Implementation of Research and Development (R&D) Results in the Design of Liner System for the Near Surface Disposal Facility (NSDF)-19089

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ABSTRACT

Canadian Nuclear Laboratories (CNL) proposes to develop a Near Surface Disposal Facility (NSDF) at the Chalk River Laboratories (CRL) site in Ontario, Canada for disposal of CNL’s Low Level Radioactive Waste (LLW) and other suitable wastes meeting the Waste Acceptance Criteria (WAC). The NSDF’s Engineered Containment Mound (ECM) includes base liner and final cover systems. These liner systems are designed to perform effectively for a total of 550 years. The specified geomembrane in the NSDF detailed design is 2 mm thick High Density Polyethylene Geomembrane (HDPE GMB) double sided textured and white surface. CNL’s approach to collaborate with Subject Matter Expert (SME) consultants and contractors, a Canadian university, and industry has enabled the NSDF to incorporate current best design practices, particularly for the design of the ECM’s liner systems. This paper describes the HDPE GMB testing program and how the results of the state-of-the-art research have been utilized in the design of the NSDF’s liner system and in selection of the best candidate materials to strengthen the confidence that the required service-life will be met. The testing program includes index properties and long-term performance evaluation tests of the five candidate HDPE GMBs using leachate simulant comparable to expected NSDF leachate and an index simulant used for testing many GMBs. The results of the tests are used as the basis to assess expected HDPE GMBs long-term performance. The expected long-term performance is applied as the key consideration for the final selection of the HDPE GMB in the NSDF project. Preliminary results of the testing program indicate that an expected service-life of 550 years will likely be met by the candidate HDPE GMB.

INTRODUCTION

In Canada, Canadian Nuclear Laboratories (CNL) is one of a few organizations responsible for long-term management of the radioactive wastes [1]. Different approaches in managing radioactive wastes can be proposed by the responsible organizations [1]. Review of trends, developments and challenges of Low Level Radioactive Waste (LLW) disposal was conducted in 2015 and concluded that: the LLW disposal was a matured practice and more than 100 LLW repositories were safely in operation all over the world, the engineered near surface disposal facility concept was considered one of the facility types suitable for disposal of LLW waste among different types of LLW disposal facilities [2]. Currently, CNL has made application to initiate the regulatory approvals process, including a federal environmental assessment, for a proposed Near Surface Disposal Facility (NSDF) at the Chalk River Laboratories (CRL) site in Chalk River, Ontario, Canada to safely reduce legacy waste liabilities. The NSDF includes an Engineered Containment Mound (ECM) to safely dispose of CNL’s solid, Low Level Radioactive Waste (LLW) and other suitable waste streams.

The ECM is designed to have a service-life of 550 years. In addition to the ECM, the NSDF also includes Waste Water Treatment Plant (WWTP), support facilities, and site infrastructure (Figure 1). The WWTP is designed to remove contaminants from precipitation that percolates through the waste placed in the ECM before the final cover system is installed, as well as waste water from operational activities.

The WWTP, support facilities, and site infrastructure will be decommissioned and removed following the end of operations.

The mound will hold 1,000,000 m^3 of waste and feature 10 waste disposal cells to be built in two phases: 6 cells in Phase 1 with capacity of 525,000 m^3 and 4 cells in Phase 2 with capacity of 475,000 m^3.

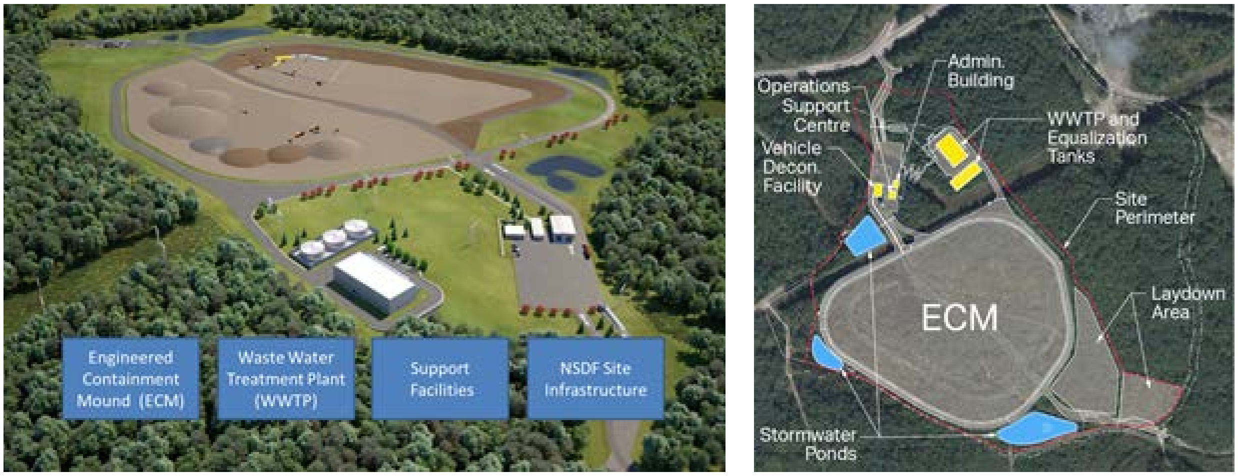


Figure 1. Elements of the Near Surface Disposal Facility (NSDF)

The ECM is designed to feature base liner and final cover systems, with the waste placed in between the liner and the cover systems. The base liner and final cover systems are designed to include multi-barrier components. The base liner includes leachate collection system (LCS), leak detection system (LDS), primary and secondary liners (Figure 2). From top to bottom, it comprises of: 300 mm thick Granular ‘A’ filter, nonwoven geotextile filter, 300 mm thick layer of 19-mm clear stone, woven geotextile separator, 200-mm-thick sand cushion, 2 mm textured high-density polyethylene (HDPE) GMB liner, geosynthetic clay liner (GCL), 300 mm thick layer of 9.5-mm clear stone, woven geotextile separator, 200-mm-thick sand cushion, 2 mm textured HDPE GMB liner, GCL, 750-mm-thick compacted clay liner (CCL). The total thickness of base liner system is approximately 2.05 m.

As part of the NSDF project, CNL is collaborating with SME consultants, contractors, and a Canadian university. This collaboration facilitated the application of state-of-the-art R&D results in the NSDF design and initiation of the HDPE GMB testing program. Two examples are discussed below.

First, a 200 mm thick layer of sand cushion layer was added above the HDPE GMB during the design. This was a modification of the initial design. This feature was based on the experience gained during large-scale tests on barrier systems. This feature was added to protect the HDPE GMB, to distribute load, to limit strain, and in the end to enhance the long-term performance of the HDPE GMB [29].

Second, a testing program on the HDPE GMB was initiated after recognizing the importance to examine long-term performance of candidate GMBs prior to final selection of the HDPE GMB for the NSDF. The topic was selected, because the HDPE GMB’s proven ability to limit leakage of leachate to negligible levels when used in a double composite liner system (Figure 2) and the GMB is the most functionally important component of the liner systems to contain the waste in the ECM. Rowe and Yu [39] have provided a review of the role of protection layer issues (aspect #1). This paper focuses the discussion on selecting a HDPE GMB with the required longevity (aspect #2). It describes the HDPE GMB testing program and how the results have been utilized to design the liner system.

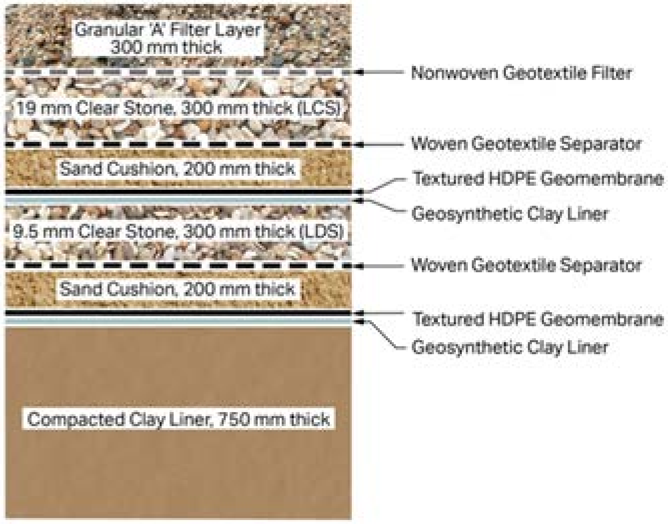


Figure 2. Base Liner System Components with Leachate Collection System (LCS) and Leak Detection System (LDS)

BACKGROUND OF THE HDPE GMB TESTING PROGRAM

The NSDF detailed design specifies a 2 mm thick textured, white-surfaced, HDPE GMB liner and sets specifications for index properties. The following aspects provide rationales to initiate for a comprehensive HDPE GMB testing program. First, there is the possibility that the HDPE GMB with the “best” index properties, may not necessarily provide the best long-term performance. Second, while HDPE GMBs have been used in comparable facilities and there is data to support a service-life beyond the 550 years design-life required for the NSDF liners, there is a need to specify the exact GMB product for the NSDF. Third, manufacturers have been improving the HDPE GMB products over time. With the motivation to select the best currently available HDPE GMB for the NSDF, the project initiated a testing program on the HDPE GMB. Finally, scientific-based methods to assess the long-term performance of the HDPE GMB have been established and be used in the testing program.

The main objective of the testing program is to provide a systematic approach to identifying the specific HDPE GMB product for construction of the Phase 1 of the ECM that is expected in the near future. Considering that a similar HDPE GMB may no longer available in Phase 2, anticipated around 2040 and better products may be available in the future, a similar testing program is anticipated to support the future selection of the HDPE GMB prior to Phase 2 of the ECM construction. In addition, for final selection of the HDPE GMB, the results of the testing program will be used to:

- improve the confidence that the design requirement for 550 years’ service-life will be met,
- refine HDPE GMB specification to particular brand(s), product(s), and formulation(s), prior to its acquisition, and
- provide information to support the regulatory licensing process.

STAKEHOLDER RELATIONSHIP

Figure 3 illustrates the stakeholder relationship in the HDPE GMB testing program. Communication between all the stakeholders are managed by CNL NSDF project. Stakeholders include the CNL NSDF Project, Technical Review Committee (TRC), Geomembrane Manufacturers, Lab-1 conducting the index performance testing on un-aged materials, Lab-2 conducting long-term performance testing, and SME consultant.

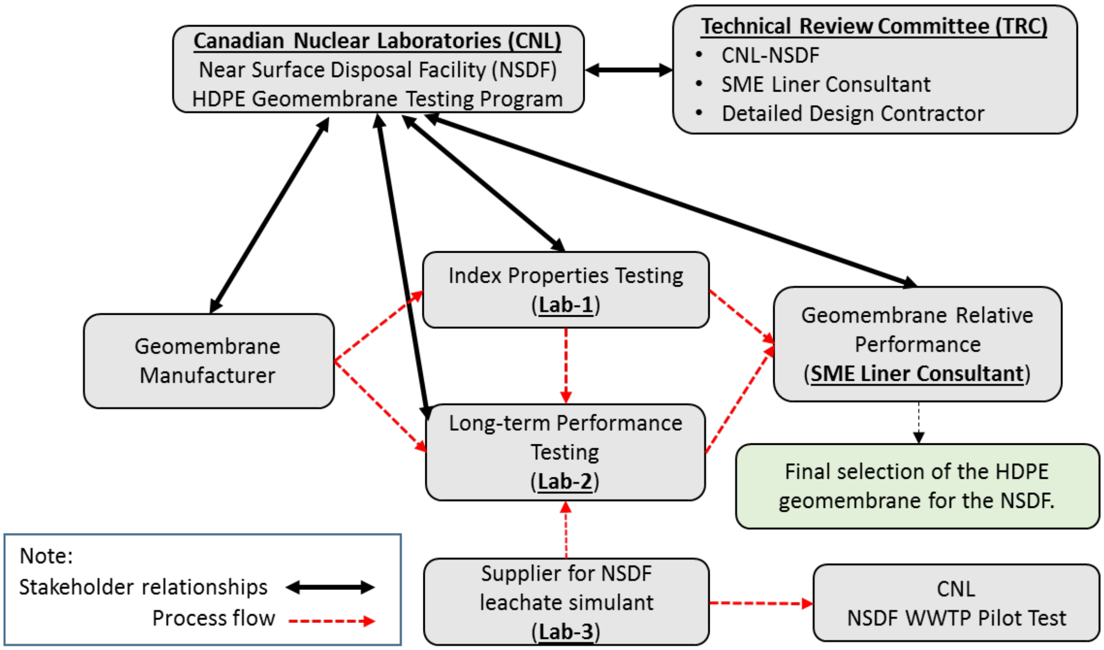


Figure 3. Stakeholder Relationship and Process Flow on the HDPE GMB testing program for the NSDF

SELECTION PROCESS OF THE HDPE GMB FOR THE NSDF PROJECT

The selection of process of the HDPE GMB is described as follows.

Formation of Technical Review Committee (TRC) and Testing Program

- Technical Review Committee (TRC) was formed to develop testing program and execute the HDPE GMB selection process. The TRC includes representatives from CNL's NSDF project, NSDF detailed design contractors, and SME Consultant. The TRC is responsible to review all reports in the HDPE GMB testing program.

Selection of Candidate Geomembranes for Testing

- CNL issued a Request for Expression of Interests (RFEOI) to potential HDPE geomembrane manufacturers to propose superior candidate geomembranes for testing program that meet the specified index properties criteria and likely meet the long-term performance criteria of 550 years. In some cases, the manufacturers had to conduct specific runs to produce the requested HDPE GMB from a similar batch.
- The TRC reviewed preliminary manufacturers' information to create a short-list of HDPE GMB candidates for the testing program. To ensure the proposed product for testing will be similar to that used for the construction, CNL requested that the date of manufacture, batch number, lot number and roll number from which the supplied sample was taken and an undertaking that the manufacturer could produce the same product if contracted to do so.
- Based on the recommendation of the TRC, CNL then requested sufficient quantities of the short-listed HDPE GMBs to be shipped to CNL's independent testing laboratories to conduct the testing.

Index Properties and Long-Term Performance Measurement Tests

- CNL awarded separate contracts to conduct the index properties testing (Lab-1) and long-term performance testing (Lab-2). To maintain continuity with the WWTP Pilot study, the same supplier (Lab-3) providing the NSDF leachate simulant was also contracted to supply the leachate simulant for the geomembrane long-term performance test (Lab-2).
- The scope of the testing includes index properties tests, long-term performance evaluation tests, and relative performance analyses of five (5) different candidate HDPE GMBs produced by three (3) different manufacturing plants. Similar HDPE GMB samples from the same manufacturing date, batch number, lot number and roll number were sent to two different laboratories for testing.

Relative performance analysis

- Based on the results of the testing program and comparison with extensive HDPE GMB database, the SME consultant is conducting the relative performance analysis to estimate the expected service-life of the candidate HDPE GMBs. Considering the importance of meeting technical requirements, cost was not considered in the selection process.

The final results of the testing program will be recommendations and supporting laboratory testing data on the preferred HDPE GMB for the NSDF project that is expected to best meet the project requirements, including service-life of 550 years. The index properties tests, long-term performance measurement tests, and relative performance analyses are described in the following sections.

INDEX PROPERTIES TESTS

The index properties tests include characterization of the properties of unaged candidate HDPE GMBs. Testing includes: thickness; asperity height; density; carbon black content; carbon black dispersion; melt flow index (MFI), tangent modulus in Machine Direction (MD) and Transverse Direction (TD); yield strength; break strength; tear strength; puncture strength; Stress Crack Resistance (SCR) SP-NCTL; UV resistance tests; Oven aging tests of Standard-Oxidative Induction Time (OIT) and High Pressure-Oxidative Induction Time (HP-OIT); and water vapour transmission. Table 1 lists the methods used for the index properties tests.

Testing methods for smooth HDPE GMB have been well established. The NSDF project has specified textured HDPE GMB to improve interface shear resistance in the NSDF design. To investigate the testing methods suitable for textured HDPE GMB, the index properties tests considered two different sample preparations for SCR, Std-OIT, and HP-OIT. SCR tests were done for smooth edge of the samples and manufactured plaques from the textured region of the samples. The Std-OIT and HP-OIT were conducted using both bore cut specimens with white side up and homogenized pulverized/plaque specimens. While both results are relatively comparable, further studies to establish testing methods for the textured HDPE GMB may be required.

PROCESS OF LONG-TERM PERFORMANCE TESTS

Figure 4 illustrates the process used for the long-term performance tests. After the samples were received from the manufacturer, the samples were prepared for accelerated ageing using the jar immersion test procedures. The samples were then harvested at selected durations between 0 to 480 days. Longer duration tests are also being considered for selected tests. During the accelerated ageing process, assessment of the antioxidant depletion stage (Stage I) and changes in physical and mechanical properties (Stage II and Stage III) were conducted. Assessment of Stage I includes HP-OIT and Std-OIT tests on aged HDPE GMB samples.

Table I. List of Index Properties Tests on Unaged HDPE GMBs

Parameters	**Methodology**	**NSDF specification**
Thickness	ASTM D 5994 [4]	2.00 mm
Asperity height	ASTM D 7466 [5]	0.40 mm
Density	ASTM D 792, Method A [6]	0.940 g/cc
Tensile properties • Yield strength • Break strength • Yield elongation • Break elongation	ASTM D 6693 Type IV, 2 ipm strain rate [11]	 29 kN/m 21 kN/m 12% 100%
Tear resistance	ASTM D 1004 [12]	249 N
Stress Crack Resistance (SCR)**	ASTM D 5397, App [15] • Test on manufactured plaque from textured GMB • Test on smooth edge of the textured GMB	1000 hours
Carbon Black Content	ASTM D 4218 [7]	2.0 – 3.0%
Carbon Black Dispersion	ASTM D 5596 [8]	Note (1)
Melt Flow Index (MFI)	ASTM D 1238, Method A, 190°C/ 2.16 kg and 21.6 kg [9]	Not specified
Tangent Moduli • MD 2% Tangent Modulus • XMD 2% Tangent Modulus	ASTM D 638/GRI 13, 2 ipm strain rate, Type IV specimen [10]	Not specified
Tear resistance	ASTM D 1004 [12]	249 N
Puncture resistance	ASTM D 4833 [13]	534 N
Oxidative Induction Time (OIT) (a) Standard OIT (b) High Pressure OIT	 ASTM D 3895 [31] ASTM D 5885 [32]	 180 min 1000 min
Oven aging at 85°C** (a) Standard OIT (b) High Pressure OIT - % retained after 90 days	ASTM D5721 [17] ASTM D 3895 [31] ASTM D 5885 [32]	 55% 80%
UV Resistance** (c) Standard OIT (d) High Pressure OIT - % retained after 1600 hours	ASTM D 7238 [16] ASTM D 3895 [31] ASTM D 5885 [32]	 Not recommended. 50%
Water Vapour Transmission	ASTM F 1249 [14]	Not specified

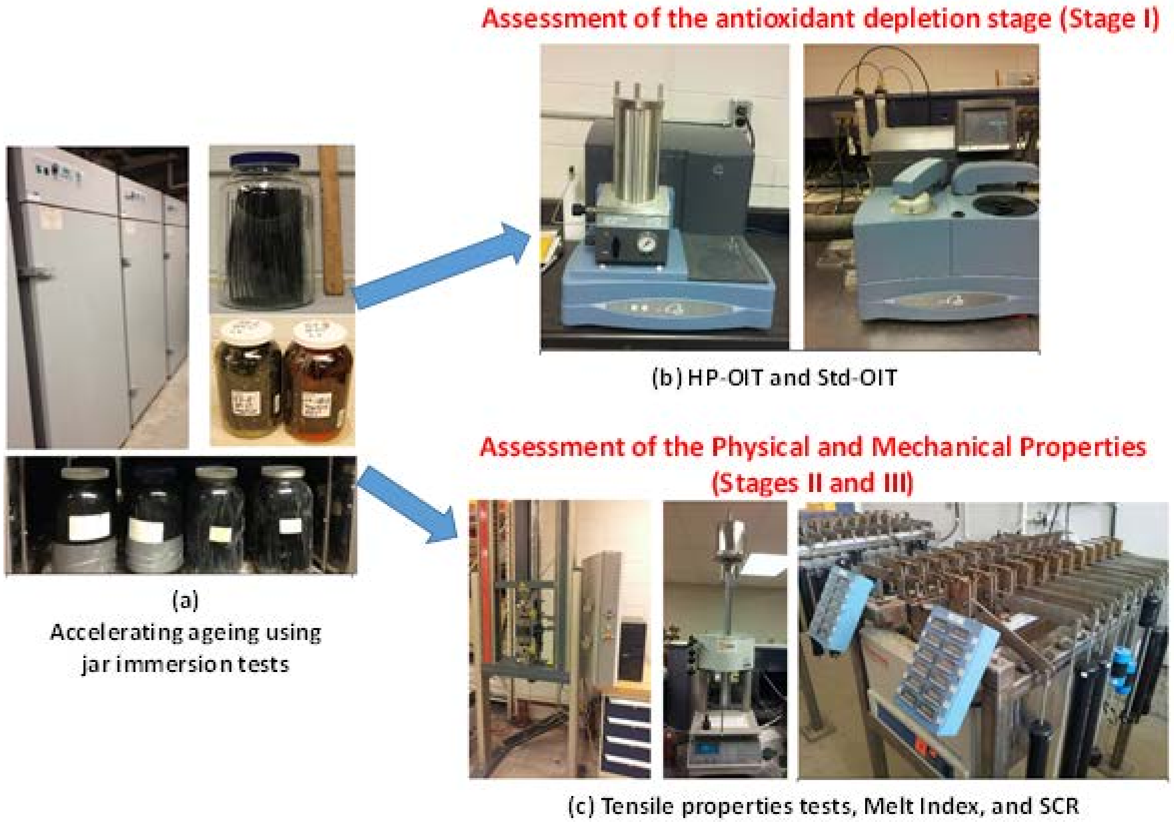
Note: *MD = Machine Direction; XMD: Cross-Machine Direction. **Test on pulverized/ plague and test on bore cut; white side up. (1) Carbon black dispersion (only near spherical agglomerates) for 10 different views: 9 in Categories 1 or 2 and 1 in Category 3.

Assessment of Stages II and III include tests to evaluate changes in the tensile properties, melt index, and SCR on aged HDPE GMB samples. Table II provides testing matrix for the long-term performance testing program.

Table II. List of Long-Term Performance Index Tests

	Parameters	**Methodology**	**Temperatures (°C)**	**Duration of incubations (days)**	**Leachate Simulants**
Stage I Assessment of the antioxidant depletion stage	Std-OIT	ASTM D3895 [31]	40, 55, 65, 70, 75, 85	Up to 480 days*	MSW-L3 NSDF-L7 NSDF-L9
	HP-OIT	ASTM D5885 [32]			
Stages II and III Assessment of the physical and mechanical properties	Melt Flow Index (MI)	ASTM D1238 [9]			
	Tensile properties	ASTM D6693 [11]/ ASTM D638 [10]			
	Stress Crack Resistance (SCR)	Appendix of ASTM D5397 [15]			

*Selected tests run longer



(a) Accelerating ageing using jar immersion tests

(b) HP-OIT and Std-OIT

(c) Tensile properties tests, Melt Index, and SCR

Figure 4. Process for Long-Term Performance Measurements

JAR IMMERSION TESTS

Background

Under long-term field exposure conditions, a polyethylene GMB experiences degradation ([18]; [19]; [20]) that results in the loss of its favorable mechanical properties with time.

The rate of degradation will depend on: (a) the GMB product formulation, thickness, etc.; (b) the surrounding field environment; and (c) the GMB field exposure temperature.

Thermo-oxidative degradation of polyethylene GMBs involves three stages until nominal failure (e.g., [21]; [18]).

- Stage I is the loss of antioxidants due to physical extraction and/or chemical consumption at a rate that is dependent on the exposure conditions.
- Stage II is a lag or induction period during which the auto-oxidation reactions that give rise to polymer degradation are initiated and begin to propagate without measurable changes in the bulk polymer properties.
- Stage III is the period when the auto-oxidation reactions degrading the polymer are measurably changing the bulk properties of the GMB.
- The time to nominal failure of the GMB is the time from the initiation of Stage I until the time in Stage III when some physical property of significance (e.g., stress crack resistance or the tensile break elongation) has reduced to a prescribed threshold level due to ageing.

Jar immersion tests (e.g., [22]; [23]; [24]; [25];[26]; [27]; [28]) are typically used in the laboratory to quantify the chemical compatibility of GMBs with immersion fluids simulating field exposure. The jar immersion tests can be used to quantify the three stages of degradation if run for an adequate duration (e.g., [26]; [29]; [30]) and hence assessing the time to nominal failure. Although nominal failure of the GMB represents a significant reduction in its performance, it does not generally correspond to the end of service-life of the HDPE GMB bottom liner. This is because (a) the degradation in immersion tests (with coupons exposed to leachate from both sides) will be much faster than in a typical landfill liner in the field (with exposure to leachate from the top side only) [29], and (b) the service-life of a GMB also depends on the tensile stresses/strains that are not simulated in the jar immersion tests [30]. However, the times to nominal failure based on jar immersion tests provide a good insight regarding which materials have the potential to provide long-term performance under the same conditions.

Objectives

The objective of the long-term performance testings is to evaluate the degradation of five candidates HDPE GMB for the NSDF project using jar immersion tests for a 16-month incubation period. The candidate HDPE GMBs are each immersed in three different leachate simulants, referred as MSW-L3, NSDF-L7, and NSDF-L9. The results will allow a comparison of the depletion/degradation rates of the five HDPE GMBs at different temperatures and an evaluation of the relative progression of the GMBs through the three degradation stages. Given the duration of the tests, predictions are expected to involve Stage I only at field-specific temperatures that are usually lower than the accelerated ageing temperatures.

The ageing of the candidate GMBs is examined by immersion in the desired solutions at elevated temperatures. In this method, GMB samples are cut into 19 x 10 cm coupons and placed in 4-L glass containers (16 coupons from each GMB per one jar) (see Figure 4a). To ensure that leachate will be in contact with both surfaces of coupons, 5 mm diameter glass rods are placed as separators between coupons (Figure 4a). Three different leachate simulants are considered in the testing program. These include: MSW-L3, NSDF-L7, and NSDF-L9 described below.

Leachate Simulants

Leachate Simulant MSW-L3.

The reference immersion solution in this study is a simulated municipal solid waste (MSW) leachate, known as MSW-L3. [25] and [28] studied different combinations of the main chemical constituents found in MSW leachate. These primary constituents were volatile fatty acids (VFAs), organic/inorganic salts (referred to simply as "salts"), surfactant, and trace metals (TMS). [28] showed that incubation in MSW-L3; combining all the primary constituents except for the VFAs) for almost 9 years resulted into the fastest degradation of the tested GMB compared to immersion in all other tested leachates including the full leachate combining all the primary constituents. Thus, MSW-L3 was used as the main immersion solution in this study to obtain degradation results in the shortest time possible allowing the comparison between the performances of the candidate GMBs.

Leachate Simulants NSDF-L7 and NSDF-L9.

The chemistry composition of these two leachate simulants are based on the NSDF WWTP pilot study. In order to be in line with the NSDF WWTP pilot test. No radioactive constituents were included in the make-up of these solutions. The same supplier provided the salt solutions for the immersion solutions in this study to match both the concentrations and the source of the chemicals used in the NSDF WWTP pilot study. The NSDF leachates were prepared by mixing the concentrated salt solution received from chemical supplier with deionized water (DI) that gave a pH of around 8.4 after dilution to the desired concentrations. For NSDF-L7, the pH was adjusted by titrating H_2SO_4 to give a pH of 7 ± 0.2. NSDF-L9 is similar to NSDF-L7 but with pH adjusted to 8.8 ± 0.2 using NaOH. Titration of H_2SO_4 or NaOH was done during the mixing stage to prevent the loss of any chemical component prior to the pH adjustment and followed the instructions provided by Chemical Supplier. Similar to MSW-L3, the NSDF leachates are also replaced every 6 weeks to ensure that the leachate strength remains relatively constant and minimize build-up of antioxidants leached from the GMB in the solution.

ASSESSMENT OF THE ANTIOXIDANT DEPLETION STAGE (STAGE I)

Standard oxidative induction time (Std-OIT; ASTM D 3895 [31]) and high pressure oxidative induction time (HP-OIT; ASTM D 5885 [32]) tests on aged HDPE GMB samples are used to assess both the initial OIT values and the antioxidants depletion time for the aged GMB specimens in different experiments. Due to the high test temperature, Std-OIT can only detect antioxidant with high effective temperatures such as phosphites and hindered phenols used to protect the GMB during the manufacturing stages and during the GMB's service-life. However, other antioxidants such as hindered amine light stabilizers (HALS) and thiosynergists may volatize at the Std-OIT test temperatures and, thus, may not be detected in the Std-OIT test. To detect these antioxidants, HP-OIT tests are conducted at 150°C but under a cell pressure of 3450 kPa (500 psi). Thus, the two tests are conducted in parallel to detect the effect of different antioxidants stabilizing the GMBs on the time to depletion under the conditions examined in these index tests. As the GMB become exposed to environmental conditions such as temperature and leachates in the laboratory immersion tests (as reported herein) or in the field, the antioxidants/ stabilizers start to deplete with time that results in the decrease of the OIT values measured by these index tests.

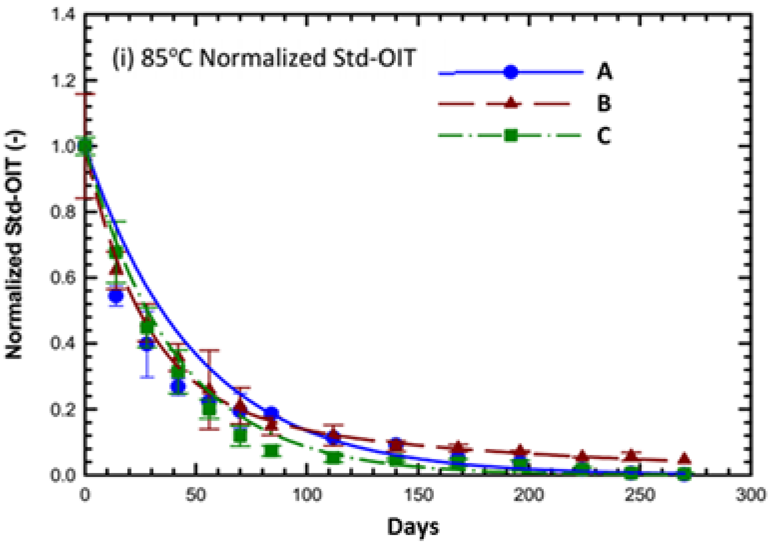


Figure 5. Example of the Results of Normalized Std-OIT for 3 different HDPE Geomembrane Candidates

ASSESSMENT OF THE PHYSICAL AND MECHANICAL PROPERTIES (STAGES II AND STAGE III)

The changes in polymer mechanical and physical properties of the tested GMBs at different temperatures are assessed in terms of MI, tensile properties, and SCR. The MI tests are performed according to ASTM D 1238 [9] where specimens are heated to 190°C and then extruded through an orifice under masses of 2.16 kg and 21.6 kg. Tensile tests are performed according to ASTM D6693 [11] (specimen Type IV) or ASTM D638 [10] (specimen Type V) testing methods at a constant rate of crosshead movement of 50 mm/min. Changes in the tensile properties such as yield strength (F_y), break strength (F_b), yield elongation (ε_y), and break elongation (ε_b) are monitored with time to assess the changes in the polymer due to incubation in the machine direction (MD) and the cross machine direction (TD) of the roll. The change in yield properties with ageing usually corresponds to a change in the crystallinity of the GMB as it stabilizes with time following the manufacturing stage to the equilibrium crystallinity ([33]; [34]; [35]; [25]; [26]). This change in yield strength is unrelated to thermo-oxidative degradation of the polymer and, thus, the yield properties are not useful in assessing the length of Stage II and degradation rates in Stage III. In contrast, the break strength and strain decrease with time as the polymer degrades (e.g., [26]; [27]; [28]) and, hence, can be used to assess the length of degradation Stages II and III.

Changes in stress crack resistance (SCR) can result from morphology changes (e.g., [36], [37]; [38]) and/or polymer degradation ([26]; [27]; [28]). SCR is evaluated using the single point notched constant tensile load test (NCTL) per ASTM D5397 [15]. Dumbbell-shaped specimens in the XD taken after various periods of incubation and notched to maintain a constant ligament of 80% of the nominal thickness are immersed in 10% Igepal solution at 50°C under a constant applied load representing 30% of yield strength measured for the unaged specimens using tensile test ASTM D6693 (Type IV) [11]. For textured GMBs, ASTM D5397 [15] concurs with GRI-GM13 [3] "*The SP-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for the textured sheet materials*". Thus, the SCR test as per ASTM D5397 [15] method is conducted during this study on the smooth edge of the GMB rolls on smooth material said to be equivalent to the textured GMBs since they had a textured edge.

RELATIVE PERFORMANCE ANALYSIS

This relative performance analysis uses the results obtained in the HDPE GMB-Long-Term Performance Measurement Testing as a basis for a comparison with data obtained from testing of a number of GMBs over the last 20 years under the direction of R. Kerry Rowe. The objective of the analysis is to review how the NSDF candidate GMBs compare with each other and the other tested GMBs immersed in the same or comparable solutions over a much longer period.

Based on this, an interim assessment is made of: (a) the relative performance and the most suitable GMBs for the NSDF facility based on the available data, and (b) the likelihood of these GMBs having a service-life that exceed the required 550 years based on the projected long-term performance for these GMBs.

At the time of preparing this paper, the long-term performance tests and preparation of final report on relative performance are still underway. Based on currently available results, the required 550 year service-life will be achieved and that it could be confidently concluded for the NSDF ECM.

CONSTRUCTION QUALITY ASSURANCE (CQA)

Selection of the best possible HDPE GMB is one of aspects to ensure a high performance of the NSDF liner system. The NSDF will implement sufficient Construction Quality Assurance (CQA) during the construction stage to ensure high quality installation of the HDPE GMB and liner system. The CQA for the NSDF will include:

- Independent full time on-site inspection by adequately trained, experienced, and qualified individuals. These individuals will be personally present and physically witness all aspects of liner construction and covering.
- There will be an Electrical Leak Location Survey (ELLS) after the liners (secondary and primary base liners) are covered by the protection and drainage layers. The ELLS will help find any holes that may have occurred during covering.

Notwithstanding a robust CQA program, the detailed design has been conservative in recognizing that these products and their associated installations may have imperfections. These potential imperfections have been taken into consideration in the NSDF detailed design.

POST CLOSURE ASSESSMENT MODEL

Collaboration between CNL and international subject matter experts in the NSDF project is also continue all the aspects of the project, including the development of Post Closure Safety Assessment (PostSA) model to assess the long-term safety of the NSDF. The realistic properties of GMB liner system, accounting expected as-built properties of the HDPE GMB has been incorporated in the PostSA model.

The PostSA model is built in AMBER, a software tool that allows users to build and visualise 3D dynamic compartment models of contaminants in environmental, biological, and engineered systems. The model includes the various barriers present in the ECM, which includes the liner system and the GMB.

The PostSA evaluates a variety of scenarios, a selection of which are categorized and listed below:

- Normal Evolution Scenario(s) – these scenarios examine the most probable and expected evolution of the facility with time. Key assumptions of these scenarios include:
  - the Institutional Control Period extends to 300 years after the closure. During this period, the facility is maintained, repaired if damaged, and land-use restrictions are enforced (i.e., there is no industrial or residential use of the land allowed);
  - the Institutional Control Period prevents human intruders;
  - a human resident builds a house on the ECM immediately after the Institutional Control Period ends;
  - the engineered barriers degrade gradually, allowing for the gradual release of radionuclides; and

    - the cap degrades faster than the liner, allowing for an accumulation of water into the ECM (i.e., “bathtub” effect).
- Disruptive Events – these scenarios examine events that have a reasonable chance of occurring during the assessment timeframe of the study, including:
    - human intrusion (i.e., site investigation, core inspection, drinking from contaminated well);
    - erosion of the cap; and
    - seismicity.
- What-if Scenarios – these scenarios are low-probability events, but worth studying to have a complete understanding of the consequences, such as road building, archeological digs, early loss of Institutional Control, and early glaciation.
- Sensitivity Cases – these scenarios examine the effects of changing a single parameter or assumption to determine how much of an effect it has on the dose consequence, including:
    - alternate radiological inventories;
    - human behaviors and the diameter of the water well excavated;
    - basement depth;
    - distribution coefficient, hydraulic conductivity, sorption coefficient, and ingestion rates; and
    - climate change.

The PostSA has been through several iterations as the inventory and design were modified. The latest results indicate that the NSDF will meet the requirements for the protection of the public and the environment, i.e., that the calculated dose rate to the critical receptor is acceptably low, and that the concentration of contaminants in the environment meet criteria for the protection of biota.

CONCLUSIONS

- The CNL approach to collaborate with Subject Matter Expert (SME) consultants and contractors, a Canadian university, and industry has enabled the Near Surface Disposal Facility (NSDF) project to incorporate current best practices. While the paper focusses on design of liner systems for the Engineered Containment Mound (ECM), the approach to collaborate between CNL and international subject matter experts has been applied for other aspects of the project, including the development of the of Post Closure Safety Assessment (PostSA) to assess the long-term safety of the NSDF.
- Early involvement of the SMEs in the NSDF project allowed the project to implement current state-of-the-art R&D results and initiation of HDPE GMB testing program to select the best possible candidate material currently available to ensure the long-term performance of the ECM liner system.
- The NSDF application of the results of the R&D was not only for the design, but also for selection of the HDPE GMB for the NSDF. The expected long-term performance is used as the key consideration for the final selection of the HDPE GMB in the NSDF project to ensure long term environmental protection.
- At the time of preparation of the document, the long-term performance testing program and relative performance assessment are still underway with five HDPE GMB candidates. The preliminary results indicate that the 550 year service-life will be achieved by at least one of the HDPE GMB candidates and that it could be confidently used for the ECM.
- In the NSDF, selection of the best candidate for the HDPE GMB will be complemented by sufficient Construction Quality Assurance (CQA) inspection and testing to achieve high performance of liner system.

- The expected long-term project life of the NSDF demands successful knowledge management and inter-generational knowledge preservation. This collaborative publication is one of initiatives to facilitate knowledge preservation in the NSDF project.
- The Post Closure Assessment Model of the NSDF has incorporated expected as-built properties of the HDPE GMB and its latest results indicate that the NSDF will meet the requirements for the protection of the public and the environment.

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