Scenarios for Atmospheric Corrosion in the 21st Century

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Much effort has been expended in the past few decades in the attempt to link the degradation of materials exposed to the atmosphere to the causative agents responsible for the degradation.[1,2] The utility in doing so is primarily to understand the cause and effect relationships involved in the atmospheric corrosion process. That goal has been slow to realize, since not until the 1990s were exposures made simultaneously with measurements of environmental parameters at the same site.[3] The data that resulted made it apparent that the response of materials to various atmospheric parameters can be very different, and that quite extensive measurements are required in order to relate damage at a particular location to the causative agents involved.

With the availability of these empirical relationships between materials damage and causative agents, a new goal can be envisioned, that of predicting the rates of damage at some future time. One wishes to know, for example, whether the rate of atmospheric corrosion of copper in a particular location is likely to increase, decrease, or remain about the same for the next 20 or 30 years. Such predictions will require that estimates be made of the values of the relevant atmospheric parameters at that time. Obviously, such estimates can be no more than guidelines to future situations, but they may help to indicate certain engineering choices or policy frameworks that can minimize materials damage under a variety of possible future scenarios.

In this paper, a first step is taken toward this predictive goal. The approach is to utilize the recently derived "dose-response" materials rela-

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tionships together with estimates of future atmospheric parameters from a global environmental assessment model. The results suggest that specific materials choices or policy approaches may be particularly desirable in certain geographical regions during the 21st century.

Dose-Response Functions

The standard approach to deriving dose-response functions utilizes as the effect of interest the rate of corrosion, and as the cause one or more atmospheric corrodants; the former is often termed the "response" and the latter the "doses." Mathematically,

$$R = f[C_i] \qquad (1)$$

where the square brackets indicate concentration, where i is the corrodant index, and where the function relating the damage to the doses remains to be specified.

It is now widely apparent that atmospheric corrosion is related not to a single corrodant, but to many, and the chemical and physical interactions among the corrodants are very complex and not yet fully elucidated. A simple conceptual inadequacy exists for measures of damage, which have been expressed in a number of quite different ways. As a consequence, scientists have searched empirically for many years to establish approximate functional relationships between variables that may or may not be mechanically optimum. The difficulties are greatly compounded by data limitations. Many of the corrodants and the resulting effects on materials are analytically determined only with great difficulty, as concentrations tend to be low, variations substantial, and corrosion times long. From a practical standpoint, therefore, the empirical search for a damage function must use whatever information is available without knowing for certain whether that information is appropriate to the task.

Attempts to apply Eq. 1 to particular systems have made it clear that both physical and chemical factors are involved. Table I lists and comments upon those that have, from time to time, been used in dose-response function studies. The entries reflect both the data available for study and the investigator's conjecture as to what might be important. Indeed, in its general expression, the damage function may have a form something like[4]

$$R_m = f(K, [H_2O], T, M)\, k_{i,m}[C_i] \qquad (2)$$

where R_m is the rate of damage of material m; K is a mass transfer coefficient; $[H_2O]$ is some appropriate measure (involving relative humidity, precipitation rate, time of wetness, etc.) of available water on the material surface; T is the ambient temperature; M is an appropriate parameter of material morphology; and $k_{i,m}$ is the rate of reaction between corrodant i and material m.

So far we have said little about how response is measured, but that determination also turns out to be problematical. Some alternative measures of response are given in Table II. If the material in question is part of an electrical circuit, conductivity may be the crucial property. If it comprises a cultural artifact, the degradation of visual appearance may be the property of interest. If it is part of a structure, corrosion fatigue may need to be predicted. These different types of damage are related to very different characteristics and spatial regions of the materials themselves.

In practice, of course, information in the detail suggested by Eq. 2 is never available, and researchers have resorted to substantially simplified versions of the dose-response function. Some parameter related to water, generally the average relative humidity or time of wetness over a specified time period, is almost universally chosen. Nearly as common a choice is the average concentration of sulfur dioxide (SO_2), a widely

Table I. Characteristics of Dose Parameters Used in Dose-Response Function Studies.

Parameters	Phase	Typical Unit	Routinely Measured at Monitoring Sites	Comments
Chemical Factors				
SO_2	Gas	ppbv µm	Yes	Fossil fuel combustion and smelting are major sources
NO_2	Gas	ppbv µm	Yes	Fossil fuel combustion is a major source
O_3	Gas	ppbv µm	Yes	Principal product of smog chemistry
H_2S	Gas	ppbv µm	No	Normal atmospheric concentrations very low
H^+	Liquid	µm eq/l µm	Yes	Approximates $2[SO_4^{2-}]+[NO_3^-]$
Cl^-	Liquid	µm/l µm	No	Invariably higher near the oceans
SO_4^{2-}	Liquid	µm/l µm	No	Related to SO_2
NO_3^-	Liquid	µm/l µm	No	Related to NO_2
Ca^{2+}	Liquid	µm/l µm	No	Related to soil dust and construction debris
Airborne particles	Solid	µm g/m^3 µm	Sometimes	Great diversity in size and chemical content
Physical Factors				
Materials Morphology	Solid	Variable	No	Porosity, mineralogy, hardness, etc.
Materials Susceptibility	Solid		No	Degree of inherent chemical reactivity between material and corrodant
Relative Humidity		%	Yes	
Precipitation flux	Liquid	µm/hr	Yes	
Time of wetness		hr	No	Corrosion-related instrumentation needed
Precipitation conductivity	Liquid	mho/m	No	A measure of ion content
Temperature		°C	Yes	

measured gas whose presence invariably results in corrosion to some degree. As a result, the literature will often present a dose-response function of the form:

$$R = A [RH] + B [SO_2] \qquad (3)$$

or some variation thereof. The correlation coefficients of the fitted equations are seldom high enough to suggest their general utility.

Thus, despite considerable qualitative understanding of the relationships between corrodants and materials, the quantitative situation is clearly marginal if we wish to derive dose-response functions useful for predictions. Perspective on the state-of-the-art is provided by a review of some careful and detailed field studies, which are discussed below.

Dose-Response Function Experience in the UN/ECE Programme

The most comprehensive program designed to gather data from which to generate dose-response functions is

Table II. Characteristics of Response Parameters Used in Dose-Response Function Studies.

Parameter	Typical Unit	Comments
Weight loss rate	µm/yr	Measurement destroys sample
Weight gain rate	µm/yr	Continuous measurement possible
Film thickness	µm (or µm/yr)	Measurement destroys sample
Recession rate	µm/yr	Thickness decrease often nonuniform
Contact resistance	mΩ	Continuous measurement possible
Visual appearance		Difficult to quantify

that of the United Nations/Economic Commission of Europe (UN/ECE), which has exposed a variety of materials for periods of up to eight years at 39 sites in Europe and North America.[3] Weather parameters, precipitation frequency, precipitation chemistry, and ambient corrosive gas concentrations were measured simultaneously. Dose-response functions were derived both at individual sites and for the group of sites as a whole; the functions varied widely in degree of complexity. The simplest was for nickel exposed at a single site within a cabinet to which ambient air had access; it was

$$R = 2.4 \, t \, [SO_2] \qquad (4)$$

where R is the corrosion rate expressed as mass loss (µg/cm^2), t is the exposure time in years, and $[SO_2]$ is the average outdoor concentration in µg/cm^3. (Within the cabinet the concentration is typically five times lower than outside, but the cabinet concentration is not routinely measured and is not part of the empirical dose-response analysis.) Nearly

as simple as the dose-response relationship for nickel are the relationships for sandstone and limestone exposed at a single site in unsheltered conditions

$$R_{sandstone} = -30\ t\ (0.0085\ [SO_2]) + 1.9 \times 10^{-4}\ Rain \qquad (5)$$

$$R_{limestone} = -30\ t\ (0.0071\ [SO_2]) + 2.4 \times 10^{-4}\ Rain \qquad (6)$$

where the rates are expressed in the total thickness decrease in μm over the period of the exposure and Rain is the amount of precipitation that fell at the site (in mm) over the exposure period. Because the rain term in each case turns out to be minor compared with the sulfur dioxide term, Eqs. 5 and 6 are very nearly linear with [SO$_2$].

The potential complexity of the damage functions is exemplified by that for unsheltered cast bronze derived from data taken at all sites. It is

$$R_{Br,\ unsh} = 0.026\ [SO_2]\ 0.44\ RH\ exp\ \{0.060\ (T\text{-}11)\ t^{\ 0.86} + 0.029\ Rain\ [H^+] + 0.00043\ Rain\ [Cl^-]\ t^{\ 0.76} \qquad (7)$$

where RH is relative humidity (%), T is temperature (°C), and [H$^+$] and [Cl$^-$] are ionic concentrations in precipitation (mg/l). In some cases, a dose parameter is important only for one or two materials. In the UN/ECE study, ozone was a factor of significance only for copper and tin, nitrogen dioxide only for glass.

The significance of these results is that if measurements or estimates of the independent variables (the doses) in any of the above equations are available, the dependent variables (the responses) can be calculated. For corrosion rate predictions where complex relationships involving several independent variables are required, such as for unsheltered copper, the input requirements are obviously more extensive than for a simpler relationship such as those of Eq. 4-6 for nickel, sandstone, and limestone. To illustrate the approach, therefore, the dose-response functions that are linear or nearly linear in SO$_2$ are particularly appropriate.

Emissions and Concentrations of Corrosive Gases

The Emissions Inventory Concept—Assessments of air quality are based in part on estimates of the fluxes of species emitted into the atmosphere: the so-called "emissions inventories." Inventories are required for a variety of uses, and, in consequence, have been prepared at a variety of spatial resolutions, species detail, and accuracy.

All emissions inventories ultimately seek to compute emission rates from a formula of the type[5]

$$E_{i,\Delta t,A_{x,y}} = \sum_t \sum_{A_{x,y}} \sum_s N_{s,A_{x,y}}\ U_{s,A_{x,y},t}\ \Theta_{s,i,t} \qquad (8)$$

where $E_{i,\Delta t,A_{x,y}}$ is the emission rate of species i over time interval Δt over an area specified by the coordinate x and y, $N_{s,A_{x,y}}$ is the number of sources of type s in area $A_{x,y}$, $U_{s,A_{x,y},t}$ is the time-dependent usage given to source s in area $A_{x,y}$, $\Theta_{s,i,t}$ is the flux of species i from source s at time t. Flux terms are sometimes called "emission factors."

The basic step in inventory construction is, of course, to decide which species are of interest, what geographical area is of concern, and what sources are to be identified and counted. This portion of the emissions inventory process is basically a detailed and exacting exercise in accounting.

The evaluation of the flux terms, $\Theta_{s,i,t}$ is an exercise not in accounting, but in science, engineering, or both. The central question is the rate of emission of species i given a particular source and set of conditions (type of fuel, ambient temperature, etc.). The answer to this question may involve *in situ* sampling of industrial processes, field measurement of natural processes, and the like. The process is as complex as the accounting functions involved in inventory development but requires different professionals with different skills.

Contemporary Sulfur Dioxide Emissions—Anthropogenic emissions of SO$_2$ are almost entirely the result of the combustion of sulfur-containing fossil fuels and the smelting of metal sulfide ores. Major emitting sectors include coal combustion, especially in large power plants, and combustion of residential fuel oil. In deriving an emissions inventory, the approach is generally to quantify fossil fuel combustion emissions from a combination of national inventory information and energy use statistics. Smelter emissions are identified and included on a facility by facility basis. Most recent efforts have produced gridded inventories, which have required that population or energy consumption or both are used to allocate emissions to specific geographical areas.

The most complete and encompassing inventory of these emissions currently available uses a sequential approach.[6] First, the global inventory is gridded to 1° by 1° on the basis of economic data for sulfur-emitting activities, emission factors, and information on sulfur recovery. Next, in geographical areas where detailed inventories have been performed (South Africa, North America, etc.), the basic inventory is replaced by the detailed, locally-generated data. Finally, major stationary sources such as power plants and smelters are added in

for regions such as the former Soviet Union, where suitable national inventories are not available. The overall result for global sulfur emissions in epoch 1985 is an anthropogenic emissions estimate of about 65 Tg S yr^{-1}.

Converting Emissions Rates to Concentrations—Once emissions rates are established, a suitable spatially-discretized model of atmospheric chemistry is needed to convert emissions into concentrations, because it is the latter that are utilized in the dose-response functions. It is beyond the scope of this discussion to describe such models in detail; useful explications are given elsewhere.[7,8] However, it is important to recognize that there are three main components. The first is the source rate of the species of interest, given by the emissions inventories discussed above. The second is a formulation of atmospheric motions and species transport, which is derived from meteorological information. The third is a calculation of loss rates, both chemical (*i.e.*, reactions with other atmospheric species) and physical (*i.e.*, losses to surfaces such as buildings, statuary, or soil).

Scenarios for 21st Century Corrosion

Can one hope to generate accurate predictions of corrosion rates for the 21st century? Unfortunately not, because atmospheric corrosion rates depend on the atmospheric concentrations of corrodants and those in turn depend on the activities of our technological society: how rapidly different countries and industrial sectors develop, what technologies are employed, how much attention is paid to pollution prevention, and so forth. Nonetheless, there is a good qualitative picture, at least, of the relationships between corrodants and materials and the fluxes to the atmosphere of those corrodants are known reasonably well. It turns out that though it is not possible to predict, it is possible to construct scenarios of possible futures that reveal interesting possibilities for the corrosion rates of the future.

Scenarios are detailed, carefully constructed stories that describe plausible alternative futures. They are not predictions, but rather are descriptions of possibilities. Their value is that they permit scientists, managers, policy makers, or other interested individuals to explore the potential consequences of different potential development paths. Scenarios have been used, for example, to guide corporate planning,[9] to explore the impacts of climate change,[10] and to investigate alternative paths of global development.[11] In this article, they are

<table>
<tr><th colspan="2">Table III. World Regions in the IMAGE2 Model.</th></tr>
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Table III. World Regions in the IMAGE2 Model.

1. Canada
2. U.S.
3. Latin America
4. Africa
5. OECD Europe
6. Eastern Europe
7. Coalition of Independent States (former USSR)
8. Middle East
9. India plus South Asia
10. China plus centrally-planned countries
11. East Asia
12. Oceania
13. Japan

Table IVa. World Regions SO$_2$ Emissions (TgS/yr) for Development Scenario S50.

Region	$[SO_2]_{1990}$	$[SO_2]_{2010}$	$[SO_2]_{2050}$	$[SO_2]_{2100}$
1	1.4	1.3	0.9	0.6
2	10.9	7.5	6.3	4.4
3	3.5	5.3	7.0	6.9
4	2.4	3.7	8.3	20.6
5	9.0	4.1	3.4	2.7
6	5.3	3.1	2.9	2.4
7	10.8	11.4	8.6	7.4
8	2.4	4.2	5.5	10.0
9	1.9	5.6	10.9	21.3
10	11.7	24.6	23.1	35.3
11	2.3	5.7	4.7	7.9
12	1.1	2.3	0.8	0.6
13	0.4	0.2	0.2	0.2

Table IVb. World Regions SO$_2$ Emissions (TgS/yr) for Development Scenario No Controls.

Region	$[SO_2]_{1990}$	$[SO_2]_{2010}$	$[SO_2]_{2050}$	$[SO_2]_{2100}$
1	1.4	2.1	1.5	1.1
2	10.9	18.6	16.2	11.3
3	3.5	5.3	14.0	13.8
4	2.4	3.7	16.5	41.1
5	9.0	12.2	10.6	8.3
6	5.3	9.5	13.8	11.4
7	10.8	12.8	17.0	14.7
8	2.4	4.3	11.0	20.1
9	1.9	5.6	21.7	42.7
10	11.7	24.6	46.1	70.7
11	2.3	5.7	9.5	15.7
12	1.1	2.3	1.6	1.2
13	0.4	0.6	0.8	0.9

used to present possible future trends in atmospheric corrosion.

Future Sulfur Dioxide Emissions and Concentration Scenarios—For the generation of future emissions scenarios, it is possible to make use of results from the IMAGE2 integrated model of the global environment, a tool that has been used for a decade to provide a disciplinary and geographic overview of global environmental change. The current version of the model is described by Alcamo[9] and the generation of baseline scenarios of global environmental change by Klein Goldewijk and Batjes.[11] The model is briefly described as follows: "Assumptions about population, economy, and economic activity are the driving forces… Based on these assumptions, IMAGE2 computes future changes in the consumption of energy, food, and timber. This consumption leads to emissions to the atmosphere from fuel combustion and industrial production, shifts in land use and land cover, and changes in the fluxes of gases from the terrestrial environment. The emission and fluxes of gases lead to changes in the atmospheric compositions of the various gases…". The calculation ignores natural sources of SO_2 such as volcanoes, but their fluxes are known to be modest compared with anthropogenic sources, especially over time scales longer than a few days or weeks.[13]

Two alternative development scenarios have been developed by the IMAGE modeling team to address emissions and impacts of SO_2.[12] They are:

• *Development Scenario S50*—a scenario that takes into account planned reductions in SO_2 emissions in industrialized regions around the world, as well as a 50% reduction in SO_2 emission factors between 2000 and 2050 for other areas.
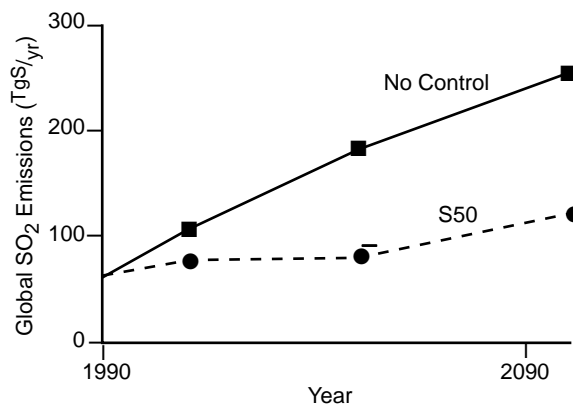

FIG. 1. *Global SO$_2$ emissions from 1990 to 2100 under Development Scenarios S50 and No Control.*

• *Development Scenario No Control*—an extreme benchmark scenario that assumes no new control measures on SO_2 emissions in any region after 1990.

The IMAGE2 model performs its calculations for 13 world regions, described by title in Table III. This spatial resolution is adequate for our purposes (and, given the estimation approach, could not reasonably be more detailed). Table IV lists the SO_2 emissions for the 13 regions under each of the development scenarios. The global quantities are, of course, given by summing those of the regions; they are illustrated in Fig. 1. Under Development Scenario S50, the global flux of SO_2 increases over the century by about a factor of two, from 63 TgS to 120 TgS. Development Scenario No Control increases the global SO_2 flux by about a factor of four.

The SO_2 emission changes that occur over time from region to region are quite different from the global total. Figure 2 plots the values for four of the 13 regions under Development Scenario S50. The U.S., currently the top region, is predicted to decrease emissions substantially over time. Japan's changes are nearly as dramatic from a percentage standpoint, though it starts at a much lower emissions level. The patterns for the China and India regions are very different. Starting from moderate emission levels in China and low levels in India, they are projected to become two of the three highest-emitting SO_2 regions by the year 2100 (Africa is the other). The increases are even more dramatic under the No Control scenario (not diagrammed, but given numerically in Table IVb).

Generating Future Corrosion Scenarios—As indicated above, the relationship between the emissions of a reactive atmospheric gas and its subsequent ambient concentrations is a complex function of atmospheric chemistry and physics. For the present purpose, however, it is satisfactory to sidestep this complexity and envision a simpler approach. Realizing that ratios of corrosion rates are more reliable values than the rates themselves, let R be the ratio of a dose-response function in the 1990 time frame to that in, for example, 2050. It is also assumed that the ratios of SO_2 emissions to concentrations will be constant region to region, which is at least approximately correct. Utilizing Eq. 4 for the corrosion of nickel, one can then write for a given region r:

$$R_r = R_{2050} / R_{1990} = [SO_2]_{2050} / [SO_2]_{1990} \quad (8)$$

where R_r is the atmospheric corrosion potential in region *r* for nickel in the year 2050 relative to that in the same region for the year 1990. The results of the calculations are given in Table V for the two development scenarios. Because the dose-response functions for sandstone and limestone are (approximately) also linear in SO_2, the same corrosion ratios apply to those materials.

Materials corrosion rates for Development Scenario S50 for four of the 13 regions are shown in Fig. 3. For Latin America and OECD Europe, no dramatic change in corrosion rates is envisioned. In the case of the Middle East, where development is expected to be rapid, rates of corrosion may increase by several times. For Africa, a rapid anticipated industrialization in the latter half of the 21st century will raise corrosion rates to nearly an order of magnitude higher than at present.
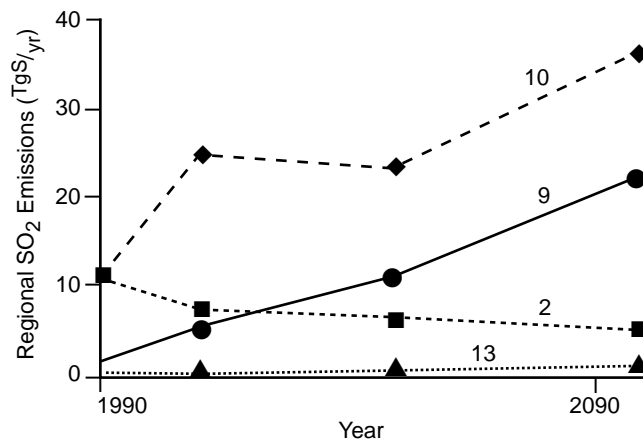

Fig. 2. SO_2 emissions under Development Scenario S50 for several regions: U.S. (Region 2), India plus South Asia (9), China plus centrally-planned Asia (10), and Japan (13).

Table Va. World Regions Nickel, Sandstone, and Limestone Corrosion Rates (Relative to 1990) for Scenario S50.

Region	[R]$_{2010}$	[R]$_{2050}$	[R]$_{2100}$
1	0.9	0.6	0.4
2	0.7	0.6	0.4
3	1.5	2.0	2.0
4	1.5	3.5	8.6
5	0.5	0.4	0.3
6	0.6	0.6	0.5
7	1.1	0.8	0.7
8	1.8	2.3	4.2
9	3.0	5.7	11.2
10	2.1	2.0	3.0
11	2.5	2.0	3.4
12	2.1	0.7	0.6
13	0.5	0.5	0.5

Table Vb. World Regions Nickel, Sandstone, and Limestone Corrosion Rates (Relative to 1990) for Scenario No Controls.

Region	[R]$_{2010}$	[R]$_{2050}$	[R]$_{2100}$
1	1.5	1.1	0.8
2	1.7	1.5	1.0
3	1.5	4.0	3.9
4	1.5	6.9	17.1
5	1.4	1.2	0.9
6	1.8	2.6	2.2
7	1.2	1.6	1.4
8	1.8	4.6	8.4
9	3.0	11.4	22.5
10	2.1	3.9	6.0
11	2.5	4.1	6.8
12	2.1	1.5	1.1
13	1.5	2.0	2.3

The situation is, of course, strongly dependent on the development scenario that is envisioned. Figure 4 pictures the relative corrosion rates for the China plus centrally planned Asia region and the India plus South Asia region under the two scenarios studied. For Development Scenario S50, the anticipated corrosion rate for the China region increases modestly (albeit from a rather

high 1990 level). For the India region, however, the growth is significantly more rapid. For the No Control scenario, the corrosion rates for both regions are approximately twice as high late in the century as are those for the S50 scenario.

An alternative way to look at corrosion rates is to compare them to those for Western Europe, a region with a strong record of emissions controls and a plan for further improvements. This comparison is made in Table VI for four regions expected to experience rapid industrial growth in the middle and latter portions of the 21st century: Africa, Middle East, India region, and China region. Depending on the region and the scenario, corrosion rates relative to those of Western Europe may be between two and 13 times higher. For most materials, such rates are likely to be untenable. It is clear that developing countries, should they industrialize as anticipated during the next century, will witness very much increased rates of corrosion than are now the case unless stringent air pollution control technologies are employed.

The calculation obviously could be repeated for materials with more complicated dose-response functions, should scenario models be developed that can predict such necessary parameters as ozone concentration and precipitation chemistry for each of the world's regions. For present purposes, however, that level of detail is probably unnecessary. Since most corrodants follow similar trends, it appears reasonable to anticipate that the corrosion futures for all susceptible materials will be qualitatively similar.

Discussion

Atmospheric corrosion has to date been largely a defensive science, one of choosing materials with corrosion resistance as high as possible consistent with materials performance and cost, and hoping that the environment in which the materials were used would be sufficiently benign that corrosion would be minimal. This empirical approach has yielded significant benefits but has not permitted much informed forward-thinking. Now, with the availability of well-established dose-response functions and scenarios representing a reasonable spectrum of possible environmental futures, we can begin to define a family of possible lifetime performance outcomes for specific materials. These outcomes differ with epoch and with geographical location, and clearly some future scenarios, some time scales, and some regions are more problematic than others.

Conclusion

The use of materials in the next half-century may increase to three times today's levels, with concomitant increases in the rates of emission of cor-
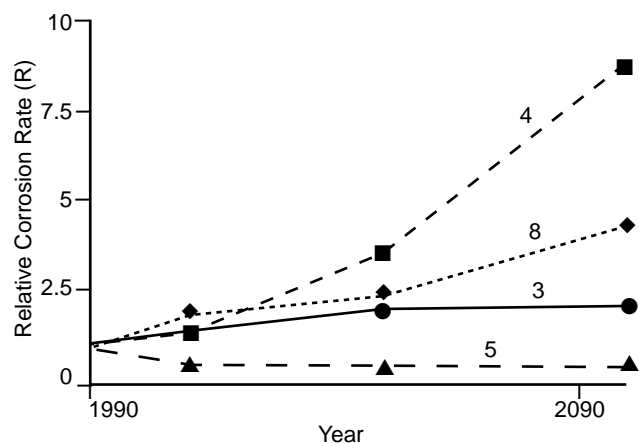

FIG. 3. Nickel, sandstone, and limestone corrosion rates relative to those in 1990 under Development Scenario S50 for several regions: Latin America (3), Africa (4), OECD Europe (5), and Middle East (8).
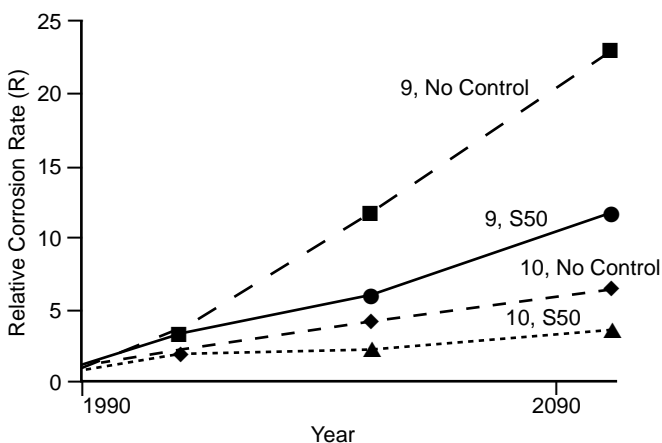

FIG. 4. Nickel, sandstone, and limestone corrosion rates relative to those in 1990 for India plus South Asia (9) and China plus centrally-planned Asia (10) for Development Scenarios S50 and No Control.

Table VI. Ratios of Selected Region Corrosion Rates for Nickel, Sandstone, and Limestone Relative to those of OECD Europe.

Region	1990	2010	2050	2100
Scenario S50:				
Africa (4)	0.3	0.9	2.4	7.6
Middle East (8)	0.3	1.0	1.6	3.7
India plus South Asia (9)	0.2	1.4	3.2	7.9
China plus centrally-planned Asia (10)	1.3	6.0	6.8	13.1
Scenario No Control:				
Africa (4)	0.3	0.3	1.6	5.0
Middle East (8)	0.3	0.4	1.0	2.4
India plus South Asia (9)	0.2	0.5	2.1	5.1
China plus centrally-planned Asia (10)	1.3	2.0	4.4	8.5

rosive gases and thus of material corrosion rates. We have built on two scenarios for possible development paths over the next century to apply dose-response functions for corrosion to 13 global regions, and determine possible corrosion rates in those regions relative to those for 1990 for nickel, limestone, and sandstone. The results suggest that in world regions where development is expected to be rapid (*e.g.,* the Indian subcontinent, the Middle East, Africa, and China and its environs), rates of corrosion could increase by an order of magnitude or more.

In general, the results in this paper indicate that the most rapid and severe changes in corrosion rates seem likely to occur in what is currently the less developed world, especially Asia, Africa, and the Middle East. Of special concern in those regions in the next several decades may be those corrosion-susceptible objects, which are essentially irreplaceable—objects of art—particularly those in outdoor locations. Curators of those objects—decorated buildings, statuary, monuments, and the like—might well be advised to employ the full spectrum of protective technology available, such as surface coatings. They should also become advocates for development policies that do not compromise the local environment, for objects of art as well as objects of technology are among the products of society that may otherwise disappear. ∎

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Centennial Moment

THE ELECTROCHEMICAL SOCIETY • 1902–2002 — **100**

Who delivered the first lecture at a Society Plenary Session?

Leo Brewer delivered the first one at the 137th ECS Meeting in Los Angeles, California, May 11, 1970. His topic was "Electrons—The Universal Glue." Born in 1919, Dr. Brewer is Professor Emeritus at the University of California, Berkeley. Among his numerous awards, he has received the ECS Olin Palladium Medal (1971) and the ECS Henry B. Linford Award for Distinguished Teaching (1988). He joined the Society in 1956. The "Highlights for Los Angeles" (*J. Electrochem. Soc.*, **117,** 148C, April 1970) noted that Leo Brewer "has systematically attacked important chemical problems at high and very high temperatures by his experimental and theoretical means. His approach includes an unusual array of techniques from the arsenal of modern chemistry, physics, and metallurgy, combined with a great imagination and a keen judgment of critical factors." Since 1970, Dr. Brewer has gone on to "attack" even more chemical problems. More information about Dr. Brewer may be found at www.cchem.berkeley.edu/~chemgrad/emeriti/emeriti.html.