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GRI-GS20[*]

Standard Practice for

"Exposed Lifetime Prediction of Geosynthetics Using Laboratory Weathering Devices"

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1. Scope

1.1 This standard practice provides detailed procedures in using laboratory weathering devices to incubate a specific geosynthetic material at several elevated temperatures so as to cause simulated outdoor, i.e., exposed, conditions.

Note 1: This procedure follows generally accepted polymer practice, e.g., gas pipelines, cable shielding, automotive paints, etc., and as such, is felt to be applicable to polymeric geosynthetics as well.

1.2 Using such incubation, samples are retrieved from the weathering devices periodically and tested for reductions in physical, mechanical or endurance properties over time. By plotting the retained values against incubation temperature, a trend is established whereby identification of a specific reduction value, e.g., 50% reduction, is obtained. This is called the "half-life" of the material.

Note 2: There obviously exists an end-of-life (EOL) beyond half-life, but conventional polymer practice uses half-life as the effective lifetime value.

1.3 When at least three half-life values are plotted against incubation temperature a trend line results which is then extrapolated down to a designated lower temperature which defines the desired "prediction" value under the specific laboratory conditions.

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[*] This GRI standard is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This practice will be reviewed at least every 5-years, or on an as-required basis. In this regard it is subject to change at any time. The most recent revision date is the effective version.

Note 3: The plotting process can be semi-logarithmic or linear depending on the circumstances as described herein.

1.4 Knowing the cumulative total radiation to half-life at each temperature in the laboratory, a ratio to radiation intensity at any particular field site can be calculated, the data replotted and extrapolated, thereby determining a lifetime prediction value in the field at a specific site and temperature.

Note 4: It should be recognized at the outset that the predictions presented herein have both technical and statistical variations embodied within the extended extrapolations. In this regard, caution in use of the data must be exercised.

1.5 This standard may involve hazardous operations, equipment and climates. This Standard Practice does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Reference Documents

2.1 ASTM Standards

D4355 Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus

D7238 Standard Test Method for Effect of Exposure of Unreinforced Polyolefin Geomembrane Using Fluorescent UV Consideration Apparatus

G151 Standard Practice for Exposing Non-Metallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

G154 Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials

G155 Practice for Operating Xenon Arc Light Apparatus for Exposure of Nonmetallic Materials

2.2 References

Hsuan, Y. G., Schröder, H. F., Rowe, R. K., Müller, W., Greenwood, J. H., Cazzufi, D. and Koerner, R. M. (2008), “Long-Term Performance and Lifetime Prediction of Geosynthetics,” Proc. 4th European Conf., Edinburgh, Scotland, UK Chapter, International Geosynthetics Society, London, UK, pp. 512-521.

Koerner, G. R. and Koerner, R. M. (2006), "Long-Term Temperature Monitoring of Geomembranes at Dry and Wet Landfills," Jour. Geotex. and Geomemb., Vol. 24, pp. 72-79.

Koerner, R. M. (2012), "Designing With Geosynthetics," 6th Edition, Xlibris Publ. Co., 914 pgs.

Koerner, R. M., Hsuan, Y. G. and Koerner, G. R. (2017), "Lifetime Predictions of Exposed Geotextiles and Geomembranes," Geosynthetics International, Vol. 24, No. 2, pp. 198-212.

NREL (National Radiation Energy Laboratory) (2012), U. S. Dept. of Interior, Washington, DC, USA.

3 Tier (2011), http://www.3tier.com/en/support (accessed 30/03/2011).

3. Terminology

3.1 Definitions

3.1.1 *Weathering Device* – A laboratory incubation device capable of generating a specific light source so as to provide UV exposure to geosynthetic samples while maintained at a constant temperature and providing water spray or moisture condensation: see ASTM Standards D4355, D7238, G151, G154 and G155.

3.1.2 *Half-life* – The 50% reduction in a physical, mechanical or endurance property of an incubated geosynthetic material from its original as-manufactured value.

3.1.3 *End-of-Life (EOL)* – The ultimate failure of a geosynthetic material beyond half-life usually by cracking, bending, powdering or chalking such that it is no longer serviceable for the intended purpose.

4. Summary of Practice

As with all polymeric materials, laboratory incubation at high temperatures under artificial generated light sources provides the mechanism of accelerated weathering to simulate exposed conditions of geosynthetic materials. Required are at least three weathering devices each set at separate elevated temperatures, e.g., 80, 70, 60°C. When test properties reduce 50% from their as-manufactured values (called the "half-life"), their incubation times are plotted and the trend line is extrapolated down to a lower site-specific temperature. Twenty degrees (20°C) is arbitrarily used throughout this standard. This results in the desired laboratory exposed lifetime at the lower temperature. To transition beyond laboratory lifetime to field lifetime at a particular site, however, requires knowledge of the radiation at the specific site. Knowing the total laboratory radiation to half-life allows for calculation of an equivalent exposure based on a specific field location and by repeating the graphing procedure as mentioned above results in the specific field lifetime prediction.

5. Significance and Use

The dual goals of use of this practice are to obtain laboratory lifetimes of geosynthetic materials under prescribed incubation conditions as well as to obtain predicted lifetimes at a specific site using an extension of the laboratory obtained data.

6. Laboratory Weathering Devices

While different laboratory devices have been developed and used for many decades (mainly by the automotive paint industry), two have emerged as being most widely used. They are the Xenon Arc and UV Fluorescent devices, see Figures 1a and 1b, respectively. While considerable controversy exists between which device to use, the financial bias greatly favors the UV-Fluorescent device particularly when multiple devices are required and for extremely long incubation times, i.e., up to 5-10 years. See Table 1 in this regard. Needless to say, UV-Fluorescent devices are used throughout this standard and for the majority of GSI durability research to date.

Table 1 – A GSI Financial Bias Toward Using UV-Fluorescent Weathering Devices

Item/Method	(a) Xenon Arc	(b) UV-Fluorescent
initial cost	$70-80,000	$10-15,000
tubes/bulbs	$15,000/year	$300/year
power cost	$5000/year	$400/year
water cost	$3000/year	none
sewer cost	$1500/year	none

(a) Xenon Arc Device and Sample Incubation Chamber per ASTM D4355

(b) UV Fluorescent Device and Sample Incubation Holders per ASTM D7238

Figure 1. Two Common Types of Laboratory Weathering Devices

7. Lifetime Prediction Methodology

7.1 Laboratory Incubation

Beginning with a representative sample of the geosynthetic material to be evaluated, coupons of 250 × 75 mm in size are prepared. Twenty-four replicates are required for each incubation device used, each having been set at a designated elevated temperature. Recommended herein are three devices set at 80°C, 70°C and 60°C, respectively.

Note 5: While such devices can reach 90°C, a maximum of 80°C is recommended for extremely long duration tests like those required for geomembranes and geogrids.

Incubated coupons are removed periodically and individual test specimens are die-cut from them. Considerable thought must be given to the type of test and the number of replicates. For geomembranes, dogbone tensile test specimens are used, for geogrids and geonets single rib test specimens are used, for geotextiles 25 mm wide strip specimens are used and for erosion control materials individual yarns or filaments are used. Since these are extremely long on-going incubation periods, we recommend single tests at each incubation time and temperature since the continuous tracking of the data identifies outliers which can be retested. Each test result is compared to the original non-incubated same test resulting in a "percent retained" value. These ongoing values are then plotted against incubation time for a non-disclosed geomembrane as shown in Figure 2.

Note 6: The data can be plotted as light hours, as shown, or converted to total hours which in this case of ASTM D7238 is 20 hrs. light then 4 hrs. dark (with condensation) resulting in a multiplication factor of 24/20 = 1.2 to convert from light hours to obtain total hours.

Light	**Non-Disclosed GM at 60C**				**Light**	**Non-Disclosed GM at 70C**				**Light**	**Non-Disclosed GM at 80C**			
Hours	Strength	Strength Ret.	Elong.	Elong. Ret.	**Hours**	Strength	Strength Ret.	Elong.	Elong. Ret.	**Hours**	Strength	Strength Ret.	Elong.	Elong. Ret.
(hr)	(N)	(%)	(mm)	(%)	**(hr)**	(N)	(%)	(mm)	(%)	**(hr)**	(N)	(%)	(mm)	(%)
0	270	100	86	100	**0**	310	100	81.1	100	**0**	298	100	80	100
4277	267	99	84	98	**2691**	289	93	81	100	**1870**	295	99	83	103
7162	275	102	81	94	**3517**	277	90	82	101	**3627**	286	96	78	98
11493	261	97	77	90	**5312**	273	**88**	81	99	**4486**	282	95	79	99
14458	274	87	76	88	**8100**	289	93	77	95	**5348**	262	88	77	96
18917	267	80	73	78	**10348**	282	91	81	100	**5846**	219	73	67	84
21117	241	78	67	73	**12905**	247	80	76	94	**6420**	220	74	63	79
24313	248	72	66	70	**17000**	228	73	58	72	**7234**	201	67	56	70
29908	229	72	64	63	**18834**	214	69	49	60	**8093**	207	69	66	82
30914	223	70	62	60	**22974**	221	71	46	57	**9111**	199	67	55	69
35000		65		52	**26287**	191	62	40	49	**10216**	190	64	45	56
40000		61		48	**30587**	185	60	30	37	**11366**	222	74	42	53
45000		57		48	**33493**	174	56	32	39	**12766**	201	67	43	49
50000		52		45	**37833**	165	53	28	34	**13886**	190	64	37	46
55000		48		40	**44196**	156	50	25	31	**14846**	183	61	35	44
					46432	154	47	20	25	**16546**	183	57	34	42
					47631	151	45	18	22	**19432**	191	52	34	42
										21792	196	48	35	43
										24312	208	43	35	43
										27192	211	38	19	24
										29672	200	32	18	22
										31502	186	30	19	24

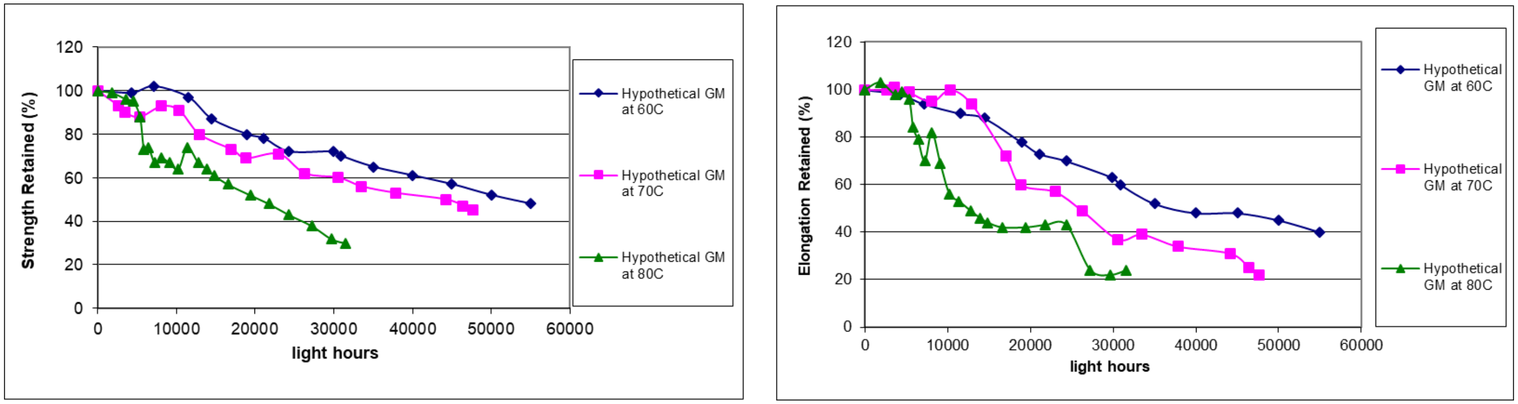


Figure 2. Strength and Elongation Retained Values Over Incubation Time and Subsequent Graphing to Obtain 50% Reduction (i.e., Half-life) Values

Note 7: The data being illustrated is for a non-disclosed geomembrane. Actual resulting lifetimes for 19 different geosynthetic materials will be given in Section 8 of the standard.

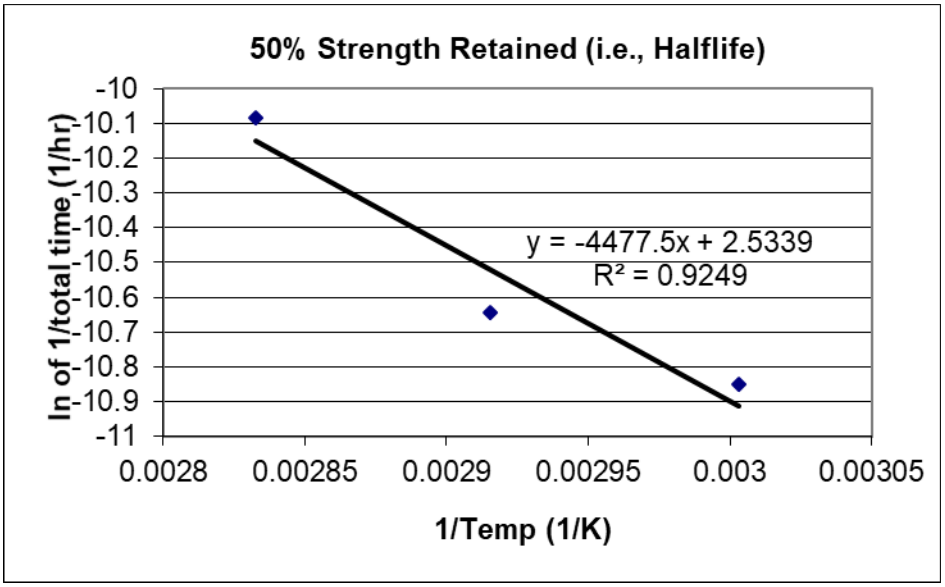
7.2 Data Analysis for Laboratory Lifetimes

Using the graphs shown in Figure 2, select the number of light hours associated with 50% strength retained and 50% elongation retained values for each of the three incubation temperatures. These are the respective laboratory "half-lifes". Plot these three strength and three elongation half-lifes separately on a semi-logarithmic graph as shown in Figure 3. The light hours from Figure 2 have now been converted to total hours as described in Note 5. A least squares fitting method is used to obtain the trend line. In this regard, the R^2 values are important in qualitatively assessing the statistical behavior of the entire process. The slope of this line is known as the "activation energy". Now extrapolate the trend line down to any specific temperature; an arbitrary value of 20°C will be used. This results in the material's half-life under these laboratory conditions. Note that the lifetime values in this case are seen to be 39.2 years based on strength reduction and 28.9 years based on elongation reduction and that the incubations took approximately seven years to reach 50% reductions at the 60°C temperature.

Note 8: A target in-situ temperature of 20°C will be used throughout this standard. While it is completely arbitrary, it represents many instances of our field measurements and is used accordingly. See, for example, Koerner and Koerner (2006).

Lifetime of Non-Disclosed Geomembrane Based on Breaking Strength

50% Strength Retained (Halflife)					
Light Time (hr) (50% Prop.)	Total Time (hr) (50% Pro.)	1/t (1/hr) (50% Pro.)	ln(1/t) (1/hr) (50% Pro.)	Test Temp (oC)	1/T (1/K)
20000	24000	4.16667E-05	**-10.08580911**	80	**0.002832861**
35000	42000	2.38095E-05	**-10.6454249**	70	**0.002915452**
43000	51600	1.93798E-05	**-10.85127695**	60	**0.003003003**



Equation: Y = Ax+C	
A	C
-4477.5	2.5339

Activation Calculation		
Slope	Gas Constant (MJ/mol-K)	**Activation Energy (MJ/mol)**
-4477.5	8.314	**-37.23**

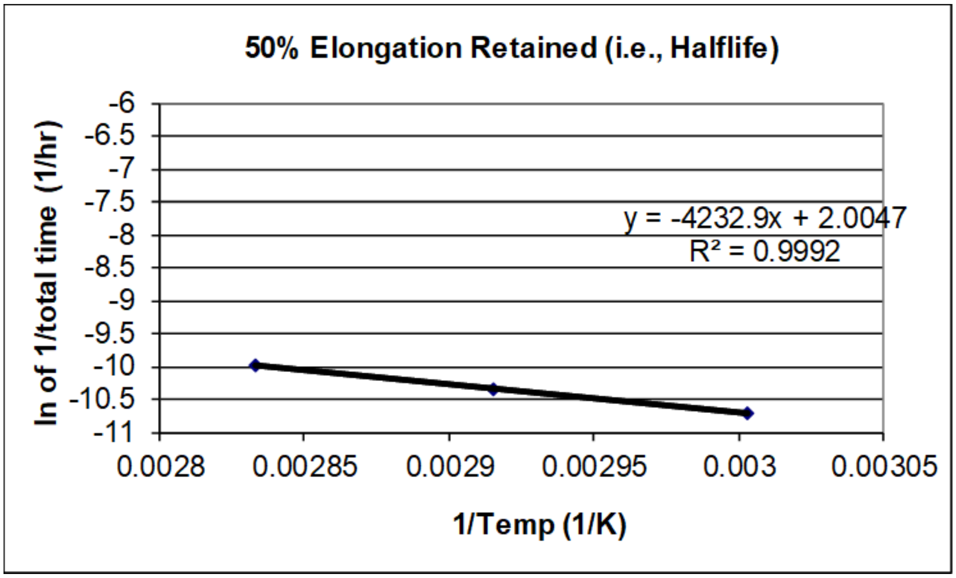
Prediction

Temperature	Lifetime (hours)	**Lifetime (years)**
80	24000	**2.7**
70	42000	**4.8**
60	51600	**5.9**
50	83144	**9.5**
40	129471	**14.8**
30	207592	**23.7**
20	343750	**39.2**

Figure 3a. Plotting of 50% Retained Strength Properties From Figure 2, Curve Fitting and Extrapolation Down to 20°C for Laboratory Prediction Half-life

Lifetime of Non-Disclosed Geomembrane Based on Breaking Elongation

50% Elongation Retained (Halflife)					
Light Time (hr) (50% Prop.)	Total Time (hr) (50% Pro.)	1/t (1/hr) (50% Pro.)	ln(1/t) (1/hr) (50% Pro.)	Test Temp (oC)	1/T (1/K)
18000	21600	4.62963E-05	**-9.980448594**	80	**0.002833**
26000	31200	3.20513E-05	**-10.34817337**	70	**0.002915**
37000	44400	2.25225E-05	**-10.70099475**	60	**0.003003**



Equation: Y = Ax+C	
A	C
-4232.90	2.00

Activation Calculation

Slope	Gas Constant (MJ/mol-K)	**Activation Energy (MJ/mol)**
-4232.9	8.314	**-35.19**

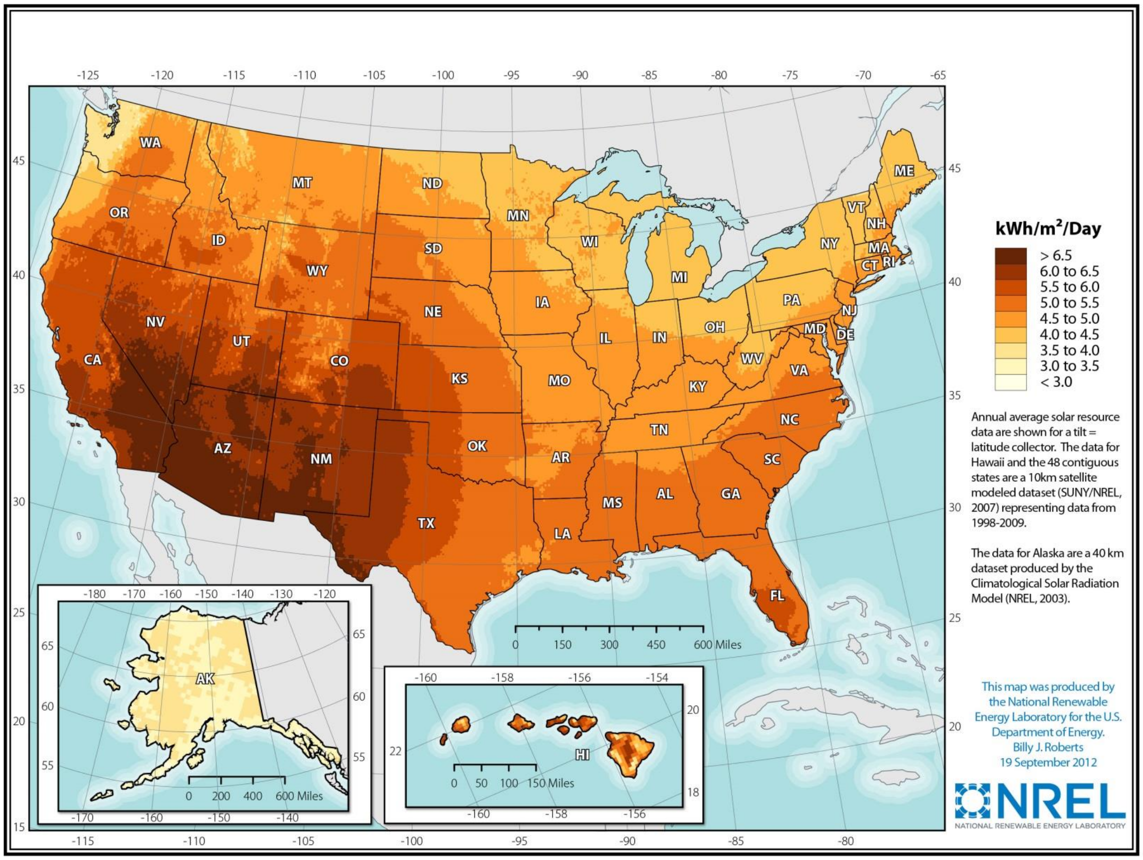
Prediction

Temperature	Lifetime (hours)	**Lifetime (years)**
80	21600	**2.5**
70	31200	**3.6**
60	44400	**5.1**
50	66188	**7.6**
40	100603	**11.5**
30	157199	**17.9**
20	253231	**28.9**

Figure 3b. Plotting of 50% Retained Elongation Properties From Figure 2, Curve Fitting and Extrapolation Down to 20°C for Laboratory Predicted Half-life

7.3 Data Analysis for Field Lifetimes

To extend the previous laboratory lifetime predictions to a particular field site requires some rather major assumptions. This is due to the laboratory device being completely controlled in its light source, radiation, temperature, moisture and environment, while in the field there are many complicating issues; e.g., latitude, altitude, ozone, environment, orientation, moisture, etc. Yet, there is one known property which is considered to be paramount. That is the particular site's radiation. Maps as shown in Figure 4a for the USA and Figure 4b for the world are available from credible governmental agencies. These irradiance maps give radiation results in units of kWh/m^2/day. When compared to the incubation device's known irradiance to half-life a ratio can be made to arrive at the equivalent energy at a specific site location. An example of this conversion follows:



Annual average solar resource data are shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states are a 10km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2009.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. Billy J. Roberts 19 September 2012

Figure 4a. Photovoltaic Solar Resource of the United States

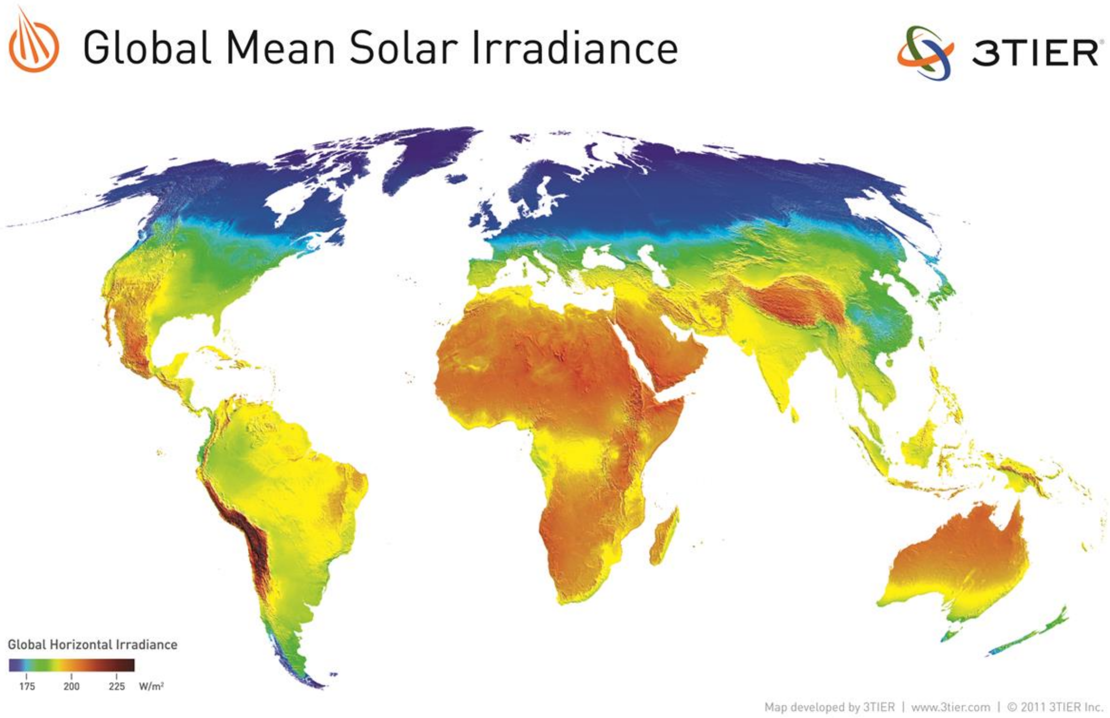


Figure 4b. Global Mean Solar Irradiance

For example, to convert a 50% strength half-life of 24,000 total hours at a specific temperature, the irradiance of the UV fluorescent device per ASTM D7238 protocol is 42.42 W/m^2 between 250-400 nm wavelength. This is a known property by the incubation device manufacturer. Furthermore, if Phoenix, Arizona is the site of interest, it has an average UV radiation of 28 MJ/m^2-month. Thus, the conversion from laboratory-to-field is as follows.

$$
\begin{aligned}
24{,}000 \text{ hr} &= 86.4 \times 10^6 \text{ sec} \times 42.42 \text{ W/m}^2 \div 10^6 \\
&= 3665 \text{ MJ/m2 total energy}
\end{aligned}
$$

which for Phoenix, Arizona is as follows:

$$
\begin{aligned}
&= 3665/28 \\
&= 131 \text{ mo}
\end{aligned}
$$

This type of process is now extended to both sets of data of Figure 2 resulting in the field predicted lifetime in Phoenix, Arizona of 49 years based on strength and 41 years based on elongation as shown in Figure 5. Thus, it is seen that the laboratory lifetimes are somewhat lower than the field lifetimes, hence the incubation devices are more severe in their radiation than it is in Phoenix, Arizona.

Input Information	
GS Type	Non-Disclosed GM in Arizona
Specification	n/a
Comment	Linear Plot
Incubation Details	
Device	QUV at GSI
Test Method	ASTM D7238
Conditions	20 hours light/ 4 hours dark
Device Irradiance	42.42 W/m^2 (= 42.24 J/sec-m^2)
Field Information	
Site Location	Arizona
Site UV-A Irradiance	28 MJ/m^2-month
Ave. Site Temperature	24^{o}C, annual average

HalfLife Laboratory Data

(a) Strength

Temperature *(° C)*	**Light time** *(hour)*	**Total Time** *(hour)*	**Irradiance** *(MJ/m^2)*	**Site Halflife** *(month)*
80	*20000*	*24000*	*3665*	*130.9*
70	*35000*	*42000*	*6414*	*229.1*
60	*43000*	*51600*	*7880*	*281.4*

(a) Elongation

Temperature *(° C)*	**Light time** *(hour)*	**Total Time** *(hour)*	**Irradiance** *(MJ/m^2)*	**Site Halflife** *(month)*
80	*18000*	*21600*	*3299*	*117.8*
70	*26000*	*31200*	*4765*	*170.2*
60	*37000*	*44400*	*6780*	*242.2*

Converting light hours to Irradiance

Total Energy (MJ/m^2) = (Halflife light time, hr) * (device irradiance, W/m^2)

Example:

At 80^{o}C, halflife of elongation is 20,000 hour

Total energy = *20,000 (hr) *3600 (sec/hr)*42.42 (J/sec-m^2)*10^{-6} (MJ/J)*

Total energy = *3054 (MJ/m^2)*

Conversion = *3600 (sec/hr)*42.42 (J/sec-m^2)*10^{-6} (MJ/J)*

Conversion factor = ***0.1527***

Corresponding to exposure time in Arizona

Halftime (month) = (total energy, MJ/m^2)/(irradiance at the site, MJ/m^2-month)

Example:

At 80^{o}C, time to reach halflife of elongation in Arizona

Halftime = *3054 (MJ/m^2)/28 (MJ/m^2-month)*

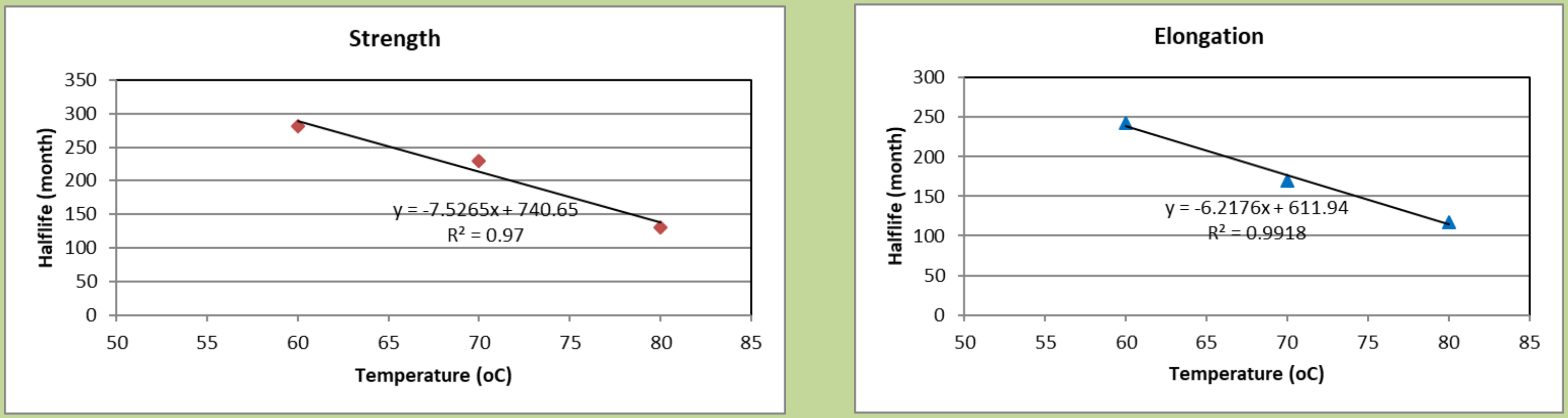
Halftime = *109 month*

Conversion = *1/(28 MJ/m^2-month)*

Conversion factor = ***0.0357***

Figure 5a. Conversion of Laboratory Half-life Values From Figure 3 to Irradiance in Phoenix, Arizona

Extrapolation



Strength

halfife (month) = A*(site temperature,°C)+B

A	-7.5265
B	740.65

Site Temperature (°C)	**Halflife (months)**	**Halflife (yrs)**
80	138.5	11.54
70	213.8	17.82
60	289.1	24.09
50	364.3	30.36
40	439.6	36.63
30	514.9	42.90
20	590.1	49.18

Elongation

halflife (month) = A*(site temperature,°C)+B

A	-6.2176
B	611.94

Site Temperature (°C)	**Halflife (months)**	**Halflife (yrs)**
80	114.5	9.54
70	176.7	14.73
60	238.9	19.91
50	301.1	25.09
40	363.2	30.27
30	425.4	35.45
20	487.6	40.63

Figure 5b. Plotting of Phoenix, Arizona Half-life Values From Figure 5a, Curve Fitting and Evaluation of Strength and Elongation Half-lifes at 20°C

Note 9: The plotting of half-life versus temperature on Figure 5 is on linear axes. This is a departure from the more conventional semilogarithmic plotting on Figure 3. It is done since field exposure is felt to be more physical and mechanically oriented rather than chemically as from radiation alone.

8. Calculated Data for 19 Different Geosynthetics

After 17-years of this type of research by the authors, on behalf of the U.S. Environmental Protection Agency and the Geosynthetic Institute and its Members, the exposed lifetime of many geosynthetics in laboratory weathering devices, as presented in this Standard Practice, has been investigated. It is, in fact, the very reason for writing the standard and making the concept and procedures available to the public-at-large. Following are published results for 7-geotextiles, 4-turf reinforcement yarns, 2-geogrids and 6-geomembranes. All are commercially available geosynthetics as of 2019, however, their exact formulations, as far as antioxidants and/or additives are concerned, is not known. Nevertheless, researchers and agencies can proceed in like manner for any specific polymeric geosynthetic material in precisely the same manner as described herein. Half-life results to date, in years, for these nineteen geosynthetics follow in Tables 2a, b and c. Half-life values in years to 50% reduction in strength and 50% reduction in elongation, are given for both laboratory lifetimes and for Phoenix, Arizona lifetimes. While half-life values of the materials still have some serviceability remaining, their properties have been compromised to the extent indicated. End-of-life is undoubtedly longer but how much so is quite uncertain.

Table 2a. Results of Seven Geotextile Field Half-life Predictions in Phoenix, Arizona Compared to Laboratory Predictions all at 20°C (from Koerner, et al., 2017)

Geotextiles (all PP)	Mass (g/m^2)	Laboratory Predicted Half-life in Years		Phoenix, Arizona Predicted Half-life in Years	
		Strength	Elongation	Strength	Elongation
Woven, monofilament	220	5.7	5.7	10.3	10.3
Woven, slit film	110	0.34	0.25	0.76	0.61
Nonwoven, heat bonded	340	4.5	4.1	4.9	5.9
Nonwoven, needle punched	130	0.22	0.22	0.42	0.55
Nonwoven, needle punched	180	0.29	0.21	0.55	0.49
Nonwoven, needle punched	360	0.24	0.22	0.58	0.55
Nonwoven, needle punched	480	0.28	0.28	0.57	0.60

Table 2b. Results of Four TRM and Two Geogrid Field Half-life Predictions in Phoenix, Arizona Compared to Laboratory Predictions all at 20°C (from GSI unpublished data)

Turf Reinforcement Mat Filaments (all PP)	Denier	Laboratory Predicted Half-life in Years		Phoenix, Arizona Predicted Half-life in Years	
		Strength	Elongation	Strength	Elongation
Tan-1	1400	31	15	15	11
Tan-2	1800	51	15	17	11
Green-3	1300	60	20	18	12
Green-4	1700	64	18	21	14

Geogrids (both PP)	Mass (g/m^2)	Laboratory Predicted Half-life in Years		Phoenix, Arizona Predicted Half-life in Years	
		Strength	Elongation	Strength	Elongation
Fine Mesh	200	48	41	22	21
Coarse Mesh	220	146	124	52	48

Table 2c. Results of Six Geomembrane Field Half-life Predictions in Phoenix, Arizona Compared to Laboratory Predictions all at 20°C

Geomembranes (Various Resins)	Thickness (mm)	Laboratory Predicted Half-life in Years		Phoenix, Arizona Predicted Half-life in Years	
		Strength	Elongation	Strength	Elongation
HDPE	1.5	76	69	97	91
LLDPE	1.0	49	46	66	63
fPP	1.0	50	41	59	54
EPDM	1.0	60	70	74	56
PVC (A2 Formulation)	0.75	21	21	23	15
PVC (E3 Formulation)	2.5	54	54	72	55

9. Summarizing Comments

Included herein is a Standard Practice focused on lifetime prediction of exposed geosynthetics. It is based on sample incubation in laboratory weathering devices which include light/dark cycling, moisture from condensation, and elevated temperatures. Three identical devices are used for the incubations which are set at 80°C, 70°C and 60°C, respectively. While many physical, mechanical or endurance tests can be used to assess the response over time, this standard uses strength retained and elongation retained from their original values. By plotting the data on a semi-logarithmic scale, it can be extrapolated to any lower temperature; 20°C being arbitrarily used herein. This results in the value of half-life under laboratory controlled conditions.

The Standard Practice then extends the laboratory data into site-specific field lifetime prediction. This attempts to answer the all-important and relevant user question of lifetime at a specific field location site. It is based on the total radiation energy input to the laboratory samples until they reached half-life compared to the iridescence level at any site-specific location. In the example herein radiation in Phoenix, Arizona (the highest radiation in the USA) at 20°C is used. This location is arbitrary and any other could have been selected. However, the extrapolation is based on a linear plot since outdoor degradation is felt to be somewhat different than a chemical reaction, i.e., other physical, mechanical and/or environmental actions may be occurring as well as ultraviolet radiation.

> Note 10: Had a semi-logarithmic plot been used, the field half-life values would have been somewhat longer than those given in Table 2. However, in all cases of laboratory and field predictions for the resulting half-life values they must be viewed with caution since both technical and statistical variations are largely uncertain and remain to be investigated by us and/or others.