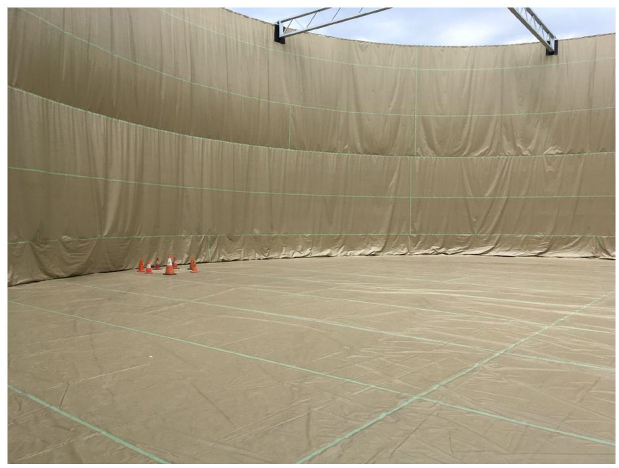
Current Overview of EIA Geomembranes

(EIA Geomembrane = PVC resin + KEE plasticizer)

Fabricated Geomembrane Institute



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I. Introduction and Purpose

This guideline provides an overview of reinforced and unreinforced EIA (EIA=PVC resin + KEE plasticizer) geomembranes. The base polymer for EIA geomembranes is polyvinyl chloride (PVC) resin as discussed below. As a result, the main purpose of this guideline is educating engineers, regulators, owners, and operators about the strengths, weaknesses, and appropriate applications of EIA geomembranes.

Because the first flexible membrane liner (FML) was used as part of an environmental liner system, the geomembrane industry has looked for innovative solutions and products to environmental containment applications. Although there have been many innovations over the last fifty (50) years, one of the most significant is the introduction of the ketone ethylene ester (KEE) plasticizer, which is a solid not liquid plasticizer. KEE is available under the Elvaloy® trade or product name and is used to plasticize PVC geomembranes as discussed in the next section (Silva and Stark, 2019). With most commercial EIA geomembranes, the actual PVC resin represents the main component making up typically 50% to 60% of the formulation. Other components include KEE plasticizers, stabilizers, fillers, and pigments required for processing and application performance.

As discussed in detail below, typical benefits of EIA geomembranes include:

- Improved performance under conditions in which a liquid plasticizer would migrate, such as outdoor exposure to weather or contact with chemicals.
- Unique chemical resistance properties, such as, resistant to chlorine in potable water applications and hydrocarbons in oil and gas development applications even in high UV exposure environments.
- Increased melt strength for thinner parts, improved foam cell structure, and increased thermoforming temperature window, which facilitates welding individual sheets together.
- Reduced scrap and higher yields through improved flow and fusion characteristics, which allows for lower processing temperatures and a wider processing window for rigid PVC resin/materials.
- Reduced cost by enabling higher filler levels while meeting required impact properties.
- High impact strength that exceeds industry standards

As discussed in detail below, the main limitation or weakness of EIA geomembranes is increased cost because of the greater cost of the KEE plasticizer compared to traditional liquid plasticizers even if the liquid plasticized material meets the Fabricated Geomembrane Institute Specification FGI-1104 (www.fabricatedgeomembrane.com) requirement of a minimum average molecular weight of 400 grams/mole. This is due to a significantly higher cost ($/lb.) of KEE plasticizer as compared to standard liquid-based plasticizers and a greater percentage of KEE being used to obtain a similar flexibility of the PVC resin and KEE plasticizer blend. The real benefit of using KEE plasticizer is the resulting geomembrane will be flexible for a much longer time and exhibit a greatly extended service life even in exposed and/or harsh chemical environments. Therefore, if a long service life is desired, a PVC resin and KEE plasticizer blend should be considered even though it may have a higher initial cost, which is important in potable water applications.

II. Terminology

KEE plasticizer was invented by DuPont and the original 1973 patent has expired. KEE plasticizer was developed to provide a solid plasticizer or polymer to replace liquid plasticizers that have been used to make PVC and other polymers flexible without concerns of plasticizer migration and loss. Plasticizer migration and loss usually results in the produced material becoming stronger but more brittle and susceptible to cracking under normal and tensile stresses.

Unfortunately, Elvaloy® has been known by several acronyms, e.g., KEE, EIA, and EIP, which has caused confusion in the industry. As a result, the purpose of this article is to clarify the meaning of KEE, EIA, and EIP for geomembrane related applications.

Compared to conventional polymeric and monomeric liquid plasticizers, KEE plasticizer exhibits a significantly higher molecular weight, which greatly reduces plasticizer migration (Stark et al., 2005). Stark et al. (2005) show that increasing plasticizer molecular weight decreases plasticizer migration because the higher molecular weight yields a larger molecule that has greater difficulty detaching from the PVC resin and migrating to the top surface of the geomembrane and out of the geomembrane. As a result, plasticizer migration and loss decrease with increasing molecular weight. In 2004, the Fabricated Geomembrane Institute (FGI) set the minimum plasticizer molecular weight at 400 grams/mole rams/mole for traditional PVC geomembranes to ensure suitable long-term performance of PVC geomembranes in containment applications. This is the FGI Material Specification dated 1 January 2004 and termed FGI104. A minimum plasticizer molecular weight of 400 grams/mole has worked well, resulted in better long-term performance, and created more consistency in the marketplace. However, recent applications, e.g., exposed and elevated temperature applications, have created a demand for even higher performance PVC geomembranes and thus higher performance plasticizers.

As a result, considerable interest has developed for the creation and use of higher molecular weight plasticizers, such as KEE. In addition to a higher molecular weight, KEE plasticizer is a solid plasticizer/polymer that does not break down under high temperatures, which prevents migration and loss from the geomembrane because it retains a large structure, strong bond to the PVC polymer, and remains as a solid.

The molecular weight of traditional plasticizers, e.g., Phthalates, ranges from 200 to 530 grams/mole (Stark et al., 2005). For comparison, KEE plasticizer exhibits a molecular weight of 100,000 to over 260,000 grams/mole or 500 times greater than the molecular weight of traditional liquid plasticizers that have been included in traditional PVC geomembranes. For example, a KEE plasticizer molecular weight of 100,000 grams/mole is 250 times higher than currently required by the FGI 1104 specification (400 grams/mole) for traditional PVC geomembranes. In addition, traditional PVC geomembranes are not reinforced or supported with a fabric as EIA geomembranes can be supported if desired.

KEE is a solid-phase (polymeric) plasticizer, not liquid, which along with its high molecular weight provides significant resistance to migration. This allows the resulting geomembranes plasticized with KEE plasticizer to maintain its flexibility for a longer time resulting in a longer service life even under exposed applications. Because of its flexibility and longevity, KEE plasticizer blended material is used for exposed single-ply roofing, environmental containment liner systems, "no-dig" water and sewer pipe repair liners, coated fabrics, footwear, and wire and cable coatings.

KEE polymeric plasticizers are available under the tradename Elvaloy®, which are now produced by Dow Chemical. Various Elvaloy® grades are used alone or in conjunction with other materials to plasticize PVC geomembranes. The benefit of the polymeric plasticizer to this industry is their permanence in the structure; unlike liquid plasticizers that migrate, evaporate, and are removed by chemical leaching, polymeric plasticizers are immobile and fixed in the structure. Elvaloy® 741 and 742 are the original and most common grades but there are many other standard grades of KEE plasticizers (https://www.dow.com/en-us/search.html#q=ELVALOY%20KEE&t=Support&sort=relevancy). Elvaloy® High Performance (HP) series grades are composed of a different monomer composition than the 741 and 742 grades. Elvaloy® has been described in the industry by several acronyms, e.g., KEE, EIA, and EIP, which unfortunately has caused confusion. To limit this confusion, we propose the following set of definitions: (1) Elvaloy® is the trade name for the Ketone Ethylene Ester (KEE) family of polymers that may also be classified as Ethylene Interpolymers (EIPs); (2) KEEs when blended with PVC form Ethylene Interpolymer Alloys (EIAs). Putting this nomenclature to practice, the geomembrane industry should use EIA to describe PVC-KEE blended geomembranes (Silva and Stark, 2019).

The relative percentage of KEE to PVC used in the blend is determined by several application specification details including the required chemical permeation resistance and permeance of the flexibility. The nature of the specific KEE and PVC resin used has a significant impact on the flexibility achieved for a given blend ratio. For example, if Elvaloy® High Performance (HP) series grade plasticizers are used, a smaller percentage will/may be needed to obtain the same flexible performance as a standard grade KEE.

The following is a brief list of acronyms related to EIA geomembranes:

EIA	ethylene interpolymer alloy
EIP	ethylene interpolymer
KEE	ketone ethylene ester is the chemical name for this plasticizer
Elvaloy®	DuPont Trademark under Registration # 73087617 and serial # 1058099.
PVC	Polyvinyl chloride is the base resin in the geomembrane
Scrim	Reinforcing fabric included in geomembrane, which provides additional dimensional stability, puncture resistance, and tensile properties.

III. Traditional PVC Geomembrane Formulation

The first installation of a plasticizer PVC geomembrane occurred in 1954 in Fort Collins, Colorado in a water canal and associated reservoir. The main ingredients comprising a traditional PVC geomembrane formulation are: (1) PVC resin, (2) plasticizer, (3) Stabilizer/lubricant, (4) pigments or colors, (5) filler, and (6) miscellaneous ingredients. Each of these ingredients is briefly discussed in this section. Traditional PVC geomembranes are unreinforced whereas EIA geomembranes can be reinforced or unreinforced depending on the application.

PVC Resin

PVC resin is by far the largest component of the PVC geomembrane formulation. PVC resin does not have variability in structure and composition because it is a homopolymer. The only property of the resin that may differ is the molecular weight or relative viscosity of the resin. The viscosity test method is ASTM D1243-22, which is titled: "Standard Test Method for Dilute Solution Viscosity of Vinyl Chloride Polymers". In general, the higher the relative viscosity, the better the physical properties, e.g., tensile strength, elongation, cold crack resistance, chemical compatibility, puncture resistance, and long-term durability of the resin. As a result, higher viscosity PVC in the range of 2.3 to 2.6 is used to manufacture geomembranes. However, increasing the viscosity, i.e., molecular weight, of the PVC resin increases the costs and temperature at which the compound will have to be processed at.

Plasticizer

Plasticizer is the next major component of the PVC formulation. Only primary plasticizers, i.e., not secondary, are used for PVC geomembranes because of greater compatibility with PVC resin. Primary plasticizers are grouped into the following two classes: (1) monomeric and (2) polymeric. Typical monomeric plasticizers are phthalates, adipates, and trimellitates. Typical polymeric plasticizers include plasticizers polymerized from adipic and glutaric acids in combination with various glycols. The higher the molecular weight the less plasticizer migration that occurs during the service life of the geomembrane.

Primary monomeric plasticizers are used in most of the PVC geomembranes because they provide the best combination of performance, processing, and cost. Hydrogen bonding between the PVC resin and plasticizer results in a high degree of permanence. As a result, even if there is some loss of plasticizer near the surface of the geomembrane, the remaining plasticizer is tightly bonded by hydrogen bonding.

Polymeric plasticizers are typically used in oil resistant PVC geomembrane formulations. Because of the large polymer chains associated with them, they are tightly entangled with the PVC resin chains. This gives the oil resistant PVC geomembrane excellent chemical resistance to solvents and oils. In general, the higher the molecular weight of the polymeric plasticizer, the better the chemical resistance of the PVC geomembrane.

Fillers
Small amounts of filler are sometimes used in PVC geomembranes to improve seaming properties, act as biocides, improve processing, and/or improve stability of the formulation.

Stabilizers
The primary function of the stabilizers is to stabilize the formula so that it can be calendared at elevated temperatures, i.e., 350 F or higher, without degrading the physical properties. The stabilizers are metallic/organic complexes, usually metallic esters. They also contain antioxidants, phosphites, and acid scavengers.

Lubricants
Lubricants are used to provide metal release of the compound during the calendaring process and affect the physical properties of the geomembrane. Lubricants are generally complex esters.

Pigments
Pigments are used in PVC geomembranes to change the color of the white PVC resin. Most PVC geomembranes are either black or shades of gray and not white. Carbon black and titanium dioxide are the two pigments commonly used to make black and gray geomembrane colors. Pigments also act as UV stabilizers, such as carbon black. Titanium dioxide reflects almost all UV radiation. Hence, together they offer excellent UV protection.

IV. Plasticizers

With a demand of more than 40 million tons per year, Polyvinyl Chloride, or PVC, is one of the world's most commonly used plastics. As produced, PVC is a rigid plastic used for a variety of purposes such as construction pipe or trim for windows and doors. Through the addition of plasticizers, PVC can be made to be flexible. Most plasticizers are low molecular-weight, oily liquids. As the term implies, plasticizers increase the plasticity of the material which provides flexibility and softness while reducing brittleness. This plastic is often referred to as flexible PVC or fPVC.

A wide variety of plasticizers have evolved over the years that have a variety of strengths and weaknesses when compounded with PVC resin. The common plasticizers include orthophthalates, terephthalates, trimellitates, and adipates. These plasticizers are liquid at room temperature and have a low molecular weight, compared to PVC (Stark et al., 2005). Because of the liquid state and low molecular weight, these plasticizers can migrate, or exude, from the Flexible PVC material, causing the fPVC to return to become more rigid and brittle. This often results in cracking or fracturing under stress. The rate of migration or exudation of plasticizer is increased when used in applications that are exposed to heat over time or chemicals such as oils, solvents, or alcohols – all factors relevant to the long-term performance of geomembranes.

Specialty plasticizers exist, which seek to reduce plasticizer migration from PVC over time and when exposed to the chemicals previously mentioned. This has been achieved through the development of high-molecular-weight, solid plasticizers that are miscible in PVC and have low extractability in chemical and solvent solutions. These specialty plasticizers can be used in combination with common plasticizers or as a replacement for common plasticizers. As a general rule, the higher the percentage of the specialty plasticizer, the greater its effect on flexibility, impact resistance, durability, chemical resistance, and the longer the life of the end PVC product, i.e., before it starts becoming brittle and ineffective.

In the world of geomembranes, ketone ethylene ester, or KEE, plasticizer has evolved to become the dominant, high-performance, specialty plasticizer. KEE is solid phase, is non-migratory from PVC, and is highly chemical resistant. It is miscible in PVC and, when formulated properly, can completely eliminate the need for less-effective liquid plasticizers. When blended, PVC resin and KEE plasticizer form a permanently elasticized alloy system (Silva and Stark, 2019). As a general rule, the lower the amount of liquid plasticizer used the less the flexibility of the geomembrane will change over the service life. In particular, a long serving EIA geomembrane will have minimal to no liquid plasticizer to sustain the flexibility, impact resistance, durability, and chemical resistance.

V. EIA Geomembrane Formulation

EIA describes a PVC resin-based geomembrane with a high proportion of KEE solid plasticizer and low proportion of monomeric liquid plasticizer developed to provide substantially better durability than PVC alternatives. Within this general description there are many different formulations of varying performance targeting different applications, which perform well in a broad range of applications. There are also application targeted EIA formulations, a well-engineered EIA formulation that performs exceptionally well in its targeted application may not perform well in a different application.

Premium product formulations are more complex than a linear relationship between solid plasticizer or higher molecular weight plasticizers and durability. A high KEE content and low liquid plasticizer content is appropriate but over certain limits the formulation becomes more critical. A range of KEE plasticizers is available and the appropriate grade must be selected to meet application requirements. These formulation characteristics are particularly important for chemical compatibility, such as chlorine resistance, hydrocarbon resistance, etc. Other formulation components are important to achieve a durable geomembrane product.

Thermal stabilizers are included to protect the materials during processing into sheet and relate to the specific material manufacturing process and resulting thermal history. They are also included to enhance the durability performance of the PVC resin in the service application and therefore relate to the expected service temperatures. Stabilizer additives are included to retard ultraviolet (UV) degradation and oxidation (antioxidants) of the geomembrane.

In exposed applications, e.g., a floating cover, UV durability is an important durability characteristic. In addition to selected additives carbon black or titanium dioxide are included as UV blocking agents. The proportion of titanium dioxide is important to providing adequate UV protection. Premium titanium dioxide additives are highly durable; these grades are required in EIA formulations intended for long life in exposed applications. Less durable titanium dioxide additives can allow photo oxidation in some applications.

Reinforced and un-reinforced EIA geomembranes generally use different formulations. Reinforced EIA materials have a higher manufacturing thermal history due to a laminated manufacturing process and the inherent characteristic of a thin covering film over the reinforcing scrim/fabric generally requires a higher performing formulation to achieve high levels of durability. Unreinforced materials can use film thickness more easily to achieve durability objectives.

VI. Strengths of EIA Geomembranes

KEE plasticizers/polymers enhance the characteristics of other resins, e.g., PVC, by making them more durable, more flexible, and longer lasting. Typical strengths of benefits of EIA blended geomembranes include:

- Improved performance under conditions in which a liquid plasticizer would migrate, such as outdoor exposure to weather or contact with chemicals. As a result, EIA geomembranes are being used for exposed, hydrocarbon, and diesel containment applications.
- Increased melt strength for thinner parts, improved foam cell structure and increased thermoforming temperature window, which has facilitated welding individual sheets of EIA geomembranes.
- Reduced scrap and higher yields through improved flow and fusion characteristics, which allows for lower processing temperatures and a wider processing window for rigid PVC resin/materials.
- Reduced cost by enabling higher filler levels while meeting required impact properties.
- High durability performance allows reduced film thickness compared with traditional PVC geomembranes.
- High-impact strength that meets or exceeds industry standards.
- EIA geomembranes can be fabricated into large panels and repaired using thermal, dielectric, and/or radio-frequency welding.

- Good chemical resistance as shown in the table below:

Chemical	Resistance to Chemical
Oil	Excellent
Fuel	Good to excellent
Acids	Pending type & concentration
Brine	Excellent
Bases	Excellent
solvents	Poor to fair
Biogas	Good to excellent

VII. Weaknesses of EIA Geomembranes

This section discusses the weaknesses or limitations of EIA geomembranes. As mentioned above, the main limitation or weakness of EIA geomembranes is increased cost because of the greater cost of the KEE plasticizer compared to traditional liquid plasticizers even if the liquid plasticized material meets the Fabricated Geomembrane Institute Specification FGI-1104 (www.fabricatedgeomembrane.com) requirement of a minimum average molecular weight of 400 grams/mole. This is due to a significantly higher cost ($/lb.) of KEE as compared to standard liquid-based plasticizers and a greater percentage of KEE being used to obtain a similar flexibility of the PVC and KEE blend. The other limitations or weaknesses of EIA geomembranes are:

- High temperature [> 150 ^{0}F (66 ^{0}C)] resistance
  - The primary resin in the formulation is PVC, which has limited resistance to elevated temperatures.
- Requires specific manufacturing processing capabilities to effectively blend the KEE plasticizer and PVC resin to create a homogeneous film/geomembrane
- Potentially higher water absorption rates when high levels of KEE plasticizer are used in the formulation compared to liquid plasticized PVC
- Cost of EIA when compared to typical PVC, PP and PE geomembranes
  - The cost per pound of the KEE plasticizer is significantly more expensive than the raw materials being replaced in a PVC geomembrane formulation.
- EIA geomembranes were first designed for geomembrane applications and now have been adapted for roofing applications. For example, the first EIA sheet was formulated and produced specifically for the stringent chemical permeation resistance requirements of geomembrane applications as early as 1979 (https://www.xrgeomembranes.com/project-profiles/xr-5-takes-on-the-tough-texas-oilfields). Other applications followed, including EIA materials specifically formulated for roofing applications in the early 1980s

(https://cdn2.hubspot.net/hubfs/481605/PDFs/Whitepapers/Sustaining_a_KEE_standard_-_Construction_Canada.pdf?t=1476815237352; https://www.fibertite.com/project-profiles/inn-maid-noodles). Despite being the later market, the roofing segment has attracted many entrants for new EIA manufacturers. The same manufacturers are also positioning sheets for the Geomembrane market; it is imperative that these sheets be challenged to adequate accelerated testing including chemical liquid immersion to ensure chemical resistance and material compatibility for geomembrane applications."

- EIA geomembranes have evolved from the roofing industry. In various chemical applications, adequate additional accelerated testing including liquid immersion testing should be conducted to ensure chemical resistance and material compatibility.

VIII. Applications of EIA Geomembranes

Because of their excellent flexibility, durability, and welding capabilities, EIA geomembranes have increasingly been used in several common geomembrane containment applications. Most EIAs are formulated with good ultra-violet (UV) antioxidant packages and can be used for moderate to long term exposed applications. They are also quite suitable in most backfilled or unexposed containment applications. With their high flexibility, longevity, and weldability, EIA geomembranes can be factory fabricated into large and custom size panels. Today, EIA geomembranes are being commercially produced in both unreinforced (monolithic) products from 20 mil to 120 mil (0.5 mm to 3.00 mm) thick as well as reinforced (scrim fabric included) grades typically ranging from 30 mil to 60 mil thick (0.76 mm to 1.5 mm). Because there are currently no industry geomembrane standards in place for testing of EIA products, it is important that users work closely with various manufacturers and choose EIA products that have been developed and evaluated for your specific applications.

Geomembranes

EIA geomembranes are suitable for many standard geomembrane applications including containment of various process storage of potable water due to Chlorine/Chloremine resistance and longevity, wastewaters due to resistance to micro bacterial growth, brine storage, leachate collection, municipal water treatment, and brownfield or remediation applications. It is recommended that you ensure chemical resistance suitability for your project with the EIA manufacturer for these applications. Today, a wide variety of both supported and unsupported geomembrane products containing KEE plasticizer, i.e., Elvaloy®, are available in the geomembrane and other industries in applications such as primary and secondary containment in harsh chemical environments, as well as exposed potable and non-potable water containment.

Potable Water Applications

New regulations require protection of potable water supplies from vandalism and losses due to seepage into subgrade soils. As a result, EIA geomembranes are increasingly being used in municipal potable water and wastewater applications both as geomembranes and floating covers. The excellent flexibility, fatigue and fabrication properties of EIA are important in floating cover applications. As various disinfectants including chlorine are known as aggressive oxidizers on many types of geomembranes, it is important that EIA formations are adequately tested for chlorine and UV resistance in these applications. Reinforced EIA geomembranes are also a good choice of product for baffle curtains used to increase disinfectant contact time in both waste and potable water treatment applications. For example, **Figure 1** shows an exposed floating cover system to protect potable water supplies in Australia. **Figure 2** shows an EIA geomembrane that is part of the bottom liner system for a potable water reservoir in the United States. **Figure 3** shows the use of a 45-mil reinforced EIA geomembrane being used to re-line and rehabilitate a concrete storage tank for potable water instead of demolishing the tank and constructing a new tank.

Figure 1: Photograph of grey 60-mil reinforced EIA geomembrane used to create floating cover systems for potable water.

Figure 2: **Photograph of tan 60-mil reinforced EIA geomembrane used in a bottom liner system for a water reservoir.**

Figure 3: **Photograph of grey 45-mil reinforced EIA geomembrane used to re-line and rehabilitate a concrete storage tank for potable water.**

Soil Covers and Caps

EIA geomembranes, both reinforced and unreinforced, have increasingly been used for soil covers and closures for various applications related to mining and waste. EIA geomembranes properly formulated with good UV resistance can be prefabricated into large panels and used for exposed soil and waste covers to help eliminate leaching of chemicals or to prevent dilution of soils under the cover being remediated.

Secondary Containment

Specific EIA geomembranes have been developed for secondary containment of various hydrocarbons, combustible liquids, and solvents and used for the prevention of spills. These materials typically have very good chemical resistance, however, in the event of spills, most chemicals should be cleaned and removed from direct surface of the liner material as soon as possible. It is recommended that chemical immersion testing be conducted for unknown chemicals and solvents and more aggressive hydrocarbons including benzene, toluene, and xylene products.

For example, **Figure 4** shows a 60-mil thick reinforced EIA geomembrane for a secondary containment application where chemical resistance is the key performance parameter. The EIA geomembrane was laminated to a 5.5 ounces/square yard polyester nonwoven geotextile to expedite installation. After installation, the geomembrane was covered with soil for an unexposed application.

Figure 4: Photograph of 60 mil EIA geomembrane for a secondary containment application with a soil cover.

When selecting a product with the appropriate level of Elvaloy®, it is critical that the product chosen for the application contains the correct level of Elvaloy® combined with the appropriate component polymer and additives to ensure the performance meets the project longevity requirements.

Conversely, **Figure 5** shows a 40-mil thick unreinforced EIA geomembrane for an exposed secondary containment application where low coefficient of thermal expansion, high abrasion and puncture resistance, and hydrocarbon chemical resistance are the key performance parameters. The white color of the EIA geomembrane lowers the Solar Reflectance Index to less than 29 and lowers the geomembrane surface temperature in the summer months by 30 ^{0}F.

Figure 5: **Photograph of white 40 mil unreinforced EIA geomembrane for a secondary containment application without a soil cover.**

Water Tanks

Based on their excellent flexibility and ability to be customer fabricated, EIA are commonly used for residential and industrial tank liners for water storage (see photo on cover page). These include tank lining for steel tanks designed for rainwater harvesting, fire suppression and agricultural water storage. Reinforced EIA geomembranes are commonly used for taller vertical tank applications providing increased tensile strengths required to prevent material elongation and creep. For potable water applications, EIA geomembranes should be tested and evaluated for long term chlorine resistance and have proper potable water certification.

Agricultural Digesters

Reinforced EIA products have been used effectively for both positive and negative air pressure anaerobic digester gas covers and liners for methane capture. In positive pressure cover applications, it is important to ensure the EIA formulations are adequately UV stabilized and can withstand the higher methane temperatures and UV exposure required for longer term gas cover projects.

IX. Evaluating Available EIA Geomembranes – GRI – GM34

This section describes the test methods, test properties, and testing frequency to evaluate EIA Geomembranes. This section is a summary of the Geosynthetics Research Institute's (GRI's) (https://geosynthetic-institute.org/) "Standard Specification for Poly Vinyl Chloride-Ethylene Interpolymer Alloy (PVC-EIA) Geomembranes – GRI – GM34". GRI-GM34 covers EIA geomembranes with nominal thicknesses of 0.76 mm (30 mil), 0.91 mm (36 mil), 1.13 mm (45 mil) and 1.52 mm (60 mil). GRI-GM34 presents the **minimum** physical, mechanical, chemical, and endurance properties that an EIA geomembrane must meet or exceed. If the tables change, a new version of this document will be issued. The geomembrane that meets this specification may or may not meet your project requirements because it is a **minimum** specification for a geomembrane to be referred to as an EIA geomembrane. You should contact the EIA geomembrane manufacturer to ensure the geomembrane meets your project requirements and application.

Many, if not most, current EIA geomembranes exceed the minimum properties presented in **Table 1a** (English Units) and **Table 1b** (Metric Units) from GRI-GM34, which follow below. **Tables 1a** and **1b** also present the minimum testing frequencies for the various material properties. The requirements in **Tables 1a** and **1b** represent the minimum properties for a product to be termed an EIA geomembrane but many projects may require higher values of these properties for successful performance. You should contact the EIA geomembrane manufacturer to discuss appropriate durability testing for your project requirements and application.

The material generally has a file or satin finish on each surface. If the geomembrane is reinforced, the surface will have indentations because of geomembrane indenting into the openings of the reinforcing fabric or scrim.

Table 1a – Poly Vinyl Chloride-Ethylene Interpolymer Alloy (PVC-EIA) Geomembrane - GM-34 (ENGLISH UNITS)

Material Properties	**Test Method**	**English Imperial**			**English Imperial**			**English Imperial**			**English Imperial**			**Testing Frequency (minimum)**
		30 mil			36 mil			45 mil			60 mil			
Thickness (min ave)- mils • Lowest individual of 10 values- %	D751	Nom- 10			Nom- 10			Nom- 10			Nom-10			Per roll
Fabric Scrim Type	NA	Polyester			Polyester			Polyester			Polyester			Per roll
Finished Coated Mass/unit area (min ave)	D751	28 osy			30 osy			40 osy			56 osy			Per roll
CONDITION *(1)*	--------	S	M	T	S	M	T	S	M	T	S	M	T	---------
Grab Tensile Properties *(2)* • Strength • Elongation	D751	200 lbs 20%	200 lbs 20%	200 lbs 20%	200 lbs 20%	200 lbs 20%	200 lbs 20%	250 lbs 20%	250 lbs 20%	250 lbs 20%	250 lbs 20%	250 lbs 20%	250 lbs 20%	50,000 lbs.
Trouser Tear Resistance (min. ave.) *(2)*	D5884	35 lbs	30 lbs	25 lbs	55 lbs	50 lbs	45 lbs	60 lbs	55 lbs	50 lbs	65 lbs	60 lbs	55 lbs	50,000 lbs
Hydrostatic Burst (min ave)	D751	350 psi	300 psi	250 psi	550 psi	500 psi	450 psi	700 psi	650 psi	600 psi	800 psi	750 psi	700 psi	50,000 lbs
Puncture Resistance (min ave)	D4833	125 lbs	100 lbs	75 lbs	200 lbs	175 lbs	150 lbs	275 lbs	250 lbs	225 lbs	300 lbs	275 lbs	250 lbs	50,000 lbs
Ply Adhesion (min ave) *(2)*	D6636	15 lbs/in			15 lbs/in			20 lbs/in			20 lbs/in			50,000 lbs
Dimensional Stability (max ave) *(3)*	D 1204	1.0%			1.0%			1.0%			1.0%			50000 lbs
EIA Only Properties														
1H-NMR Determination of PVC and KEE content	D8154	PVC 30% KEE 10%			PVC 30% KEE 10%			PVC 30% KEE 10%			PVC 30% KEE 10%			Per each formulation
Chlorinated water resistance star fold at 50 deg C *(4 & 6)* Pass/ Fail after 90 days by GRI GM 16 and ASTM D882 strip tensile properties	GRI GM 24	Pass (i.e., no cracks observed) Retained 80%			Pass (i.e., no cracks observed) Retained 80%			Pass (i.e., no cracks observed) Retained 80%			Pass (i.e., no cracks observed) Retained 80%			Per each formulation
Oven Aging at 85 deg C *(6)* Pass/Fail after 90 days by GRI GM 16 and ASTM D882 strip tensile properties	D 5721	Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Per each formulation
UV Resistance *(5 & 6)*	D 7328	Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Per each formulation

Pass/Fail after 10,000 light hours by GRI GM 16 and ASTM D882 strip tensile properties						

NOTES:

(1) (S) Severe, (M) Moderate, (T) Typical

(2) Regardless of machine direction (MD) or cross machine direction (XMD).

(3) Incubated at 100^0C $\pm$ 1^0C for one hour.

(4) Incubated at 50^0C $\pm$ 1^0C at 1- ppm chlorine concentration in distilled deionized water. Samples are dried and the solution is changed once a week during incubation.

(5) The conditions of the UV Fluorescent exposure method should be 20-hour UV cycle at 75^0C followed by 4 hour condensation at 60^0C.

(6) Tested on unreinforced geomembrane specimens.

Table 1b – Poly Vinyl Chloride-Ethylene Interpolymer Alloy (PVC-EIA) Geomembrane - GM-34 (METRIC UNITS)

Material Properties	Test Method	Metric			Metric			Metric			Metric			Testing Frequency (minimum)
		0.76 mm			0.91 mm			1.13 mm			1.52 mm			
Thickness (min ave)- mils • Lowest individual of 10 values- %	D751	Nom- 10			Nom- 10			Nom- 10			Nom-10			Per roll
Fabric Scrim Type	NA	Polyester			Polyester			Polyester			Polyester			Per roll
Finished Coated Mass/unit area (min ave)	D751	949 g/m^2			1,017 g/m^2			1,356 g/m^2			1,899 g/m^2			Per roll
CONDITION *(1)*	--------	S	M	T	S	M	T	S	M	T	S	M	T	---------
Grab Tensile Properties *(2)* • Strength • Elongation	D751	890 N 20%	890 N 20%	890 N 20%	890 N 20%	890 N 20%	890 N 20%	1,112 N 20%	890 N 20%	890 N 20%	890 N 20%	890 N 20%	890 N 20%	22,680 kg
Trouser Tear Resistance (min. ave.) *(2)*	D5884	156 N	133 N	111 N	245 N	222 N	200 N	267 N	245 N	222 N	289 N	267 N	245 N	22,680 kg
Hydrostatic Burst (min ave)	D751	2,413 kPa	2,068 kPa	1,723 kPa	3,792 kPa	3,447 kPa	3,102 kPa	4,826 kPa	4,481 kPa	4,137 kPa	5,516 kPa	5,171 kPa	4,826 kPa	22,680 kg
Puncture Resistance (min ave)	D4833	556 N	444 N	334 N	890 N	778 N	667 N	1,223 N	1,112 N	1.001 N	1,334 N	1,223 N	1,112 N	22,680 kg
Ply Adhesion (min ave) *(2)*	D6636	2.6 N/mm			2.6 N/mm			3.5 N/mm			3.5 N/mm			22,680 kg
Dimensional Stability (max ave) *(3)*	D 1204	1.0%			1.0%			1.0%			1.0%			50000 lbs
EIA Only Properties														
1H-NMR Determination of PVC and KEE content	D8154	PVC 30% KEE 10%			PVC 30% KEE 10%			PVC 30% KEE 10%			PVC 30% KEE 10%			Per each formulation
Chlorinated water resistance star fold at 50 deg C *(4 & 6)* Pass/ Fail after 90 days by GRI GM 16 and ASTM D882 strip tensile properties	GRI GM 24	Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Per each formulation
Oven Aging at 85 deg C *(6)* Pass/Fail after 90 days by GRI GM 16 and ASTM D882 strip tensile properties	D 5721	Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Pass(i.e., no cracks observed) Retained 80%			Per each formulation

UV Resistance *(5 & 6)* Pass/Fail after 10,000 light hours by GRI GM 16 and ASTM D882 strip tensile properties	D 7328	Pass(i.e., no cracks observed) Retained 80%	Pass(i.e., no cracks observed) Retained 80%	Pass(i.e., no cracks observed) Retained 80%	Pass(i.e., no cracks observed) Retained 80%	Per each formulation

NOTES:

(1) (S) Severe, (M) Moderate, (T) Typical

(2) Regardless of machine direction (MD) or cross machine direction (XMD).

(3) Incubated at 100^0C $\pm$ 1^0C for one hour.

(4) Incubated at 50^0C $\pm$ 1^0C at 1- ppm chlorine concentration in distilled deionized water. Samples are dried and the solution is changed once a week during incubation.

(5) The conditions of the UV Fluorescent exposure method should be 20-hour UV cycle at 75^0C followed by 4 hour condensation at 60^0C.

(6) Tested on unreinforced geomembrane specimens.

X. Summary

In summary, a wide variety of both supported and unsupported geomembrane products containing KEE plasticizer are available in the geomembrane and other industries in applications such as primary and secondary containment in harsh chemical environments, as well as exposed potable and nonpotable water containment.

When selecting a product with Elvaloy, it is critical that the product chosen for the application contains the correct level of Elvaloy combined with the appropriate component polymer to ensure the performance meets the project longevity requirements.

XI. Acknowledgements

This document is the product of the FGI PVC-EIA Geomembrane (EIA) Subcommittee, which consists of in alphabetic order: Graham Fairhead, Brian Fraser, Doug Hilts, Tina Oliver, Ray Pace, Ray Peebles, Greg Roscoe, Bill Shehane, Ed Silva, and Nurit Naveh.

XII. References

Fabricated Geomembrane Institute (FGI) (2017). "FGI 1117 Specification: Effective Jan. 1, 2017." https:// global-uploads.webflow.com/5977726c80d12837b9592f29/5b208b56f4d69dd83949fe3f_FGI-1117-PVC-Final-4-1-18.

Silva, E. and Stark, T.D. (2019), "Clarifying the Nomenclature of Elvaloy-based Geomembranes: EIA, EIP, or KEE," *Geosynthetics*, Industrial Fabrics Association International, Vol. 35(4), June/July, 2019, 8-11.

Stark, T. D., Choi, H., and Diebel, P. (2005). "Influence of plasticizer molecular weight on plasticizer retention in PVC geomembranes." *Geosynthetics International Jour.*, 12(2), 99–110.

XIII. Revision Schedule

1.	2023-6-20-23	Original version sent to FGI Membership for review
2.	2023-7-22-23	Revision #1 based on FGI Membership received comments and final version (version #9) of GM34 issued on July 18, 2023. This version was posted on FGI website on July 25, 2023.