	~ 18 years (halflife)
PVC-Eur.	proprietary	> 32 years (ongoing)

4.0 Conclusions and Recommendations

This White Paper is bifurcated into two very different parts; covered (or buried) lifetime prediction of HDPE geomembranes and exposed (to the atmosphere) lifetime prediction of a number of geomembrane types. In the covered geomembrane study we chose the geomembrane type which has had the majority of usage, that being HDPE as typically used in waste containment applications. Invariably whether used in landfill liner or cover applications *the geomembrane is covered.* After ten-years of research Table 2 (repeated here) was developed which is the conclusion of the covered geomembrane research program. Here it is seen that HDPE decreases its predicted lifetime (as measured by its halflife) from 446-years at 20°C, to 69-years at 40°C. Other geomembrane types (LLDPE, fPP, EPDM and PVC) have had essentially no focused effort on their covered lifetime prediction of the type described herein. That said, all are candidates for additional research in this regard.

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage "A" (years)			Stage "B" (years)	Stage "C" (years)	Total Prediction* (years)
	Standard OIT	High Press. OIT	Average OIT			
20	200	215	208	30	208	446
25	135	144	140	25	100	265
30	95	98	97	20	49	166
35	65	67	66	15	25	106
40	45	47	46	10	13	69

*Total = Stage A (average) + Stage B + Stage C

Exposed geomembrane lifetime was addressed from the perspective of field performance which is very unequivocal. Experience in Europe, mainly with relatively thick PVC containing high molecular weight plasticizers, has given 25-years of service and the geomembranes are still in use. Experience in the USA with exposed geomembranes on flat roofs, mainly with EPDM and CSPE, has given 20^{+}-years of service. The newest geomembrane type in such applications is fPP which currently carries similar warranties.

Rather than using the intricate laboratory setups of Figure 1 which are necessary for covered geomembranes, exposed geomembrane lifetime can be addressed by using accelerating laboratory weathering devices. Here it was shown that the UV fluorescent device (per ASTM D7238 settings) versus the Xenon Arc device (per ASTM D 4355) is equally if not slightly more intense in its degradation capabilities. As a result, all further incubation has been using the UV fluorescent devices per D7238 at 70°C.

Archived flexible polypropylene geomembranes at four field failure sites resulted in a correlation factor of 1200 light hours equaling one-year performance in a hot climate. Using this value on the incubation behavior of seven commonly used geomembranes has resulted in the following conclusions (recall Figure 6 and Table 6);

- HDPE geomembranes (per GRI-GM13) are predicted to have lifetimes greater than 36-years; testing is ongoing.
- LLDPE geomembranes (per GRI-GM17) are predicted to have lifetimes of approximately 36-years.
- EPDM geomembranes (per GRI-GM21) are predicted to have lifetimes of greater than 27-years; testing is ongoing.
- fPP geomembranes (per GRI-GM18) are predicted to have lifetimes of approximately 30-years.
- PVC geomembranes are very dependent on their plascitizer types and amounts, and probably thicknesses as well. The North American formulation has a lifetime of approximately 18-years, while the European formulation is still ongoing after 32-years.

Regarding continued and future recommendations with respect to lifetime prediction, GSI is currently providing the following:

(i) Continuing the exposed lifetime incubations of HDPE, EPDM and PVC (European) geomembranes at 70°C.

(ii) Beginning the exposed lifetime incubations of HDPE, LLDPE, fPP, EPDM and both PVC's at 60°C and 80°C incubations.

(iii) With data from these three incubation temperatures (60, 70 and 80°C), time-temperature-superposition plots followed by Arrhenius modeling will eventually provide information such as Table 2 for covered geomembranes. This is our ultimate goal.

(iv) Parallel lifetime studies are ongoing at GSI for four types of geogrids and three types of turf reinforcement mats at 60, 70 and 80°C.

(v) GSI does not plan to duplicate the covered geomembrane study to other than the HDPE provided herein. In this regard, the time and expense that would be necessary is prohibitive.

(vi) The above said, GSI is always interested in field lifetime behavior of geomembranes (and other geosynthetics as well) whether covered or exposed.

Acknowledgements

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