Karin Wernståhl

A Comparison of testing in Global UV and Xenon Arc Test Cabinet

Ytskydd och korrosion
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ABSTRACT

In the present report, the general characteristics of two different kind of weathering equipment are compared, the Weiss Global-UV and the Xenon-arc test cabinet.
Also presented are the results of some comparative tests.

The GUV test cabinet uses fluorescent lamps as light source, they simulates only the ultraviolet part of the natural sunlight.

In Xenon-arc test cabinets a spectrum of light is created that consists of UV-VIS and IR irratiation.

The prescence of infrared light in the sun and in the Xenon-arc spectrum have the effect that test objects will have different temperatures and relative humidity at the surface, depending on the material and its ability to absorb infrared irradiation.
As there is no IR-irradiation present in the GUV, there exists no such differences in surface climate contidions.

In the comparative tests, paints with well documented outdoor performance were used.
It was found that the correlation with outdoor exposure was good for both the GUV and the Xenon-arc test cabinet when gloss retention was used as an evaluation parameter. When comparing colour changes the correlation was poor.

Key words: accelerated weathering, Global-UV, Xenon-arc, paints

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Postal address:
P.O. Box 857, S-105 15 BORÅS, Sweden
Telephone Int. + 46 33 - 16 50 00
Telefax + 46 33 - 13 55 02
Telex 36252 Testing S

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SAMMANFATTNING

I denna rapport jämförs karakteristiska egenskaper hos två typer av utrustningar avsedda för accelererad väderbeständighetsprovning, Weiss Global-UV och Xenon-testutrustning.

Resultat från en jämförande undersökning presenteras också.

Utrustningar av Global-UV typ använder fluorescerande lysrör som ljuskälla. De simulerar endast den ultra violetta delen av det naturliga solljuset. I test-utrustningen med Xenon-lampa skapas ett komplett ljus-spektra med UV-VIS och IR-strålning.

Närvaron av IR-strålning både i solljuset och i Xenon-lampas spektra har effekten att exponerade prov-föremål antar olika temperaturer och relativa fuktig-heter på ytan beroende på provmaterialet och dess för-måga att absorbera IR-strålning.

Frånvaron av IR-strålning i Global-UV medför att inga sådana skillnader i ytklimat uppstår i denna typ av utrustning.

I den jämförande undersökningen användes färger med väldokumenterad långtidshållbarhet.

Korrelationen med utomhusexponering befanns vara god både för Global-UV och Xenon-utrustningen när glans-förändringar användes som utvärderingskriterie. För kulörförändringar befanns korrelationen vara dålig.

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A special thanks also to Mr I. Andersson, SP who performed all measurements of spectral irradiance.

1. INTRODUCTION

For many years the accelerated weathering test has been a well established method to get a quick, if not always correct, answer to the durability of a material. Today most artifical weathering tests are performed in equipment utilizing either a Xenon-arc or fluorescent tubes as light source.

The Xenon-arc has a spectral distribution that corresponds rather well to the solar spectrum, but which is expensive and somewhat difficult to handle. The uv fluorescent lamps, on the other hand, are rather cheap and easy to handle but they have the disadvantage of generating a spectrum of light quite different from the solar spectrum.
None of these equipment are very flexible when it comes to varying and controlling the climatic conditions during the tests.

Recently, however, Weiss technik introduced a new kind of artifical weathering equipment on the market - the Global-UV test cabinet (GUV). This test cabinet uses a combination of different fluorescent tubes as light source.The fluorescent tubes give an overall spectrum of light that corresponds rather well to the solar spectrum in the uv-band. The test cabinet also has all the advantages of a modern programmable climatic chamber.

In the present report, the general characteristics of the GUV test cabinet are compared with those of existing Xenon-arc test cabinets. Also presented are results of some comparative tests using a GUV test cabinet, a Xenon-arc test cabinet and outdoor exposure. The correlations between the different results obtained are calculated to illustrate the differences between the two kinds of equipment.

2. GENERAL CHARACTERISTICS OF ACCELERATED WEATHERING EQUIPMENT

The GUV test cabinet has a general outline that is very similar to an ordinary climatic chamber. A figure of the Global -UV is shown below.

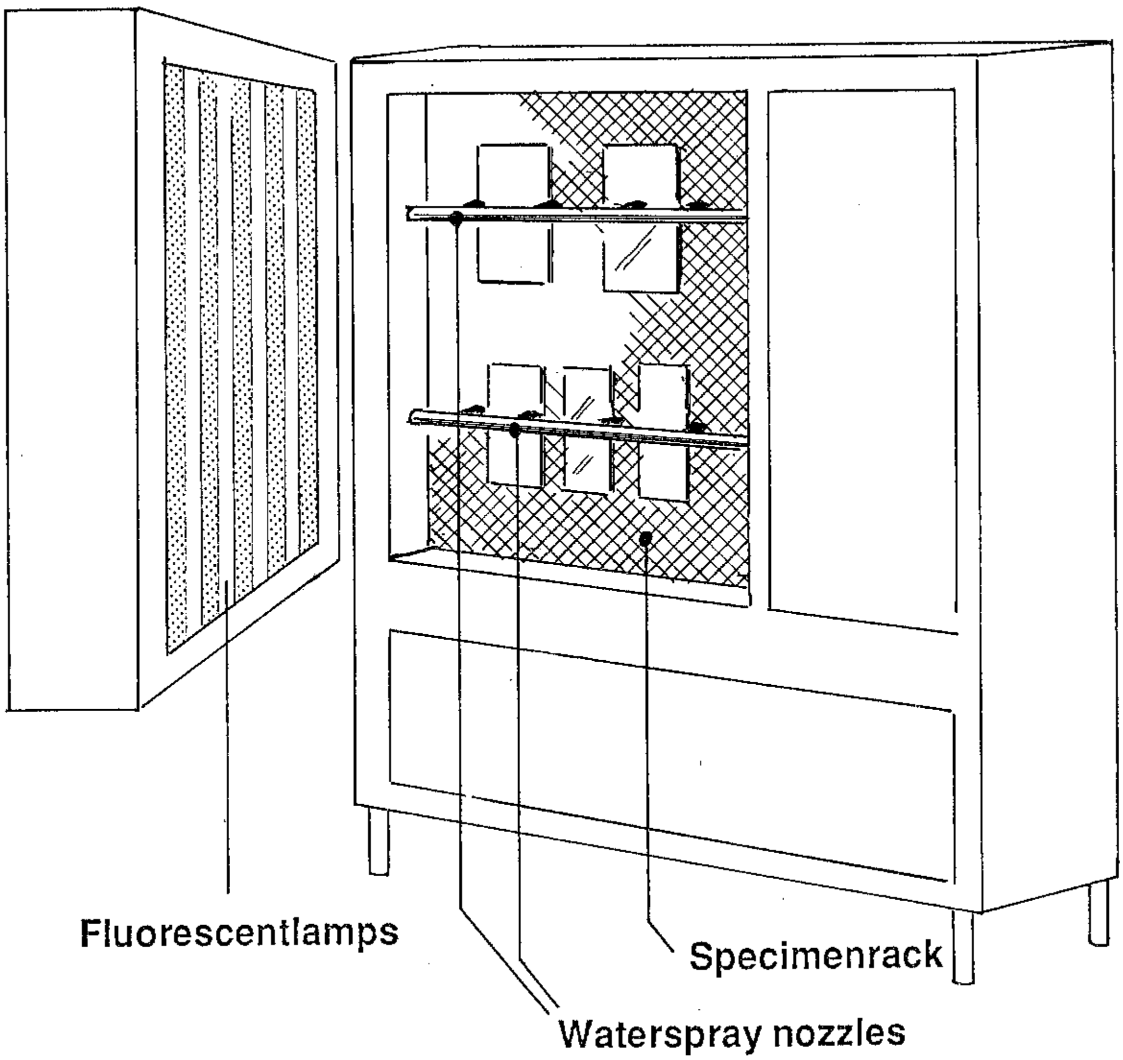

Fig.1 Global-UV test cabinet

The test objects are placed vertically on a net at the back of the cabinet. The light source , 18 fluorescent tubes are placed in front of the test objects inside the door behind a quartz glass plate.

It is possible to perform different mecanical tests on the test objects during aging. A lead-through is prepared in the side wall of the cabinet for this purpose. The GUV test cabinet is equipped with a programmer which makes it possible to vary temperature, humidity, duration and frequency of water spray, and light intensity during the test cycle. The temperature range is between -20 ^{o}C - + 90 ^{o}C and the relative humidity range between 15 % - 90 %.

In Xenon-arc test cabinets, the test objects are usually placed on a rack that rotates around the Xenon-lamp during the test program. In older models of equipment the tests are conducted at constant temperature and humidity, only the light intensity and duration, and frequency of the water spray can be varied. However some of the most recent models released on the market, e.g. the Atlas XR-35, can be programmed in the same way as the GUV test cabinet.

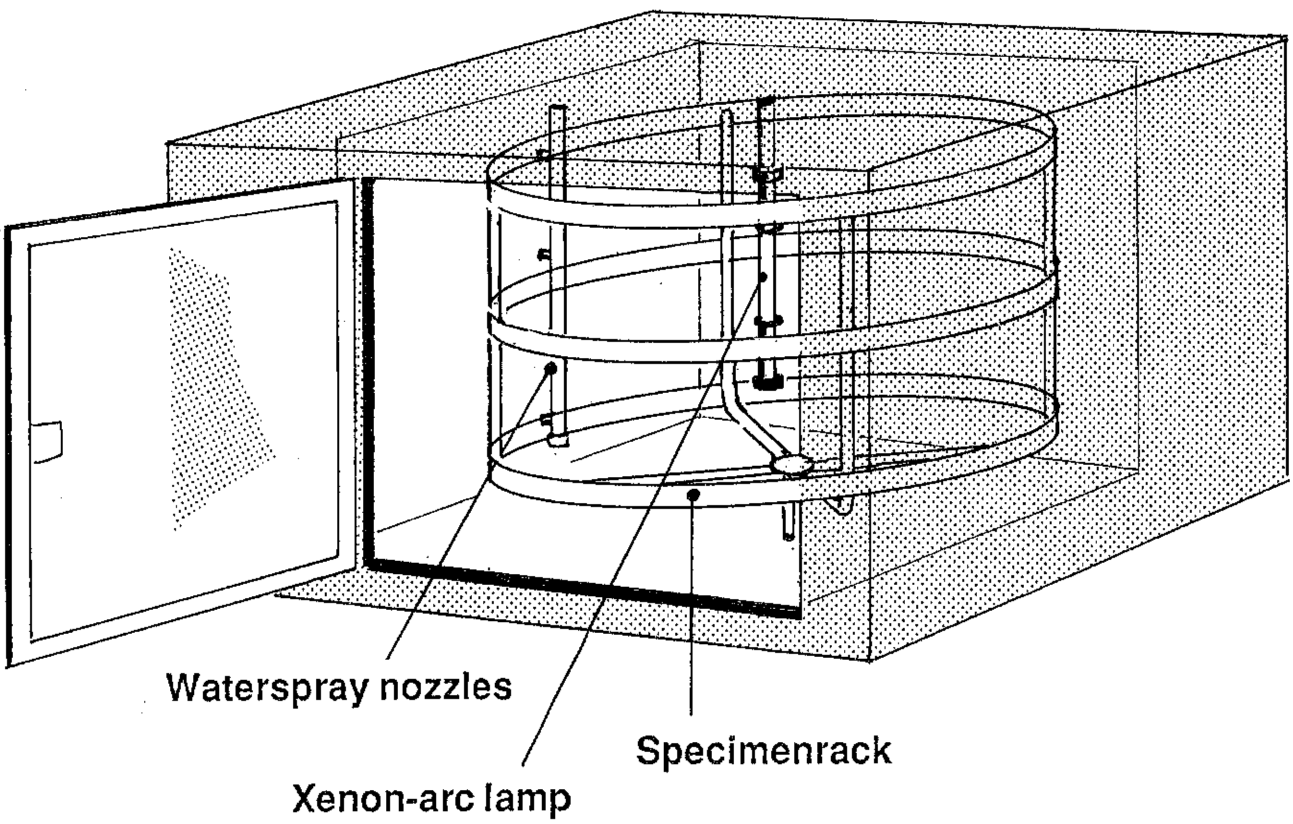

Fig 2. Atlas Xenon-arc weather-o-meter

2.1. Wetting of test objects

In the GUV test cabinet, the test objects are wetted by spraying water using eight nozzles arranged as shown in figure 1. The flow rate during water spraying is 92 l/h m^2. In the Xenon-arc test cabinets, the water is sprayed in a different way . Since the test objects are fixed on a rack that moves around the lamp, all test objects are not sprayed at the same time. The nozzles, normally three or four, are placed vertically in a row and the test objects are wetted as they pass the nozzles. The total flow rate in the Xenon-arc test cabinet is 115 l/h m^2 but, as the test objects are only sprayed directly for about one tenth of the time, the amount of water that directly hits the surface is only 11.5 l/h m^2 .

2.2. Humidity control

In the GUV test cabinet, air is humidified by a Raschig ring humidifier which gives completely aerosol-free humidification.The humidity level in the chamber is controlled by introducing an air flow with a known dew-point into the chamber. The dew-point in the air is regulated by varying the temperature in the water bath of the humidifier. No measurement or direct control of the actual humidity in the chamber is possible in the standard version of the equipment. This means that the dew-point temperature shown on the display is the one corresponding to the temperature in the water bath, and not the real humidity in the chamber.

In most Xenon-arc test cabinets, the humidifier consists of an atomizer connected to a water bath. The vapor generated in the atomizer is transported to the test chamber by a blower. This system allows fine water droplets to be introduced into the chamber by the air stream. The relative humidity is calculated from measurements of the dry and wet bulb temperature in the chamber. The humidity is controlled by switching the atomizer on/off. It is also possible to regulate the relative humidity by manually changing the temperature of the water bath.
Recent models of Xenon-arc test cabinets, e.g. Atlas XR 35, have a humidification system similar to the one used in the GUV test cabinet. However, the humidity level is still controlled by measuring the dry and wet bulb temperature in the chamber.

In cases where water spraying is not included in the test cycle, a system for humidification like the one used in the GUV test cabinet is excellent. However when using a test program that includes water spray, as is normally the rule in artifical weathering, the system becomes very slow, and according to our findings it is difficult to get the chamber to dry up after a period of water spraying.

2.3. Spectral characteristics

The light source in the GUV test cabinet consists of eighteen 40 W fluorescent tubes. They are of four different types all of which have their own characteristic spectrum as shown in figure 3.

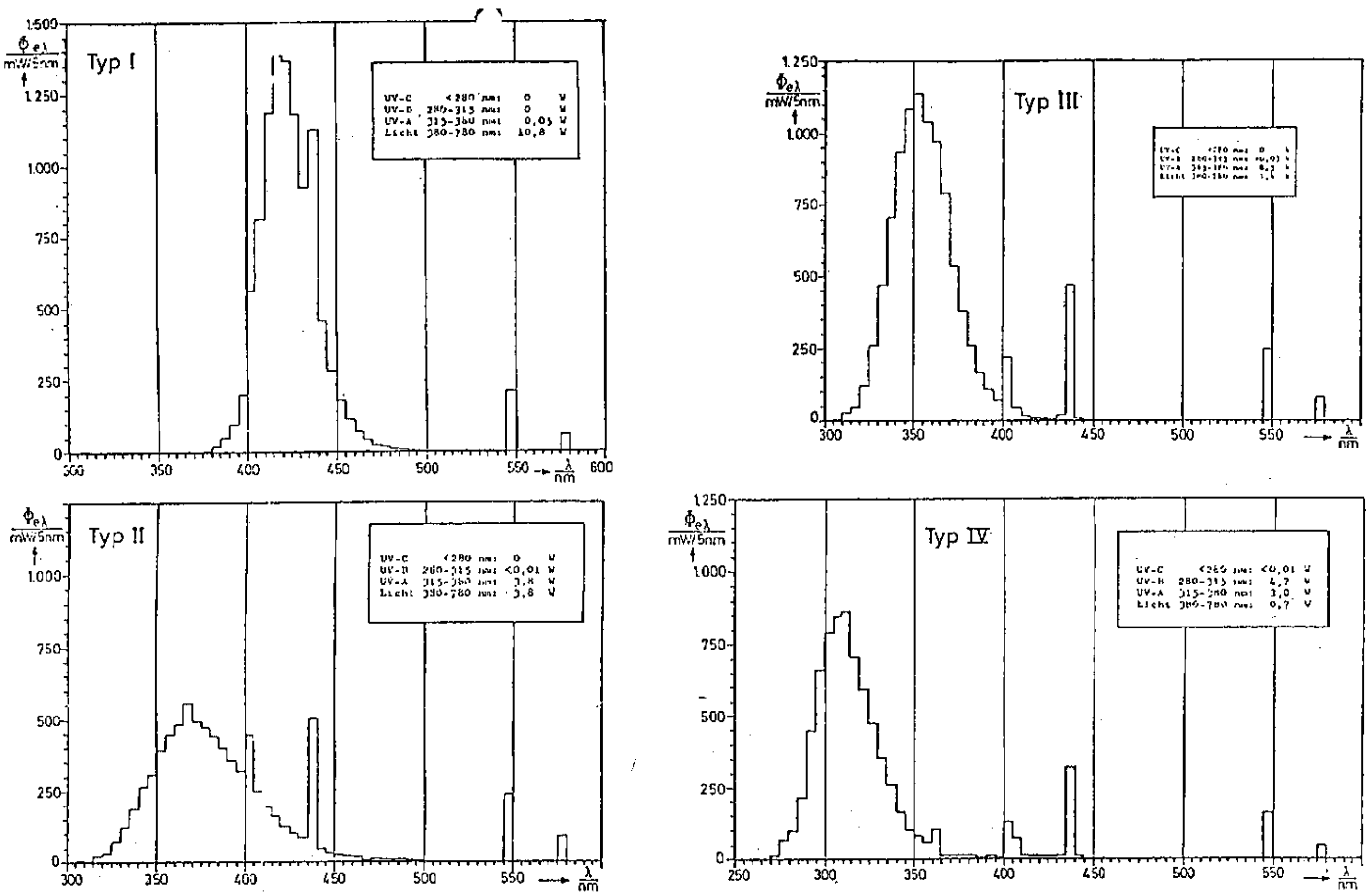

Fig.3 Spectral distribution of the four types of fluorescent tubes in the GUV.

The overall spectrum of the different lamps in the GUV test cabinet is compared to the solar spectrum in fig.4

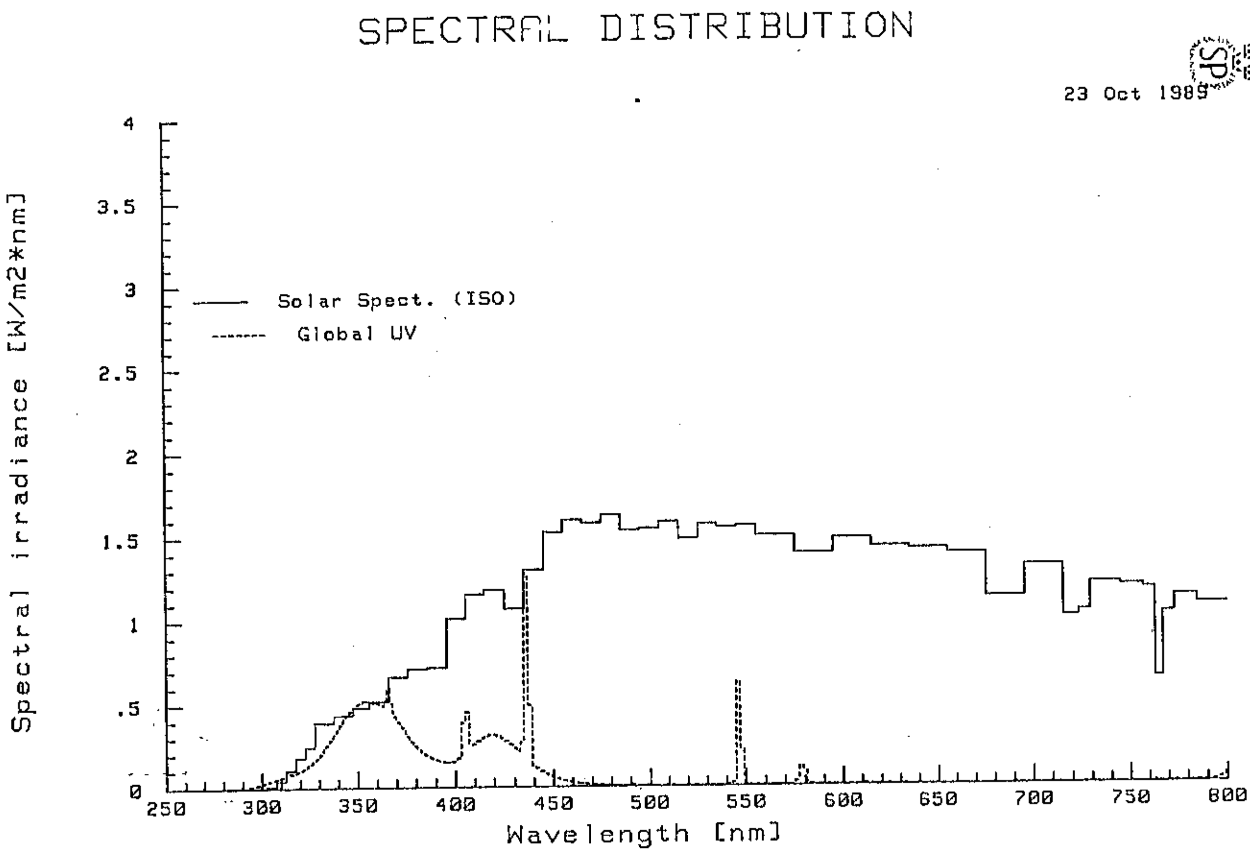
SPECTRAL DISTRIBUTION
23 Oct 1989
Spectral irradiance [W/m2*nm]
4
3.5
3
2.5
2
1.5
1
.5
0
Solar Spect. (ISO)
Global UV
250
300
350
400
450
500
550
600
650
700
750
800
Wavelength [nm]

Fig. 4

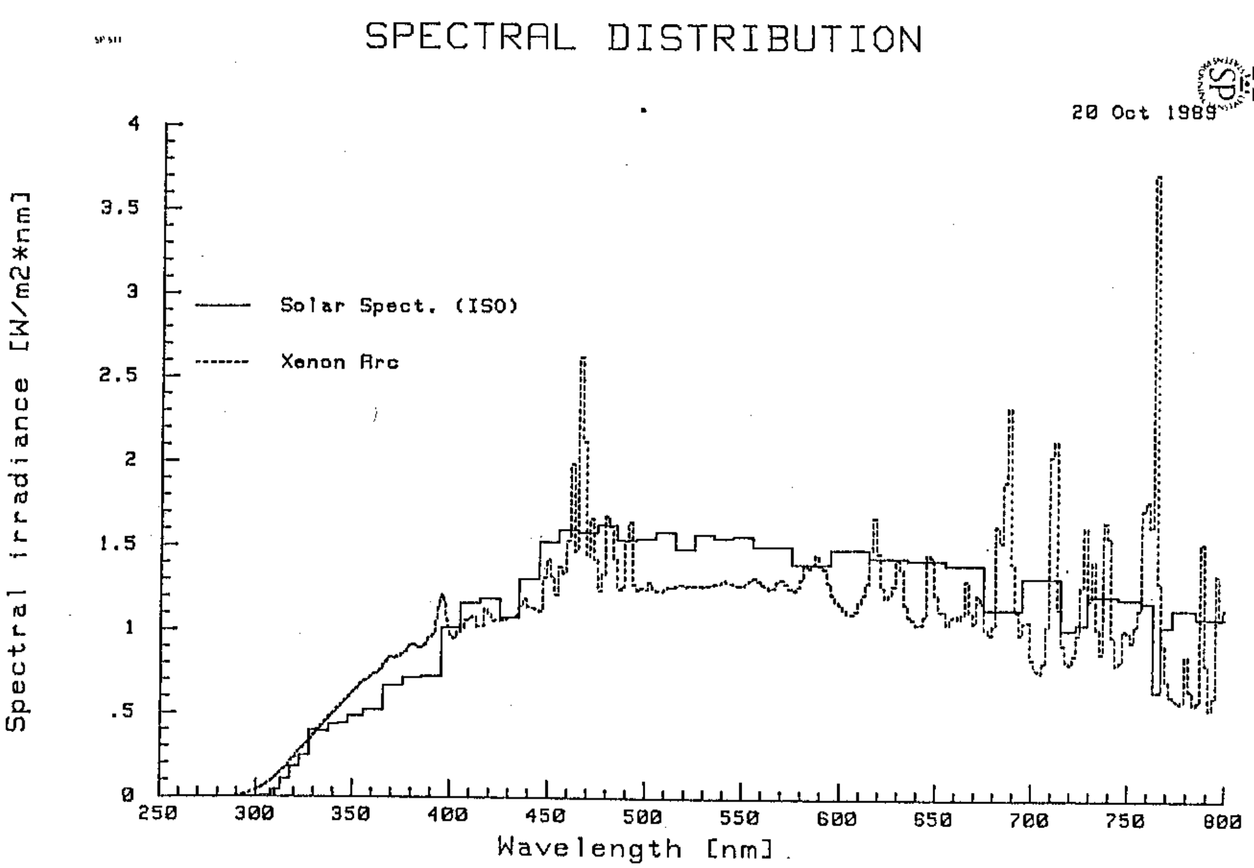
SPECTRAL DISTRIBUTION
20 Oct 1989
Spectral irradiance [W/m2*nm]
4
3.5
3
2.5
2
1.5
1
.5
0
Solar Spect. (ISO)
Xenon Arc
250
300
350
400
450
500
550
600
650
700
750
800
Wavelength [nm]

Fig. 5

There is no irradiance above 450 nm in the GUV test cabinet. The visible and infrared irradiation natural sunlight is therefore not present in the GUV test cabinet. The agreement with the solar spectrum is rather good from 290 nm up to about 370 nm.

The Xenon-arc generates a spectrum of light as shown in fig 5. The Xenon-arc has a larger part of its intensity in the infrared region compared to the sun.
In the ultraviolet and visible wavelength regions, the Xenon-arc spectrum corresponds well to the global solar irradiation.

Table 1

nm	GUV W/m^2	Xenon W/m^2	Sun W/m^2
280-320	1.5	2.8	1.25
320-360	13.9	20.0	16.2
360-400	11.7	36.2	28.7
total 280-800	45.7	550	585

Equipment for artifical weathering can also be used to simulate indoor conditions, this is normally called daylight behind window glass. A typical window glass cuts off irradiation at wavelenghts shorter than 320 nm. In a Xenon-arc test cabinet, the indoor conditions are generated simply by using a filter made of soda lime glass.
In the GUV test cabinet, the lamps of type IV (see fig.1) are disconnected.
The resulting irradiance spectra are shown in fig.6.

The main technical reason for using fluorescent tubes as light source in artificial weathering is that photochemicaly induced degradation of materials is caused mainly by irradiation at wavelengths below 400 nm. The visible part of the light is thought to be of little importance in this case. However, the general applicability of such an assumption is not fully known, when considering the great variety of existing materials.
A practical consideration when choosing fluorescent tubes is the relative ease of operation compared to a Xenon-arc. As fluorescent tubes do not produce excess heat, no complicated cooling of the lamp is needed. Fluorescent lamps are also cheaper and generally easier to handle than a Xenon-arc.

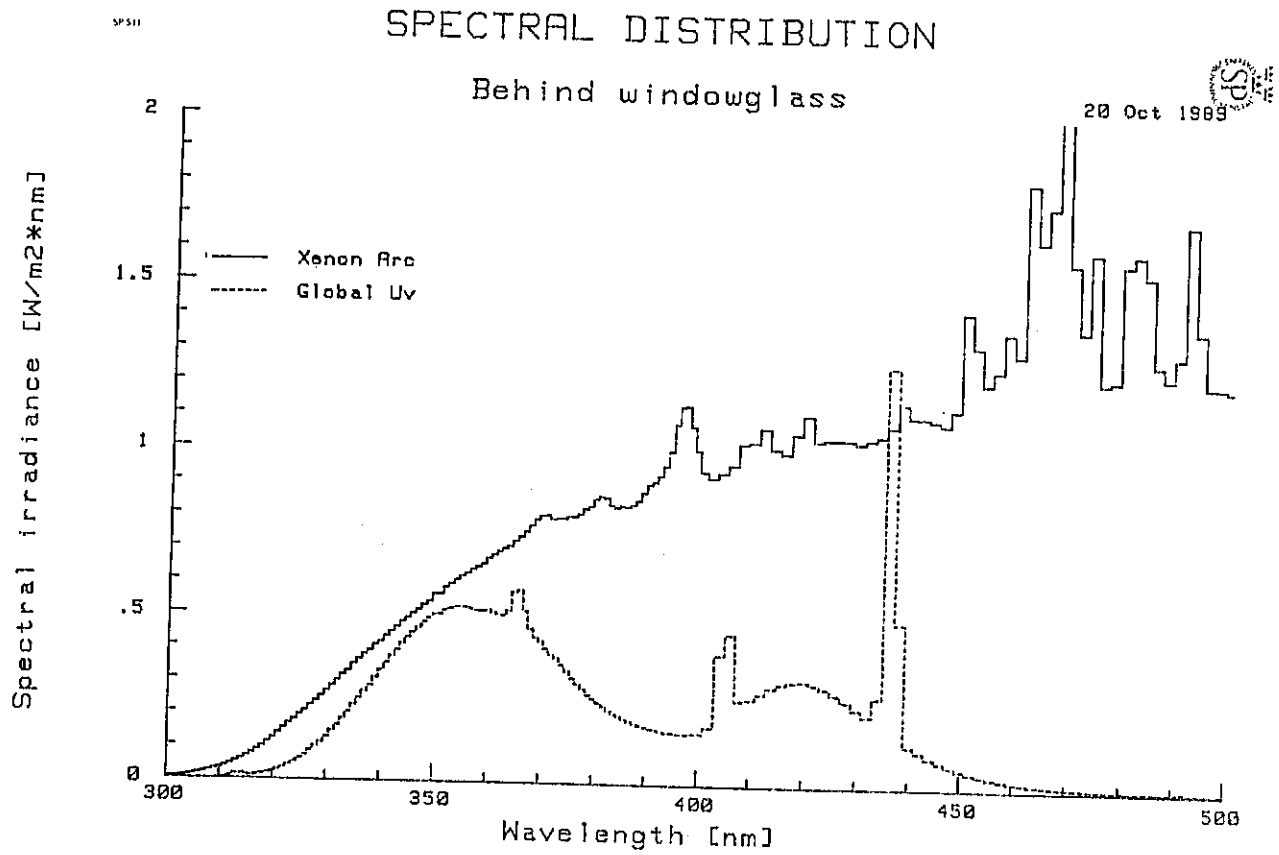

Fig.6

2.4 Surface climate of test objects

One main difference between the GUV test cabinet and test cabinets using a Xenon-arc lamp as light source is that, in the latter, the test objects are mainly heated by the infrared irradiation from the light source while, in the former, case the test objects are heated by the circulating air.

In the Xenon-arc test cabinet, there will be a rather large temperature difference between the surrounding air and the surface of exposed test objects. How large this temperature difference will be depends on the material and its ability to absorb/reflect infrared irradiation. Accordingly, at an air temperature of 48 ^{o}C and an irradiation level of 550 w/m^2 (300-800nm) a so-called black standard thermometer will reach a temperature of 85 ^{o}C, while a white PVC pannel will have a temperature of 63 ^{o} C .
In the GUV test cabinet, all objects will have nearly the same temperature as the surrounding air, independent of material and colour.

In natural sunlight 40% of the energy is in the infrared range. This is relatively less than in the Xenon-arc which has 60% of its energy in the infrared range. The spectral distribution of the infrared light also differs from sunlight to the Xenon-arc.

Consequently, test objects exposed to the outdoors or in the Xenon-arc will not always reach the same surface temperature even when exposed at conditions which give the same black standard temperature.

The large differences in temperature between the surrounding air and the test objects in an Xenon-arc test cabinet also affect the relative humidity on the surface of the test objects. For example if the surrounding air has a relative humidity of 50% at an air temperature of 30 ^{o}C the corresponding climate at a black surface will be 60 ^{o}C and 10 % RH. The example given represents a very common situation in Xenon-arc weatherability testing. In a GUV test cabinet, the relative humidity on the surface of all test objects will be almost the same at the surface as in the surrounding air.

Consequently, when exposed to the outdoors, the test objects will have different climates at the surface depending on the material and its ability to absorb infrared irradiation.In the Xenon-arc test cabinet, there will also be differences but they are not exactly the same as outdoors. Thus, unless you are actually capable of measuring or calculating the climatic conditions at the surface of the different test objects, the climate is largely unknown and difficult to control. In the GUV test cabinet, there exists no differences in surface climate conditions between different kinds of materials. However in this use the climatic conditions at the surface of the test objects are known and can be controlled.

Consequently both methods of accelerated weathering have their advantages and disadvantages and it is very difficult to make a general statement about which is the best.

3. RESULTS OF SOME COMPARATIVE TESTS -COIL COATING PAINTS

3.1. Comparative testing

To get an idea of how the GUV test cabinet operates in relation to a Xenon-arc test cabinet, some selected materials with well documented durability from outdoor exposures were exposed in a GUV test cabinet. The study carried out was not intended to be complete. But it gives some valuable information on the durability properties of the specific materials that have been tested, and might give a hint of what can be expected from the exposure of other materials in the GUV test cabinet.

In the tests performed, two different kinds of materials were used, coil-coating paints and exterior wood paints. Samples were exposed both in a GUV test cabinet and in an Xenon-arc test cabinet.
The aging of the materials was followed by measuring changes in colour and gloss during the exposures.
The test results were compared to results from outdoor exposures.

For statistical evaluation of the test results, two different methods were used, namely, the Spearman rank correlation and the linear regression analysis. For further information on evluation methods see Appendix A.

3.2. Test objects

Thirteen different coil-coating paints for facades were used in this test. Information on colour and type of binder in the paints is shown in table 2.
The paints were applied to steel or aluminium substrates.

table 2.

	type of binder	colour
1P	polyester	white
2P	polyester	cream
3P	polyester	brown
4P	polyester	yellow
5P	polyester	dark blue
1S	PVC-plastisol	white
2S	PVC-plastisol	dark brown
3S	PVC-plastisol	dark brown
1A	acrylic	white
2A	acrylic	dark brown
3A	acrylic	dark blue
1F	PVF2	white
2F	PVF2	light blue

3.3. Test methods

The exposure in the GUV test cabinet was carried out according to DIN 53 384 procedure B. This method means testing according to the following cycle: 5 hour dry period with a temperture of 50 °C and a relative humidity of 10 % followed by 1 hour at 20 °C with water spraying. The total test period was 1000 h.

The Xenon-arc test was carried out in an Atlas Weather-ometer with a 6000W lamp.The exposure was made according to ASTM G 26 which implies a cycle with a dry period of 102 min at a black panel temperature of 63 °C and a humidity of 30 % followed by an 18 min period of water spraying. The total test period was 2000 h.

All test panels were inspected at 250 h intervals.
The outdoor exposure used as reference had been carried out at a South Florida test station. However data for changes in gloss and colour were only available for an exposure period of 24 months.

3.4. Gloss retention

The changes in the gloss of the test objects were on the same order in the accelerated tests and in the outdoor exposure. Figure 7 shows an example of changes in the gloss with time for a test panel in the GUV test cabinet and in the WOM.

COIL COATING PAINTS
GLOSS RETENTION

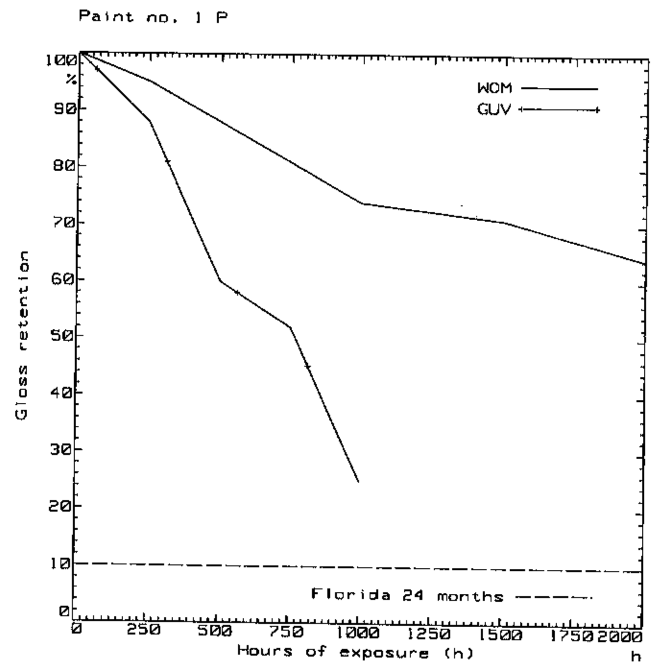

Fig.7

3.4.1 Spearman rank correlation

The Spearman rank coefficient was calculated for a number of different cases as shown in table 3.
Table 3,

	Spearman rank correlation Gloss retention			
	GUV 1000h	WOM 1000h	WOM 2000h	Florida 24 months
GUV 500h	0.62	0.84	0.74	0.61
GUV 1000h	-	0.67	0.64	0.65
WOM 1000h	-	-	0.97	0.67
WOM 2000h	-	-	-	0.71

As can be seen in the table, all accelerated tests show reasonably good correlation with the Florida exposure. To see if the correlation could be improved if the test panels were sorted into more homogenous groups, the panels were classified as either light coloured or dark coloured. The Spearman rank coefficient of these two groups was calculated separatly. The result is shown in table 4.

Table 4.

Spearman rank correlation Gloss retention Light coloured test objects				
	GUV 1000h	WOM 1000h	WOM 2000h	Florida 24 months
GUV 500h	0.78	0.78	0.75	0.52
GUV 1000h	-	1.00	0.99	0.62
WOM 1000h	-	-	0.99	0.62
WOM 2000h	-	-	-	0.63

table 5.

Dark test objects				
	GUV 1000h	WOM 1000h	WOM 2000h	Florida 24 months
GUV 500h	0.47	0.99	0.93	0.87
GUV 1000h	-	0.39	0.50	0.54
WOM 1000h	-	-	0.94	0.90
WOM 2000h	-	-	-	0.99

As is seen, this way of grouping the test objects considerably changed the correlation. In the GUV test cabinet, the coefficient for the dark objects increased for the 500h exposure and decreased for the 1000h exposure. In the WOM, the coefficient increased as compared to outdoor exposure incresed giving a very good correlation for the dark test objects, and remained about the same for the light objects. Thus the best correlation with outdoor exposure is obtained for dark test objects in the WOM. The ranking between the test panels does not change with exposure time in the WOM test, but it does in the GUV test cabinet. The differences in correlaton might be explained by the

differences in surface climate which were already discussed in chapter 2.
A study performed by P.Pagan at the U.K. Ministry of Defence had shown that the weather varied sufficiently from one exposure site to another, even in the same climate, that the Spearman rank correlation was only approx. 0.75.
A comparison of an outdoor exposure at a temperate test site with exposure at a tropical test site, revealed that the result was even worse, between 0.55 and 0.75 depending on the period of exposure used in the calculations of ranking coefficients.

The artifical tests in the study by Pagan were performed using a QUV equipment which made use of so called UVA-351 flourescent tubes as light source. (These are similiar to the lamps of type III used in the GUV test cabinet). Compared with the results from the two temperate outdoor sites the QUV test results gave a correlation of 0.6 and 0.8, respectively. Compared with the results from the tropical site, the correlation was as poor as approx. 0.4.

The conclusion is that the accelerated test methods used in our survey were as good as, or better than expected.

3.4.2. Linear regression analysis

To get another view of the correlation between different test results a linear regression analysis was performed. Figure 8 gives an idea of a plot of the measured data.

The calculated slope of the regression line and coefficient of correlation (r) for each set of data to the line are shown in table 6.

The best correlation with outdoor exposure is found for the GUV test cabinet at 1000h. If once again we perform the exercise of grouping the test objects according to colour,(table 7 and 8) we obtain a result similar to the one obtained for the ranking procedure.The correlation of the dark coloured objects is excellent in the WOM test and the GUV test at 1000h and good in the GUV test at 500h.In most cases the correlation between the two test methods is also good.
The GUV 1000h exposure of the light colured objects is the only one that gives good correlation to outdoor exposure.

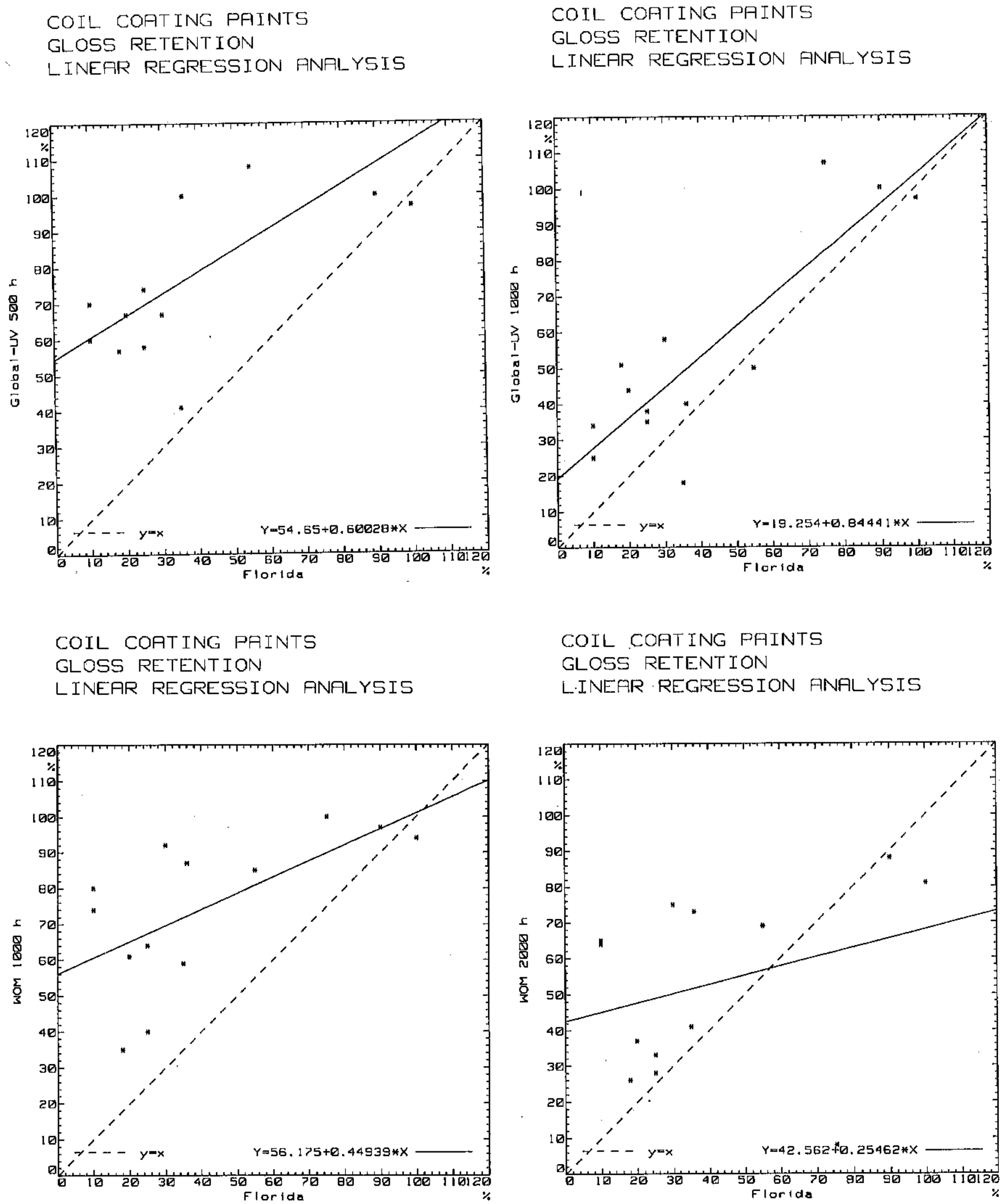
COIL COATING PAINTS
GLOSS RETENTION
LINEAR REGRESSION ANALYSIS
Global-UV 500 h
Florida
%
y=x
Y=54.65+0.60028*X
COIL COATING PAINTS
GLOSS RETENTION
LINEAR REGRESSION ANALYSIS
Global-UV 1000 h
Florida
%
y=x
Y=19.254+0.84441*X
COIL COATING PAINTS
GLOSS RETENTION
LINEAR REGRESSION ANALYSIS
WOM 1000 h
Florida
%
y=x
Y=56.175+0.44939*X
COIL COATING PAINTS
GLOSS RETENTION
LINEAR REGRESSION ANALYSIS
WOM 2000 h
Florida
%
y=x
Y=42.562+0.25462*X

Fig. 8

Table 6.

Linear regression analysis Gloss retention				
	GUV 1000h	WOM 1000h	WOM 2000h	Florida 24 months
GUV 500h	0.65 r=0.749	0.89 r=0.746	0.81 r=0.733	0.60 r=0.713
GUV 1000h	-	0.84 r=0.609	0.84 r=0.656	0.84 r=0.867
WOM 1000h	-	-	0.90 r=0.963	0.45 r=0.635
WOM 2000h	-	-	-	0.50 r=0.663

Table 7.

Linear regression analysis Gloss retention Light objects				
	GUV 1000h	WOM 1000h	WOM 2000h	Florida 24 months
GUV 500h	0.52 r=0.753	1.47 r=0.853	1.33 r=0.873	0.41 r=0.652
GUV 1000h	-	2.12 r=0.849	1.88 r=0.853	0.83 r=0.903
WOM 1000h	-	-	0.87 r=0.980	0.22 r=0.591
WOM 2000h	-	-	-	0.25 r=0.601

Table 8.

	Dark objects			
	GUV 1000h	WOM 1000h	WOM 2000h	Florida 24 months
GUV 500h	0.89 r=0.799	1.13 r=0.963	1.18 r=0.990	1.25 r=0.979
GUV 1000h	-	0.73 r=0.694	0.87 r=0.817	0.97 r=0.902
WOM 1000h	-	-	0.95 r=0.946	0.97 r=0.902
WOM 2000h	-	-	-	1.05 r=0.981

3.5. Colour differences

To be able to draw more reliable conclusions from the correlation of the different test methods, it was considered important to use more than one measured parameter in the evaluation. That is why changes in colour were also measured during tests.

The colour changes obtained during exposure in the accelerated test equipment were much smaller than the changes obtained at outdoor weathering, especially for test objects exposed in the WOM cabinet. This is shown in figure 9.

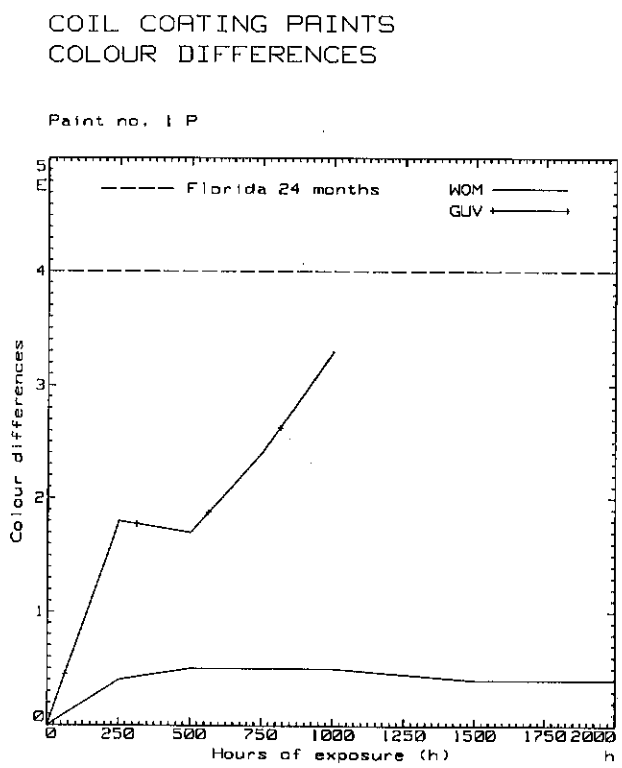

Fig. 9

The small differences in colour between the test panels makes it difficult to statistically evaluate the data. In some cases, the differences between the test panels were not big enough to be of significance.

However an attempt was made to use the ranking method in this case as well. The results are given in table 9.

Table 9.

	Spearman rank correlation Colour differences			
	GUV 1000h	WOM 1000h	WOM 2000h	Florida 24 months
GUV 500h	0.73	0.33	0.18	0.08
GUV 1000h	-	-0.04	-0.10	0.33
WOM 1000h	-	-	0.80	0.00
WOM 2000h	-	-	-	0.03

The table above shows that there is no correlation between outdoor exposure and any of the accelerated test methods. Moreover, there is no correlation between the two accelerated methods.
When the light and dark coloured test objects were evaluated separately, the dark coloured objects showed some improvement. The GUV method gave a reasonably good correlation to outdoor exposure.
Table 10.

	Spearman rank correlation Colour differences Light coloured objects			
	GUV 1000h	WOM 1000h	WOM 2000h	Florida 24 months
GUV 500h	0.86	0.49	0.54	-0.01
GUV 1000h	-	0.22	0.28	0.12
WOM 1000h	-	-	0.88	0.18
WOM 2000h	-	-	-	0.07

Table 11,

	Spearman rank correlation Colour differences Dark coloured test objects			
	GUV 1000h	WOM 1000h	WOM 2000h	Florida 24 months
GUV 500h	0.26	0.39	0.16	0.79
GUV 1000h	-	-0.44	-0.30	0.64
WOM 1000h	-	-	0.24	0.01
WOM 2000h	-	-	-	-0.06

In the study by Pagan, the Spearman rank correlation was not found to be considerably poorer for colour differences than for gloss retention.

Summary

The artifical methods used here seem to accelerate the gloss deterioration much more rapidly than colour deterioration . Changes in gloss and colour are caused by different kinds of mechanisms which are probably the reason for the poor correlation obtained for colour changes.

The main conclusion is that these accelerated methods are reasonably good at simulating outdoor exposure for this type of test objects if gloss retention is used as a criterion.

4. PAINTS FOR EXTERIOR WOOD

4.1. Test objects

Seven white paints designed for use on exterior wood were used in this test series . They were applied by brush to pine wood panels sized 23x7x2 cm. Table 12 shows type of binder.

Table 12.

TYPE OF BINDER IN PAINT SYSTEMS

No	base coat	top coat
1	acrylic	acrylic
2	alkydemulsion	acrylic
3	alkyd	acrylic
4	alkyd	oilmodified acrylic
5	alkyd	alkyd
6	alkyd	alkyd
7	linseedoil	linseedoil

4.2. Test methods

The exposure in the Xenon-arc test cabinet was carried out according to ASTM G 26, the same procedure as used for the coil-coating paints. The test panels were exposed for 2000 h.

The exposure in the GUV test cabinet was carried out according to a special weathering cycle tailored to simulate the Scandinavian climate with its long wet and cold periods. One test cycle, 12 h long, is described in the table below.

Table 13.

section	time	temp. °C	RH %	water spray	light
1	3:00	45	60	no	yes
2	3:00	20	-	yes	yes
3	3:00	45	80	no	yes
4	0:30	20		no	no
5	0:30	5	-	yes	no
6	1:30	-15	-	no	no
7	0:30	5	-	no	yes

Reference samples were exposed to the outdoors 1 year at test facilites at the Swedish National Testing Institute.

4.3. Test results

The wood panels were inspected at regular intervals for cracking and blistering as well as for changes in gloss and colour.
After 1000 h of exposure in the GUV cabinet, paint systems 1,2 and 3 all with acrylic topcoats showed no sign of cracking and blistering. Paint system no 4 showed signs of chalking and had yellowed. The alkyd type paint systems 5 and 6 had chalked moderately and had also yellowed. Paint system no 7, the linseed oil, the panels were completely covered with blisters and the paint was very brittle.

After 2000h of exposure in the WOM, the paint systems with acrylic top coats 1, 2 and 3 were intact, system no 4 showed signs of chalking but no yellowing , the alkyd paints no 5 and 6 had chalked heavily and yellowed slightly. The linseed oil paint system no 7 showed heavy chalking, severe cracking and the paint was very brittle.

The differences in the results of the two accelerated tests performed were that the alkyd paints seemed to chalk more heavily in the WOM test than in the GUV test, while the colour changes were greater in the GUV. The linseed oil paint system failed in both tests although due to two different mechanisms.
The test panels at SP exposed to the outdoors for one year showed no signs of cracking or blistering. Paint systems 5,6 and 7 had started to chalk.

The heavy blistering and cracking of the linseed oil test panels made it impossible to measure changes in gloss and colour, which is why these panels were excluded from the statistical analysis of the test results.

In figure 10 are changes in gloss and colour of two selected paint systems as a function of time.

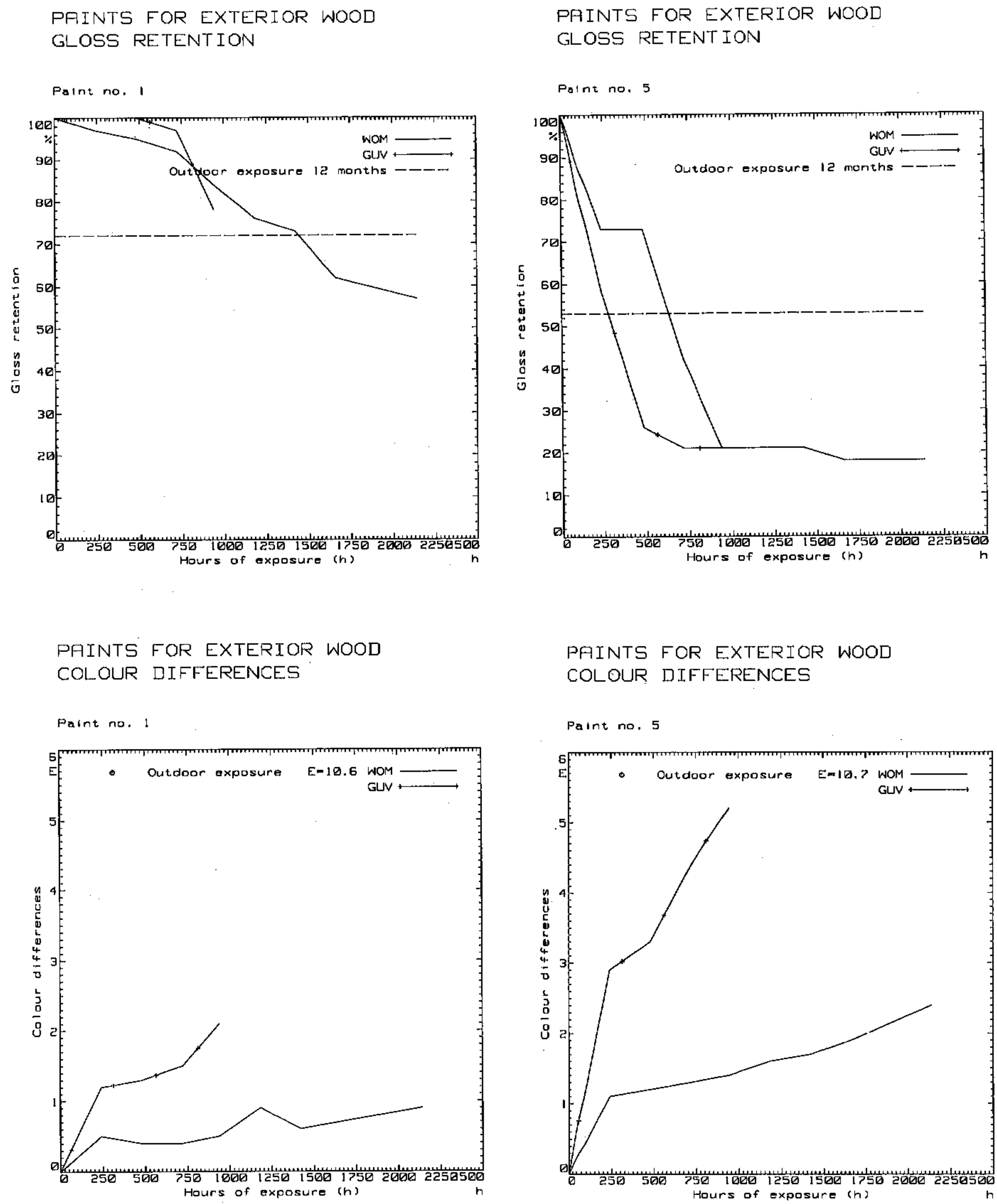
PAINTS FOR EXTERIOR WOOD
GLOSS RETENTION
Paint no. 1
WOM
GUV
Outdoor exposure 12 months
Gloss retention
%
Hours of exposure (h)
h
PAINTS FOR EXTERIOR WOOD
GLOSS RETENTION
Paint no. 5
WOM
GUV
Outdoor exposure 12 months
Gloss retention
%
Hours of exposure (h)
h
PAINTS FOR EXTERIOR WOOD
COLOUR DIFFERENCES
Paint no. 1
Outdoor exposure E=10.6
WOM
GUV
Colour differences
Hours of exposure (h)
h
PAINTS FOR EXTERIOR WOOD
COLOUR DIFFERENCES
Paint no. 5
Outdoor exposure E=10.7
WOM
GUV
Colour differences
Hours of exposure (h)
h

Fig. 10

4.3.1. Spearman rank correlation

The correlations between the results from those test methods were calculated using the spearman rank method and the results are shown in the table below.

Table 14.

	Spearman rank correlation Gloss retention			
	GUV 1000h	WOM 1000h	WOM 2000h	Outdoor 12 months
GUV 500h	0.67	0.81	0.81	0.89
GUV 1000h	-	0.84	0.90	0.91
WOM 1000h	-	-	0.97	0.84
WOM 2000h	-	-	-	0.84

All accelerated methods show good correlation of the gloss retention with outdoor exposure. The accelerated methods also correlate well with each other.

When using colour changes as an evaluation parameter the correlation is not good, neither between accelerated tests and outdoor exposure, nor between the various accelerated tests.
The result is shown in the table below.

The tendencies are the same here as in the coil-coating paints. Good correlation is shown for both methods with respect to gloss retention. No correlation at all is obtained for colour changes.

Table 15.

	Spearman rank correlation Colour differences			
	GUV 1000h	WOM 1000h	WOM 2000h	Outdoor 12 months
GUV 500h	0.89	0.28	0.29	-0.25
GUV 1000h	-	0.08	0.11	0.16
WOM 1000h	-	-	0.97	0.04
WOM 2000h	-	-	-	0.07

4.3.2 Linear regression analysis

The result did not improve when linear regression was used as an evaluation method. On the contrary, using this method, only the 500 h exposure in the GUV test cabinet correlated well with outdoor exposure. This might be explained by the fact that this test series only comprised six test objects compared to thirteen for the coil-coating paints. The correlation for the colour changes was as bad as for the use of the ranking method.

Table 16.

	Linear regression analysis Gloss retention			
	GUV 1000h	WOM 1000h	WOM 2000h	Outdoor 12 months
GUV 500h	0.37 r=0.680	0.51 r=0.796	0.43 r=0.609	0.99 r=0.826
GUV 1000h	-	0.94 r=0.797	1.27 r=0.979	2.05 r=0.931
WOM 1000h	-	-	0.93 r=0.841	1.48 r=0.794
WOM 2000h	-	-	-	1.50 r=0.888

Table 17.

	Linear regression analysis Colour differences			
	GUV 1000h	WOM 1000h	WOM 2000h	Outdoor 12 months
GUV 500h	0.75 r=0.882	0.32 r=0.327	0.24 r=0.280	-0.31 r=0.384
GUV 1000h	-	0.11 r=0.009	0.12 r=0.001	-0.22 r=0.223
WOM 1000h	-	-	0.83 r=0.969	-0.40 r=-0.486
WOM 2000h	-	-	-	-0.30 r=-0.313

Summary

The degree of changes in gloss correlates well with the outdoor exposure, while the changes in colour show no correlation whatsoever. The same kind of damage is not generated by the two accelerated test methods. Linseed oil deteriorates much more rapidly in the accelerated tests than in real life conditionsich as has already been observed in other investigations carried out at SP.

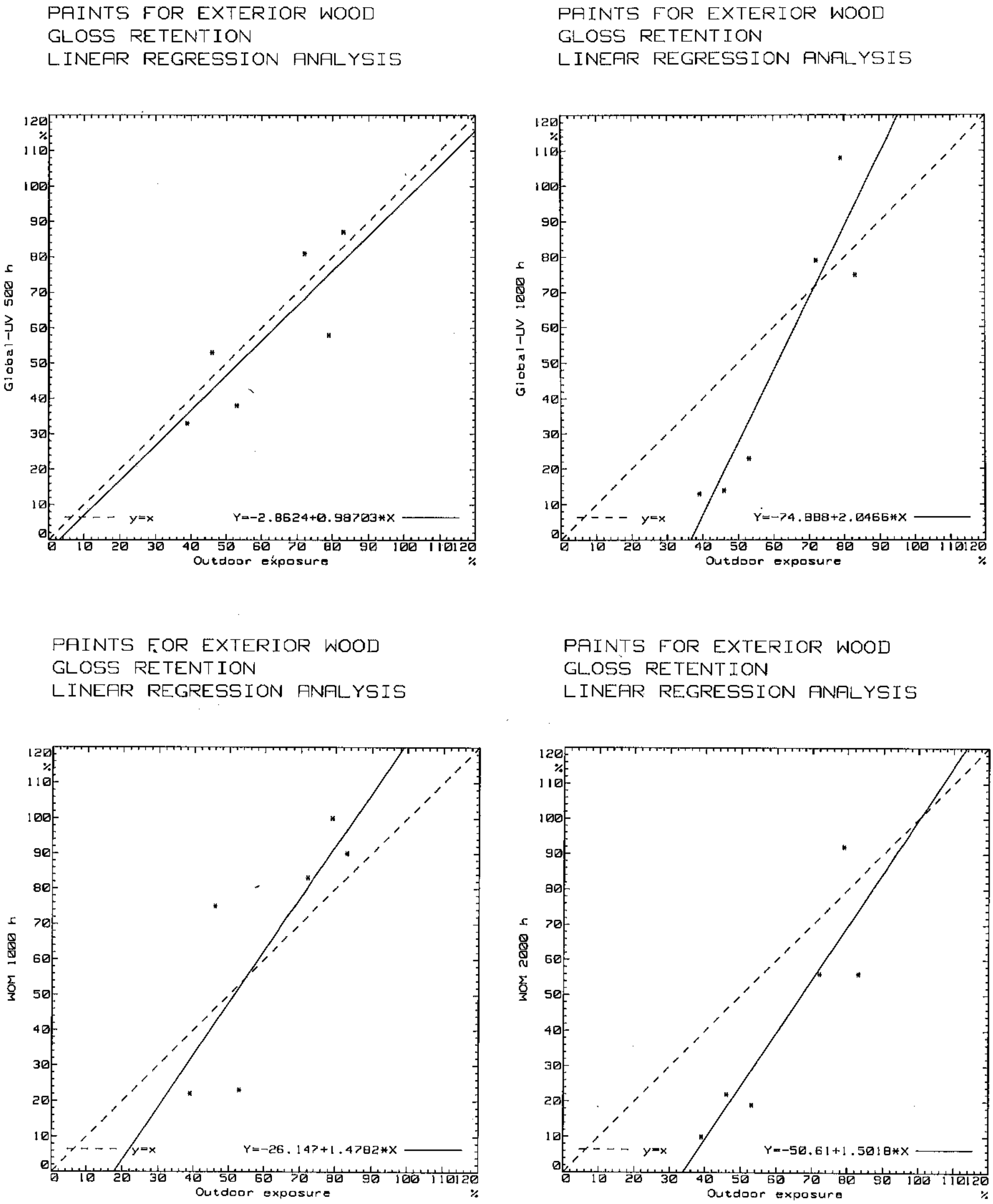

Fig. 11 Plott of data

APPENDIX A

Regression analysis

The correlation of measured values to a straight line so called linear regression is a very common way of evaluating data.
In this case the absolute values of the change in gloss or colour at one exposure period in the accelerated equipment were plotted against the values achieved during outdoor exposure or for another accelerated exposure period. For the ideal case, the values should form a line with the deviation of 1 that pass through the zero point. But as the tests were run for specific time periods, not to a certain change in gloss, the line could not be expected to pass through zero but should be parallel to such a line. However to use absolute values when evaluating weathering can be a somewhat awesome task. Even when objects are exposed at the same outdoor site, the size of the absolute values can vary between different exposures.

Spearman rank correlation

Bearing the above in mind, ranking may be regarded as a more accurate method of evaluating the correlation between different methods of weathering. The scale of measurement can be stretched differently for different methods but the ranking can still remain the same, thus a perfect correlation can be achieved without a strict linear relationship between the measured parameters.

Ranking means that all test objects are numbered from 1 to n according to their performance in the test. The Spearman rank coefficient R is calculated by the expression:

$$R = 1 - \frac{6\,S(d^2)}{n^3 - n}$$

Where $S(d^2)$ is the sum of the squares of the rank differences and n the number of ranked members in the group.

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