
**Plastics — Use of polyethylene
reference specimens (PERS) for
monitoring laboratory and outdoor
weathering conditions**

*Plastiques — Utilisation d'éprouvettes de référence en polyéthylène
pour l'évaluation des conditions de vieillissement climatique*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 6, *Ageing, chemical and environmental resistance*.

This second edition cancels and replaces the first edition (ISO/TR 19032:2006), which has been technically revised.

The main changes compared to the previous edition are as follows:

- the shipping address of PERS in 3.1 has been cancelled;
- a cautionary sentence has been added in [Clause 4](#).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The method described in this document demonstrates the use of polyethylene reference specimens (PERS) for monitoring conditions in weathering tests used for plastics. PERS has double bonds in its molecular structure, which are easily oxidized to produce carbonyl groups. The change in carbonyl index of PERS is produced by the combined effects of ultraviolet (UV) and temperature. Therefore, the carbonyl groups proportionally increase, depending on the received UV and temperature. Based on this relationship, the effect of UV radiation and temperature on PERS can be expressed quantitatively. For laboratory-accelerated exposures, PERS is also sensitive to changes in the chamber air temperature. The effect of moisture was not determined in the study.

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Plastics — Use of polyethylene reference specimens (PERS) for monitoring laboratory and outdoor weathering conditions

1 Scope

This document describes a method that demonstrates the use of polyethylene reference specimens (PERS) for monitoring laboratory and outdoor conditions in weathering tests used for plastics.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

4 Background information

Degradation of plastics in an outdoor environment is mainly influenced by the ultraviolet radiation received, environmental temperature, moisture, etc. Especially in photo-oxidation induced from ultraviolet radiation, temperature plays a very important role. Measuring the ultraviolet radiation during the exposure period is useful for comparison of the result of the exposure test, but it is not enough to compare the exposure results. Therefore, it is very important to find some index that can be used to evaluate the complex effect of received ultraviolet radiation and environmental temperature. PERS is used to characterize the level of combined effect of ultraviolet radiation and temperature, and its characteristic proportionally increases depending on the UV radiation and temperature received.

NOTE The test results presented in this document were generated with PERS from Japan Weathering Test Center 1-3-7 Shibakoen Minatoku Tokyo Japan. This material is no longer available. No new material has been qualified to be used as a replacement in this document at the time of its publication.

5 Material

5.1 General

PERS is high-density polyethylene polymerized using molybdenum dioxide as a catalyst, containing the trans-form vinylene group. Other basic properties are as follows:

- absorbance ratio of trans-form vinylene group to methylene group: 1,0 to 1,3;
- melt flow rate (2,16 kg, 190 °C): 0,2 g to 0,4 g/10 min;
- density: 950 kg/m³ to 965 kg/m³;
- thickness: (0,2 ± 0,02) mm.

5.2 Preparation of PERS

After kneading for 5 min, the material between two rolls whose surfaces are heated at 150 °C to 170 °C are cut into small pieces of 0,4 g to 0,5 g.

After pre-heating for 90 s in a compression moulding machine with a surface that is heated at 160 °C to 180 °C, the material is compressed for 60 s, cooled in a compression moulding machine with a surface temperature of 30 °C to 40 °C for 60 s, and the press sheet of the thickness mentioned above is prepared.

6 Procedure

6.1 Method for measuring the carbonyl index of PERS

An infrared (IR) spectrophotometer should be used as the measuring apparatus.

The infrared absorption spectra is measured after irradiation, in the range of 2 200 cm⁻¹ to 1 600 cm⁻¹. In this case, the same method for a quantitative analysis is used for the scanning speed.

The carbonyl index is determined in accordance with [Formula \(1\)](#), based upon infrared absorbance spectra of exposed PERS. Absorbance at near 2 020 cm⁻¹ peak is employed as an internal standard to correct for sample film thickness, while absorbance at near 1 715 cm⁻¹ peak is used to indicate carbonyl group content. A typical diagram of IR absorbance is shown in [Figure 1](#).

$$A_r = \frac{A_{1\ 715}}{A_{2\ 020}} \quad (1)$$

where

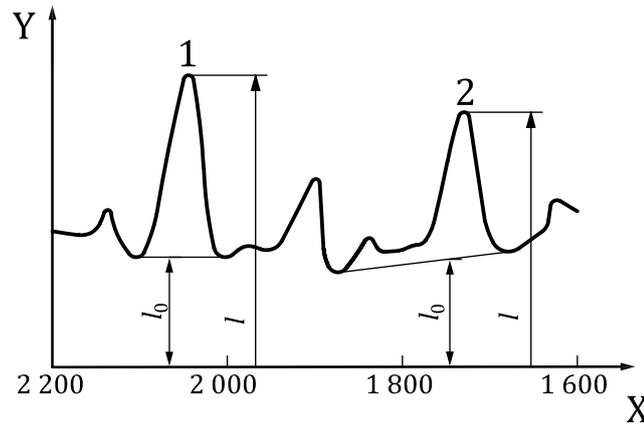
A_r is the absorbance ratio (carbonyl index);

$A_{1\ 715}$ is the absorbance at near 1 715 cm⁻¹ ($I - I_0$);

$A_{2\ 020}$ is the absorbance at near 2 020 cm⁻¹ ($I - I_0$);

I_0 is the absorbance measured by the base-line method at individual wave number;

I is the absorbance at the peak of individual wave number.



Key

- Y absorbance
- X wavenumber (cm^{-1})
- 1 peak near $2\,020\text{ cm}^{-1}$
- 2 peak near $1\,715\text{ cm}^{-1}$

Figure 1 — IR absorbance diagram showing base line and peak absorbance

6.2 Round robin test of laboratory light-source exposure devices with PERS

6.2.1 General

It is well known that the degradation of plastics materials or products used outdoors will occur by the combined effect of ultraviolet radiation and temperature, or other factors. It is also recognized that the reproducibility in the laboratory light-source exposure test will vary with the change in ultraviolet spectrum distributions and the chamber temperatures caused by deterioration of lamps and filters with operating time, even if ultraviolet radiation and black standard temperature (BST) or black panel temperature (BPT) are under constant conditions.

Since PERS can quantitatively evaluate, as carbonyl index, the combined effect of UV radiation and temperature, the carbonyl index obtained can reflect changes in a given environment.

In order to verify the repeatability and reproducibility of the specimens and exposure test, the round robin test (RRT) using PERS by laboratory light-source exposure devices in ISO/TC 61/SC 6 was conducted.

6.2.2 Xenon-arc-lamp exposure

The test conditions were according to ISO 4892-2^[1]. The conditions are shown in [Table 1](#). It was not requested to control the chamber temperature, but participants have been requested to report this temperature.

Each participant has been provided with 4 sets of PERS that were mounted in $150\text{ mm} \times 70\text{ mm}$ plastics holders. One set of holders consists of 3 pieces of PERS.

Table 1 — Exposure conditions for xenon-arc lamp

Filter	daylight filter
Irradiance	0,5 W/(m ² ·nm) at 340 nm or 60 W/m ² (300 nm to 400 nm)
BST or BPT	(65 ± 3) °C for BST or (63 ± 3) °C for BPT
Chamber temperature	Arbitrary
Water spray	102 min of light only followed by 18 min of light plus water spray
Humidity	(50 ± 5) %
Period	24 h, 48 h, 72 h and 96 h

6.2.3 Open-flame carbon-arc-lamp exposure

The test conditions were according to ISO 4892-4^[2]. The conditions are shown in [Table 2](#). The chamber temperature was not specified, but participants were requested to report this temperature.

Each participant has been provided with 4 sets of PERS that were mounted in 150 mm × 70 mm plastics holders. One set of holders consists of 3 pieces of PERS.

Table 2 — Exposure conditions for open-flame carbon-arc lamp

Filter	Type 1 (Type 1 known as Corex 7058 filter)
BST or BPT	(65 ± 3) °C for BST or (63 ± 3) °C for BPT
Chamber temperature	Arbitrary
Water spray	102 min light only followed by 18 min of light plus water spray
Humidity	(50 ± 5) %
Period	24 h, 48 h, 72 h and 96 h

6.2.4 Fluorescence lamp exposure

The test conditions were according to ISO 4892-3^[3]. The conditions are shown in [Table 3](#). Irradiance was not specified at any intensity.

Each participant was provided with 4 sets of PERS that were mounted in 150 mm × 70 mm plastics holders. One set of holders consists of 3 pieces of PERS.

Table 3 — Exposure conditions for fluorescent lamp

Lamp type	UVA340
Irradiance	Arbitrary
Mode	Mode 1: 4 h of dry UV exposure followed by 4 h of condensation
BPT	(63 ± 3) °C at UV exposure and (50 ± 3) °C at condensation
Period	8 h, 24 h, 32 h and 48 h

After each sample had been exposed for each exposure period, the carbonyl index was determined, based upon the method described in [6.1](#).

6.3 Outdoor exposure test of PERS

The result of the outdoor exposure test varies, even if it is conducted in the same place, because of differences due to the seasonal climate changes. Although it is useful to measure the amount of ultraviolet radiation for comparison of exposure tests, it is not enough in the comparison only to consider the amount of ultraviolet radiation, because plastics are influenced not only by ultraviolet radiation but

by temperature or by moisture. Since PERS is influenced by the combined effect of ultraviolet radiation and temperature, PERS have been exposed in various places where the climate was different.

Six locations in different climates and different countries were selected: Sapporo, Choshi, Miyakojima (Japan), Serpong, Bandung (Indonesia) and Phoenix (USA). Locations and exposure angles are shown in [Table 4](#).

Table 4 — Locations and exposure angles

Exposure site	Exposure angle	Latitude
Sapporo (Japan)	45° South	43° 03' N
Choshi (Japan)	30° South	35° 43' N
Miyakojima (Japan)	20° South	24° 44' N
Serpong (Indonesia)	5 ^{°a} South and north	6° 15' S
Phoenix (USA)	34° South	33° 54' N

^a From November to February, the samples face south; and from March to October, they face north.

The conditions of the outdoor exposure test are based on the relevant ISO 877 part^[4]. Three pieces of PERS were exposed for 1 month. By replacing exposed PERS with new ones, the exposure test was repeated in the following months successively. The exposure test was repeated successively for more than 24 months.

The practical procedure of the outdoor exposure test is shown below.

- 1) The conditions of the outdoor exposure test are based on the relevant ISO 877 part.
- 2) Prepare a minimum of three PERS and expose them for 1 month. It is desirable to expose them at the beginning of a calendar month, in order to evaluate the condition of the month.
- 3) By replacing exposed PERSs with new ones, the exposure test is repeated in the following months successively.
- 4) The exposure test is repeated successively for at least 12 months.
- 5) The accumulated value of the carbonyl index for each month will be adopted for the index of combined effect of UV radiation and temperature at the site of exposure.

6.4 Consistency of laboratory light-source exposure devices

It is recognized that changes in the characteristics of lamps and filters with time, and changes in the chamber temperature of laboratory light-source exposure devices, influence the reproducibility and repeatability of test results, even if the test is operated under constant conditions of ultraviolet radiation and BST or BPT.

Since the carbonyl index of a polyethylene reference specimen is proportional to the environment where ultraviolet radiation and temperature are compounded, consistency of the exposure environment could be monitored with this reference material.

In order to verify the correct operation of a particular xenon-arc-lamp device, the control limit was determined by PERS.

The test conditions were according to ISO 4892-2. For different operating times of lamp and filters, exposure was repeated three times.

The practical procedure was carried out as follows.

- 1) The conditions of the laboratory light-source exposure test are based on the relevant ISO 4892 part.
- 2) PERS should be irradiated for about 100 h. The number of PERSs should not be less than three.

- 3) Carbonyl indices are measured after removal from exposure.
- 4) Repeat 1) to 3), at three different times.
- 5) The standard deviation “S” of each exposure is calculated.
- 6) The repeatability standard deviation “S_r” is calculated using [Formula \(2\)](#).

$$S_r = \sqrt{\frac{\sum S^2}{3}} \tag{2}$$

- 7) The control limit “CL” of this apparatus is calculated using [Formula \(3\)](#).

$$CL = \text{total average value} \pm (2 \times S_r) \tag{3}$$

7 Results and discussion

7.1 Result of RRT of laboratory light-source exposure devices with PERS

7.1.1 Xenon-arc-lamp exposure

Fourteen devices from 13 organizations of five nations, Japan, the USA, Germany, Switzerland, and France, participated.

The test results are shown in [Table 5](#).

Table 5 — Results of the round-robin test of xenon-arc-lamp exposure with PERS

Hours	Measurement	Lab. A	Lab. B	Lab. C	Lab. E	Lab. G	Lab. H	Lab. J-1	Lab. J-2	Lab. J-3	Lab. K	Lab. M	Lab. N	Lab. O	Lab. Q	
24 (film 1, 2 and 3)	each lab.	mean	—	—	—	0,241	0,218	0,180	0,216	0,188	0,140	0,244	0,205	0,358	0,367	0,367
		std	—	—	—	0,011	0,005	0,020	0,011	0,008	0,013	0,008	0,008	0,005	0,010	0,012
		%	—	—	—	4,7	2,2	11,1	4,9	4,3	9,3	3,3	3,7	1,3	2,6	3,1
	ref. lab.	mean	0,202	0,310	0,214	0,256	0,214	0,189	0,222	0,209	0,149	0,242	0,226	0,377	0,463	0,355
		std	0,018	0,013	0,016	0,020	0,001	0,008	0,010	0,008	0,008	0,007	0,020	0,005	0,026	0,021
		%	8,7	4,2	7,5	7,9	0,3	4,3	4,3	3,9	5,4	2,9	8,9	1,3	5,5	6,0
48 (film 4, 5 and 6)	each lab.	mean	—	—	—	0,529	0,478	0,400	0,486	0,473	0,377	0,514	0,451	0,851	0,550	0,810
		std	—	—	—	0,014	0,008	0,010	0,026	0,070	0,012	0,024	0,008	0,038	0,022	0,026
		%	—	—	—	2,7	1,8	2,5	5,4	14,8	3,3	4,7	1,7	4,4	4,0	3,3
	ref. lab.	mean	0,510	0,659	0,492	0,552	0,488	0,393	0,543	0,520	0,395	0,533	0,488	0,879	0,665	0,824
		std	0,013	0,013	0,019	0,011	0,010	0,006	0,072	0,065	0,013	0,016	0,011	0,025	0,032	0,021
		%	2,6	2,0	3,9	2,0	1,9	1,4	13,2	12,5	3,2	3,0	2,2	2,8	4,7	2,6
72 (film 7, 8 and 9)	each lab.	mean	—	—	—	0,768	0,719	0,543	0,701	0,687	0,597	0,749	0,634	1,407	0,751	1,203
		std	—	—	—	0,029	0,041	0,006	0,009	0,024	0,058	0,012	0,022	0,056	0,031	0,055
		%	—	—	—	3,7	5,7	1,1	1,3	3,5	9,8	1,5	3,5	4,0	4,2	4,6
	ref. lab.	mean	0,688	1,039	0,723	0,779	0,705	0,530	0,728	0,731	0,641	0,767	0,697	1,456	0,885	1,234
		std	0,030	0,028	0,021	0,023	0,039	0,015	0,015	0,030	0,045	0,024	0,020	0,040	0,012	0,070
		%	4,3	2,7	2,9	3,0	5,5	2,9	2,1	4,1	7,1	3,1	2,9	2,8	1,4	5,7

each lab.: carbonyl index measured by each laboratory.
ref. lab.: carbonyl index measured by reference laboratory.
std.: standard deviation.
%: percentage of standard deviation to mean value.

Table 5 (continued)

Hours	Measurement	Lab. A	Lab. B	Lab. C	Lab. E	Lab. G	Lab. H	Lab. J-1	Lab. J-2	Lab. J-3	Lab. K	Lab. M	Lab. N	Lab. O	Lab. Q	
96 (film 10, 11 and 12)	each lab.	mean	—	—	—	1,053	0,897	0,697	0,943	0,928	0,800	0,968	0,836	1,909	0,947	1,517
		std	—	—	—	0,031	0,070	0,023	0,060	0,022	0,006	0,017	0,034	—	0,037	0,107
		%	—	—	—	3,0	7,8	3,3	6,3	2,4	0,7	1,8	4,1	—	3,9	7,1
	ref. lab.	mean	0,882	1,351	0,953	1,058	0,922	0,689	1,010	0,990	0,845	0,961	0,906	1,969	1,090	1,516
		std	0,021	0,100	0,044	0,032	0,051	0,026	0,072	0,038	0,013	0,020	0,051	—	0,024	0,141
		%	2,4	7,4	4,6	3,0	5,6	3,7	7,1	3,9	1,6	2,0	5,6	—	2,2	9,3

each lab.: carbonyl index measured by each laboratory.
ref. lab.: carbonyl index measured by reference laboratory.
std.: standard deviation.
%: percentage of standard deviation to mean value.

After finishing the exposure test, specimens were measured to calculate carbonyl indices at each laboratory, and returned to the reference organization (Japan Weathering Test Center). In this reference organization, the characteristic values were measured by a single operator with a single item of equipment.

As shown in Table 5, the data of the reference laboratory showed the same tendency as the data of each laboratory. Mean values and standard deviations of each laboratory and of the reference laboratory were almost the same. This means that even if the position of the films, measurement apparatus, and operators are different, almost the same results can be obtained.

Each laboratory's data were plotted together with those of the reference laboratory in Figure 2. All data showed linear relations between carbonyl indices (CI) and testing hours. The correlation coefficients were 0,95 or more.

The slope showing the relation between testing hours and CI differed between items of equipment, and this is collectively indicated in Figure 3. Eight of 14 different items of equipment demonstrated slopes in a range from 0,009 to 0,011, another two were less than 0,009 and the remaining four were more than 0,011.

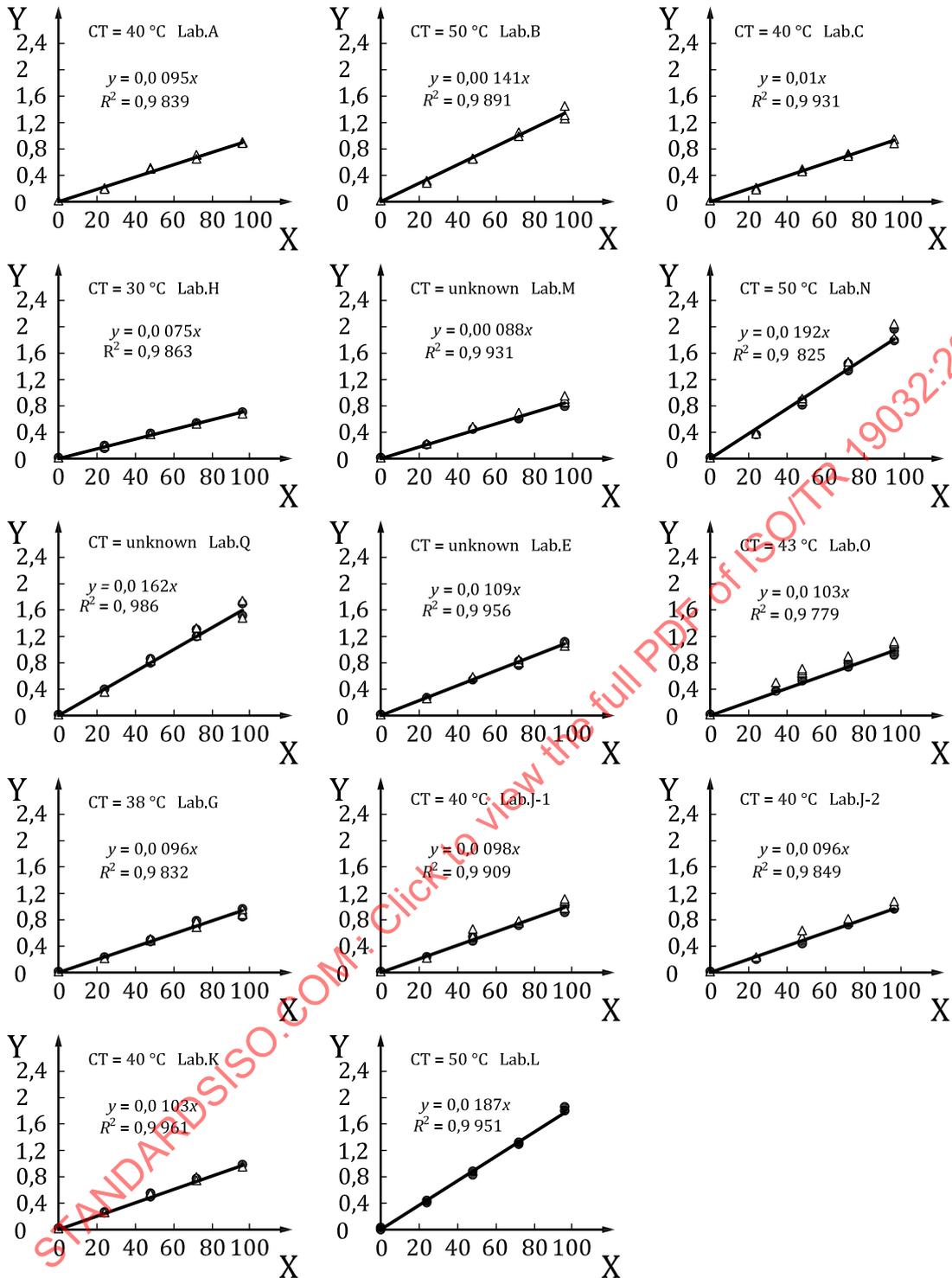
On the other hand, the relation between slopes and chamber temperatures was examined. As a result, the temperatures of eight items of equipment ranged from 38 °C to 43 °C, and the temperature of the equipment having the maximum slope was as high as 50 °C, as opposed to the equipment with the minimum slope indicating 30 °C.

From this fact, the chamber temperature has a great influence on the slope. If the chamber temperature is not kept constant, even though items of equipment are controlled with a UV radiometer and BST or BPT, the result obtained would vary (see Reference [5]). Thus, a quantitative indication of exposure environments obtained through PERS is vital for the reproducibility of the experiment.

The Arrhenius plot of the chamber temperature and slope is shown in Figure 4. The activation energy calculated was about 35 kJ/mol, which was consistent with previous studies (see References [6] and [7]). All these data include BPT and BST and the higher point also had a higher BPT. PERS is susceptible to chamber temperature, therefore, if PERS was used, it is able to indicate the different chamber conditions.

The results of analysis of variance in data from all laboratories participating in the RRT are shown in Table 6. The variances between laboratories were about 98 %, so this means that the difference of the test results was attributable to exposure itself.

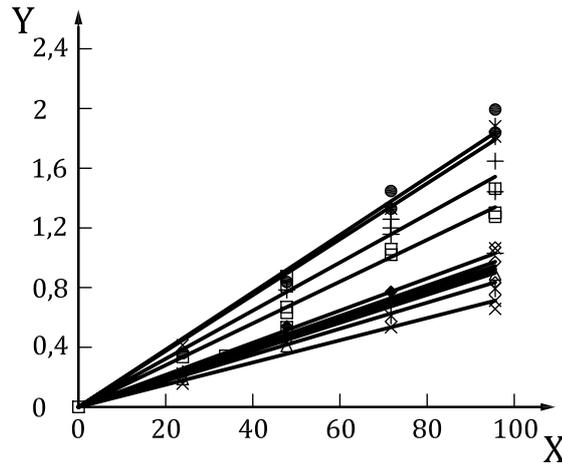
Although this RRT unified the test conditions of UV intensity and BST or BPT, the chamber temperatures were different among laboratories, and therefore, different slopes were mainly due to differences in the chamber temperatures of equipment.



Key

Y	carbonyl indices	△	reference laboratory	CT	chamber temperature
X	testing hours	●	each laboratory	R^2	determination coefficient

Figure 2 — Round robin test of PERS in xenon-arc exposure apparatus



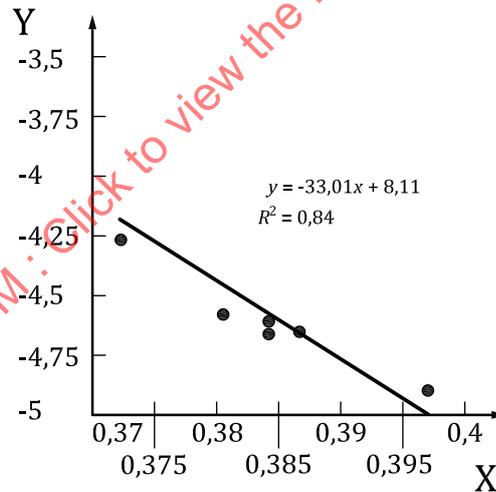
Key

Y carbonyl indices

X testing hours

- | | | | | |
|-----------|------------|---------|---------|---------|
| ◆ Lab A | □ Lab B | △ Lab C | × Lab H | * Lab M |
| ● Lab N | + Lab Q | ◇ Lab E | — Lab O | ◇ Lab G |
| □ Lab J-1 | △ Lab J-2B | × Lab K | * Lab L | |

Figure 3 — Summary of xenon-arc exposure



Key

R^2 determination coefficient

X $1/RT$ (RT gas constant \times chamber temperature)

Y LNK logarithm of slope K of regression line

Figure 4 — Relationship between chamber temperature and degradation speed

Table 6 — Result of analysis of variance of xenon-arc-lamp exposure

Exposure hours	Participating laboratory measurement			Reference laboratory measurement		
		Sum of squares	% of total variance		Sum of squares	% of total variance
24	between lab.	0,214	98,2	between lab.	0,291	98,0
	within lab.	0,004	1,8	within lab.	0,006	2,0
	total	0,218	100,0	total	0,297	100,0
48	between lab.	0,759	97,4	between lab.	0,800	96,9
	within lab.	0,020	2,6	within lab.	0,026	3,1
	total	0,779	100,0	total	0,826	100,0
72	between lab.	2,331	98,6	between lab.	2,457	98,8
	within lab.	0,033	1,4	within lab.	0,031	1,2
	total	2,364	100,0	total	2,487	100,0
96	between lab.	3,392	97,5	between lab.	3,394	96,8
	within lab.	0,086	2,5	within lab.	0,114	3,2
	total	3,478	100,0	total	3,508	100,0

7.1.2 Open-flame carbon-arc-lamp exposure

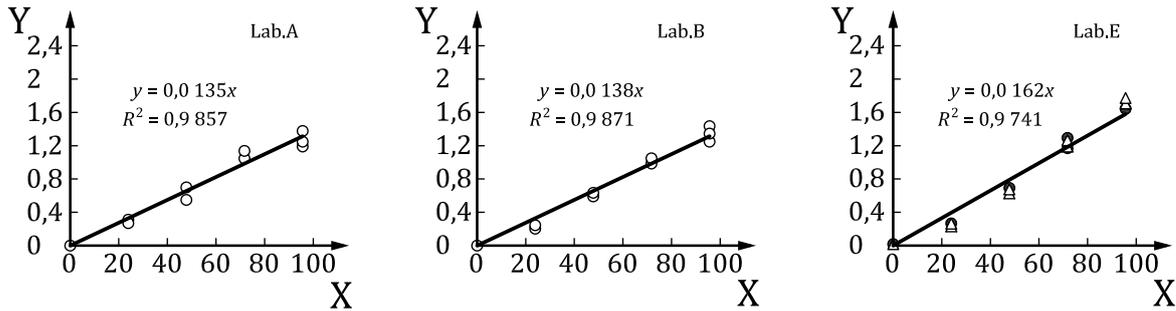
Three devices from three organizations of two nations, Japan and the USA, participated.

The result of open-flame carbon is shown in a [Figure 5](#). Three organizations participated. The data from every organization indicated linearity and a correlation coefficient of 0,95 or more. In these three devices, the reported BPT was the same. Therefore, it is thought that it reflects the difference of chamber temperature. The slope is larger than for the xenon-arc lamp. It is based on difference of light intensity, difference of spectral distribution, difference of chamber temperature, etc.

7.1.3 Fluorescent lamp exposure

Five devices from four organizations of three nations, Japan, the USA and Switzerland, participated.

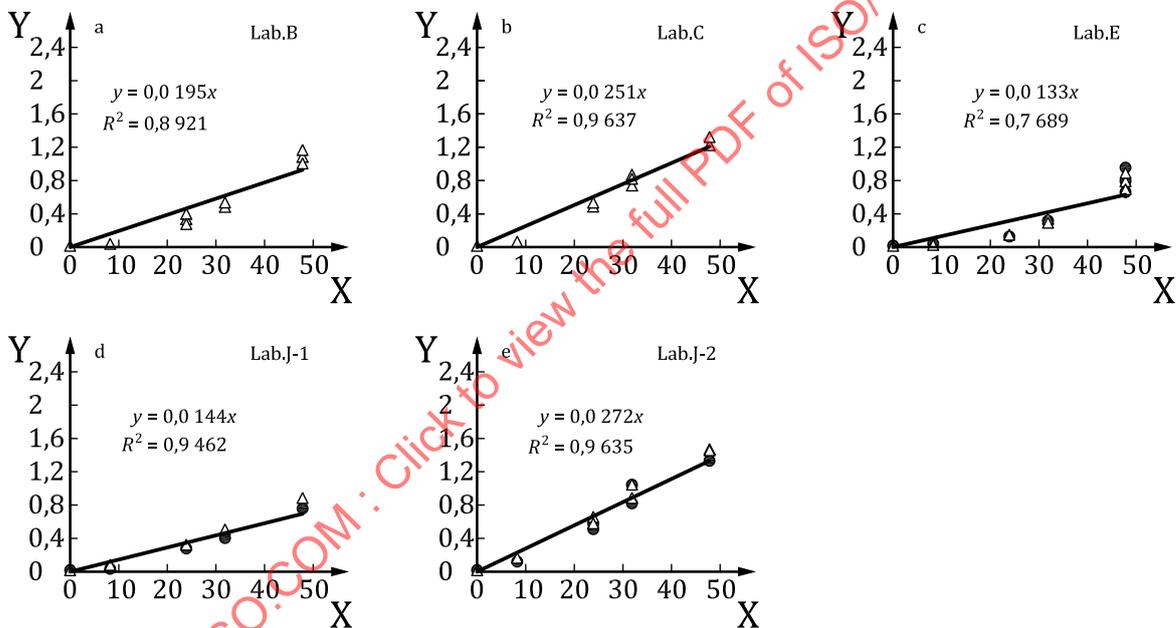
[Figure 6](#) represents the results of an ultraviolet fluorescent light test in which five organizations participated. For the test conditions, a repeat of a cycle composed of 4 h irradiation and 4 h darkness was used, which means that the period when UV is irradiated is half of that for other light sources. The results show that the linearity is not as good as for other light sources, and the data after 24 h exponentially increased despite the half of UV irradiation. The reason that this phenomenon occurred is because temperatures in the chamber were kept at about 50 °C during darkness, whereby a reaction in PERS proceeded. Thus, in this case, it cannot be said that it is proportional to the exposure environment.



Key

- Y carbonyl indices
- X testing hours
- R² determination coefficient

Figure 5 — Round robin test of PERS in open-flame carbon-arc exposure apparatus



Key

- Y carbonyl indices
- X testing hours
- R² determination coefficient
- △ reference lab
- each lab
- a UV intensity is unknown.
- b 0,76 W (m²·nm) at 340 nm.
- c UV intensity is unknown.
- d 0,77 W (m²·nm) at 340 nm.
- e 0,63 W (m²·nm) at 313 nm.

Figure 6 — Round robin test of PERS in fluorescent-UV-lamp exposure apparatus

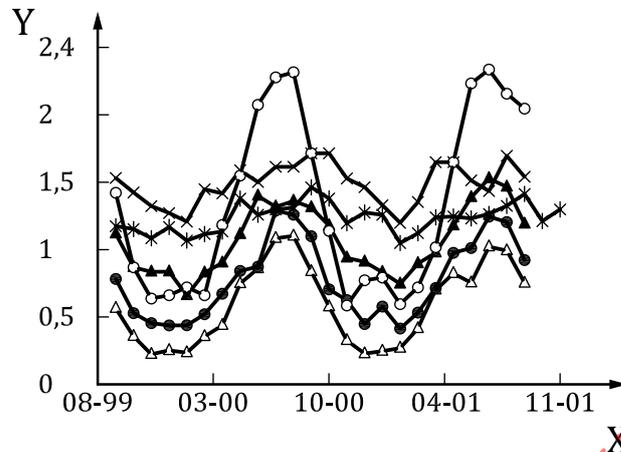
7.2 Characterizing the conditions of outdoor exposure test site

The results of the outdoor exposure test on PERS carried out in six places, Sapporo, Choshi, Miyakojima (Japan), Serpong, Bandung (Indonesia), and Phoenix (USA), are shown below. Figure 7 shows carbonyl indices calculated from PERS exposed every month, and Figure 8 shows the cumulative sum of them.

These values reflect the difference of the climate of the sites where the exposures took place. Serpong is in the tropics where the climate change is rather small throughout the year. In contrast, the differences

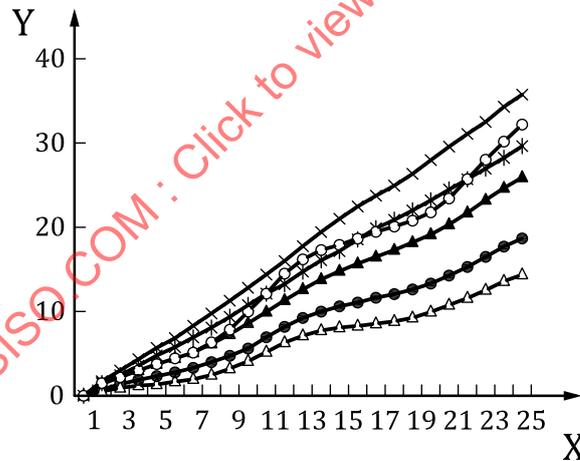
between summer and winter are quite pronounced in the other places. The cumulative value of CI recorded from Serpong is relatively linear due to the small climate change, while those recorded in the other areas have a wavy character reflecting seasonal variation.

From Figures 7 and 8, it is evident that the carbonyl index reflects definitely the climatic features of the sites where the exposures were conducted.



Key
 Y carbonyl index X months
 ▲ Sapporo (Japan) ● Choshi (Japan) ▲ Miyakojima (Japan)
 × Serpong (Indonesia) ○ Phoenix (USA) * Bandung (Indonesia)

Figure 7 — Behaviour of monthly carbonyl index at each place



Key
 Y accumulated carbonyl index X accumulated months
 ▲ Sapporo (Japan) ● Choshi (Japan) ▲ Miyakojima (Japan)
 × Serpong (Indonesia) ○ Phoenix (USA) * Bandung (Indonesia)

Figure 8 — Cumulative sum of monthly carbonyl index at each place

7.3 Examples of correlation between outdoor exposure test and laboratory light-source exposure test using PERS

The degree to which plastics materials are damaged in outdoor environments is influenced by the UV radiation, temperature, humidity, etc., that they received. Of these factors, in photo-oxidation caused by UV, temperature in particular plays an important role.

In evaluating the weatherability of plastics, it is often found that it is not possible to correlate the outdoor exposure test with the laboratory light-source exposure test for only the amount of UV received. This indicates the need for some index indicating combined effects based on received UV and temperature.

The test method described here is one that uses carbonyl indices, as an index showing combined effects, determined from carbonyl group linearly increasing in PERS, depending on received UV and temperature. As shown in [Figure 2](#), the carbonyl index of PERS is proportional to the exposure period, and as shown in [Figure 7](#), it reflects the seasonal change of climate in an outdoor environment. Thus, from these results, the carbonyl index can be used as the index exhibiting the environmental condition of the laboratory light-source exposure test and the outdoor exposure test mainly dominated by UV and temperature.

[Table 7](#) shows examples of the correlation between outdoor exposure and xenon-arc exposure. The exposure was carried out according to the methods described in [6.2](#) and [6.3](#). When the carbonyl index obtained from outdoor exposure and xenon-arc exposure is the same, it is considered that these exposures are equivalent.

This value includes the effect of temperature. Since the temperature in the chamber of a laboratory light-source exposure device is higher than that outdoors, the time to become equivalent to a cool climate area like Sapporo (Japan) becomes short, and the time to become equivalent to a high temperature area like Phoenix (USA) becomes long.

The degradation mechanism of PERS is an auto-oxidation reaction caused by ultraviolet irradiation. In many cases, plastics materials also degrade, mainly by photo-induced auto-oxidation in outdoor environments. Therefore, when the temperature promotes the diffusion rate of the substances such as oxygen in the rate-determination stage, it is thought that the carbonyl index correlates with the oxidation rate of other plastics materials. Changes in experimental properties that originated in the decrease in molecular weight result from a photo-induced auto-oxidation reaction, like gloss loss or elongation of tensile test, often correlate with the carbonyl index (see References [\[8\]](#) and [\[9\]](#)).

Table 7 — Comparison between outdoor exposure and xenon-arc exposure for PERS

Exposure site	Cumulative carbonyl index value of 1 year ^a	UV radiant exposure at exposed angle ^a (MJ/m ²) (315 to 400 nm)	Average temperature of 1 year ^a	Equivalent hours of xenon exposure ^b to 1 year outdoor exposure based on the comparison of carbonyl index
Sapporo, Japan	7,2	300 ^c	9,3	700 to 800 ^d
Choshi, Japan	9,3	336	14,9	900 to 1 100
Miyakojima, Japan	12,7	377	23,4	1 300 to 1 500
Phoenix, USA	16,1	434 ^c	22,7	1 600 to 1 900

^a Observed value from October 1999 to September 2000.

^b Test condition: Irradiance level 60 W/m², BPT (63 ± 3) °C, 18 min spray/120 min.

^c The Sapporo value is converted from the solar radiation, and the Phoenix value is 1,3 times the value obtained by actual measurement to allow for a different UV range.

^d The minimum and maximum values are based on the value of the equipment given in [6.4](#). This value changes with each item of equipment as in [5.1](#).

This correlation, however, is not applicable simply to all kinds of plastics materials. Certain relations can only be expected if the influence of the degradation factor on carbonyl generation of PERS, and the influence of the degradation factor on the change in properties of interested materials, are either equivalent or their effect on the material is known.

7.4 Control limit of particular laboratory light-source exposure apparatus

An example of the control limit of the equipment is shown in [Table 8](#) and [Figure 9](#), from the results of 3 times the 120 h xenon exposure. How to calculate these values is described in [6.4](#). These were conducted in the same conditions and using the same machine at different times.