

FOREWORD

The 4th International Symposium on High Temperature Corrosion and Protection of Materials, attended by over 190 participants, from twenty six nations, was held at Les Embiez, France, May 25-29, 1996. This truly international meeting, fourth of a series of Colloquia devoted to environmental behavior of materials and coatings in aggressive environments, continues to demonstrate the strong technical interest and importance of the subject matter, which is of vital economic concern for the transportation, energy generation, and chemical processing industries in the developing as well as the developed nations of the world. The dual thrusts of conservation of resources and protection of the environment have strongly influenced the tone of the technical submissions and thus reflect a world wide concern.

These Proceedings contain 115 contributions, by 308 authors, selected from the nearly 180 papers submitted. The format of this Proceedings breaks with the usual (and sometimes tedious) presentation following the usual series of themes found in any Conference on High Temperature Corrosion and Coatings. In this conference we have introduced an approach in which the papers presented are arranged to follow the life of the materials under the attack of a corrosive environment, from diagnosis of the attack, to the identification of the problems of materials degradation and to the approaches developed to address the solution of these problems. This has resulted in the following six chapters of the Proceedings.

1. Fundamentals of high temperature corrosion and special experimental technics
 - Metals and Alloys
 - Intermetallics
 - Special Experimental Technics
2. The Failure of the Protective Oxide
 - The Oxide-Metal Interface: Stress Generation, Oxide Cracking, and the Reactive Element Effect.
 - Interactions Between Corrosion and Mechanical Stress or Strain.
 - Wear and Erosion-Corrosion
3. Some Examples of the Problems
 - Industrial Applications; Complex Alloys in Complex Environments.
 - Corrosion in the Liquid State
4. How to Overcome These Problems?
 - Coatings (Other than TBC).
 - Ceramics, Ceramic Matrix Composites.
5. The Next Step : Thermal Barrier Coatings.
6. Data banks (Data generation, databases and expert systems)

A plenary session convened the participants with six lectures: "Mathematical modeling of alloy oxidation" (by F. Gesmundo), "The oxidation of alumina-forming alloys" (F. H. Stott), "Oxidation of intermetallics" (H.J. Grabke), "Fundamental aspects of reaction at the metal/scale interface during metal scaling" (B. Pieraggi), "Some practical aspects of corrosion and coatings in high temperature technology" (H.W. Grünling), "Oxidation and corrosion of silicon-based ceramics and composites" (N.S. Jacobson). These presentations set the tone and focal point of the subsequent sessions, some of which were introduced with a keynote lecture highlighting topics of special interest and presented by a well recognized expert in the topical area.

Poster papers were summarized in oral review sessions, and many were selected for inclusion in these Proceedings. All of the papers chosen for the proceedings were subject to thorough peer review by members of the Advisory and Executive Committees and conform to the standards of "Materials Science Forum". This Proceedings will act as a basis to identifying future research directions in this technically important area.

**Roland Streiff, John Stringer,
Richard Krutenat, Marcel Caillet.
and Robert A. Rapp
Guest Editors of the Symposium**

AVANT PROPOS

Le 4ème colloque international sur "La corrosion et protection des matériaux à haute température" s'est déroulé aux Embiez, France, du 20 au 24 mai 1996. Plus de 190 participants venant de 26 pays y ont participé. Ce congrès véritablement international a montré à nouveau le grand intérêt technique et l'impact économique des thèmes retenus, que ce soit dans le domaine des transports, dans les systèmes producteurs d'énergie ou dans l'industrie chimique. Les articles proposés reflètent bien le fait que les recherches conduites dans ces domaines sont influencées par la double nécessité de maîtrise des ressources énergétiques et de protection de l'environnement. On le voit, il s'agit de travaux intéressants aussi bien les nations économiquement avancées que celles en voie de développement.

Ces Actes contiennent 115 articles, de 308 auteurs, sélectionnés parmi près de 180 communications proposées. La présentation de ces actes se distingue des habituelles (et parfois fastidieuses) organisations qui suivent les thèmes classiques que l'on retrouve dans tout colloque sur la corrosion à haute température et les revêtements. Dans ce colloque nous avons choisi de classer les différentes communications en suivant la vie des matériaux soumis à un environnement hostile, depuis le diagnostic de l'attaque jusqu'à l'identification des problèmes liés à la dégradation des matériaux et jusqu'aux propositions faites pour apporter une solution à ces problèmes. Ceci a conduit aux six chapitres suivants :

1. Aspects fondamentaux de la corrosion à haute température et techniques expérimentales spéciales.
 - Métaux et alliages,
 - Intermétalliques,
 - Techniques expérimentales particulières.
2. La défaillance des oxydes protecteurs.
 - L'interface métal-oxyde, la croissance de contraintes, la fissuration de l'oxyde et l'effet d'éléments réactifs,
 - Interactions entre corrosion et contraintes ou déformations mécaniques,
 - Usure et érosion-corrosion.
3. Quelques exemples :
 - Applications industrielles. Alliages complexes dans des atmosphères complexes.
 - Corrosion par une phase liquide.
4. Comment surmonter ces problèmes ?
 - Revêtements (autres que barrières thermiques).
 - Céramiques, composites à matrice céramique.
5. Revêtements barrières thermiques.
6. Les banques de données (production de données, bases de données, systèmes experts).

Six conférences plénières ont été présentées portant respectivement sur "Mathematical modeling of alloy oxidation" (par F. Gesmundo), "The oxidation of alumina-forming alloys" (F. H. Stott), "Oxidation of intermetallics" (H.J. Grabke), "Fundamental aspects of reaction at the metal/scale interface during metal scaling" (B. Pieraggi), "Some practical aspects of corrosion and coatings in high temperature technology" (H.W. Grünling), "Oxidation and corrosion of silicon-based ceramics and composites" (N.S. Jacobson). Ces conférences ont permis de bien positionner les travaux du colloque et leur répartition dans les sessions qui ont suivi, dont certaines étaient introduites par un exposé mettant l'accent sur des sujets d'un intérêt particulier et fait par un expert reconnu dans le thème correspondant.

Les communications par affiches ont été très brièvement résumées au cours d'une session orale. Plusieurs de ces communications par affiches ont été sélectionnées pour figurer dans ces Actes. Tous les articles de ces Actes ont été minutieusement revus par des membres du Comité Scientifique International ou du Comité Technique afin, notamment, de les adapter aux normes de "Materials Science Forum". Ces actes devraient constituer un ouvrage de référence pour déterminer les directions dans lesquelles il convient de faire porter les efforts de recherche pour ce domaine aux retombées industrielles importantes.

**Roland Streiff, John Stringer,
Richard C. Krutenat, Marcel Caillet,
et Robert A. Rapp
Coordinateurs des Actes du Colloque**

PREFACE

This series of Colloquia, of which this is the fourth, was initiated ten years ago. The first, under the title of "the International Symposium on High Temperature Corrosion of Materials and Coatings for Turboengines and Energy Systems" was held in Marseilles, July 7-11, 1986 with the primary aim of comparing the results of research being done in France and in the U.S.A. in this technically and scientifically important area. The interest which this first meeting stimulated in the international community of high temperature corrosion investigators resulted in a continuing series of Symposia with a wider geographical representation, although the importance of the French and American interaction has continued to be our principal objective. The three subsequent Colloquia in this series have all been held at Les Embiez, an island in the Mediterranean not far from Marseilles.

The papers submitted for each of the Symposia were reviewed by an International Advisory Board of distinguished contributors to the field, and selected for presentation at the meeting by an Executive Committee. A further review process selected from among those papers presented a number to be published in the Proceedings: this volume is the fourth of these.

The present Proceedings provides an opportunity to briefly overview the trends in the field of High Temperature Corrosion over the past decade as reflected in these Symposia: of what has been achieved and what are the current issues.

ISSUES IN THE FIELD OF HIGH TEMPERATURE CORROSION AS REFLECTED IN THE SYMPOSIA

The 1st Symposium on High Temperature was dedicated to the environmental behavior of materials and coatings in Energy Systems and in Turboengines. The aim of this symposium was to update our knowledge of the mechanisms of oxidation and hot corrosion reactions on the one hand, and to analyze the methods used to combat materials degradation especially through protective coatings on the other hand.

The response to the call of papers for the 1st Symposium was very high, and the papers submitted of high quality. On the basis of this, ten themes were identified, of unequal size; the chapters of the Proceedings, entitled HIGH TEMPERATURE CORROSION of Materials and Coatings for Energy Systems and Turboengines, the first Proceedings of the series, were named for these themes:

1. High Temperature Gaseous Corrosion-Enhanced Sulfidizing or Carburizing Oxidation (29)
2. Failure and Spalling of Protective Oxide Layers (8)
3. Enhancement of Attack by the Presence of Molten Salts (12)
4. Protective Coating Formulation and Application Techniques (6)
5. Ceramic Coatings (5)
6. Role of Coating Microstructure in Corrosion (5)

7. Post-Coating Treatments: Laser Irradiation and Ion Implantation Techniques (7)
8. Effect of Coating on the Mechanical Properties of the Substrate, Particularly in High- and Low-Cycle Fatigue, and Corrosion Fatigue (11)
9. Corrosion-Erosion (5)
10. Performance Experience of Coatings in Practice (4).

The numbers in parentheses after the section titles is the number of papers in each.

The purpose and themes of the second Symposium, which was held at Les Embiez, May 23-26 1989, was essentially the same as for the first Symposium, but the call for papers addressed to a broader range of materials than the superalloys which were the major concern of the first.

Safe and environmentally acceptable sources of energy continued to be matters of major concern for developed and developing countries. Since the first Symposium, concern over nuclear power stations slowed and even reversed the development of nuclear power in many countries. Limits on the emission of oxides of sulfur and nitrogen, associated with the acidification of rain, leading to forest damage and changes in the ecology of lakes, continued to tighten. The concern about the so-called "Greenhouse Effect" which arose at that time resulted in discussions of the possibility of limiting CO₂ emissions: in the case of heat engines, this places a premium on the improvement of thermal efficiency, and on the use of fuels with a high hydrogen-to-carbon ratio, such as petroleum, as opposed to those with a low ratio, such as coal.

In HIGH TEMPERATURE CORROSION II - High Temperature Corrosion of Advanced Materials and Coatings, the Proceedings of the 2nd Symposium, eleven themes were identified:

1. Fundamental aspects of corrosion by hot gases (16)
2. Failure and spalling of protective scales (20)
3. Hot corrosion and attack in the presence of molten salts (10)
4. Protective coatings, selection and application techniques (11)
5. Ceramic materials and thermal barrier coatings (8)
6. Surface modification treatment by high energy beams (10)
7. Interactions of corrosion and mechanical factors including erosion (10)
8. Mechanical properties of coated systems (2)
9. High temperature corrosion and erosion monitoring (2)
10. Performance of systems in practice (2)
11. Data banks and expert systems (2).

These topics differed a little from those for the first Symposium. Quality assurance for coatings was recognized as an important issue and thermal barrier coatings were expressly identified in this second Symposium. Surface modification methods, not solely as post-coating treatments, were identified. Finally, the new topic of data banks and expert systems was introduced.

In the first Symposium, problems related to the burning of low-grade fuels were of major interest, and there were several papers on molten-salt-accelerated high-temperature corrosion ("hot corrosion") and on mixed oxidant corrosion, relating to the problems of oxidation in the presence of second oxidants such as sulfur and carbon. It seems that the interest in these topics has diminished in the 2nd meeting. In the case of hot corrosion, there are probably two reasons for this: the understanding of the problem has developed to the point where operational limits and materials selection have been defined to the point where the impact of the corrosion has been minimized; and the need to use lower-grade fuels, which was emphasized in the Preface to the First Symposium, has not turned out to be as great as expected, in part due to the small changes in oil supply and price since then. The relative decline in the interest in mixed oxidant corrosion was less easy to understand, because the need to reduce NO_x emissions increased interest in staged combustion, with an initial substoichiometric stage. However, expectations were reduced in the high temperature capabilities of metals and alloys in these environments, and testing in gasification systems, for example, does not anticipate metal temperatures much in excess of 450°C . Similarly, the corrosion processes in fluidized bed combustors were recognized, and materials and design criteria to avoid the problems have been developed.

The interactions of minor elements in the oxidation process continued to be a major topic of interest. In the first Symposium eight papers addressed this issue: in the second Symposium, more than fourteen papers were concerned with this and related problems. Connected with this, the problems of scale adhesion and cracking have become of increasing interest, and were addressed in several papers in the second Symposium. Nevertheless, there was still no general consensus on the Reactive Element Effect.

The treatment of surfaces by high energy beams, including particularly laser beams, attracted much more interest in the second Symposium than in the first one: several papers relate to these topics.

In the first Symposium, we commented that the number of papers on ceramic coatings was less than we had expected, although the discussion was active. In the second meeting, many more papers addressed this issue, including five largely concerned with thermal barrier coatings. This reflected the increasing use of the coatings in practical applications, both in diesel engines and in gas turbines.

In the first Symposium only a few papers dealt with the microstructure of coatings. There was considerably more interest in this aspect in the second meeting. The same was true of minor constituents in the coatings: in the first meeting there was some discussion of the role of silicon, but in the second Symposium there was in addition discussion of the role of minor tantalum additions to coating properties, and of the merits of palladium as an alternative to platinum in modifying aluminides.

In the second Symposium the new area of data banks received significant interest, but there was little discussion of expert systems.

The third Symposium on High Temperature Corrosion which held at Les Embiez, May 25-29, 1992 was dedicated, as were the previous two Symposia, to the environmental behaviour of materials and coatings; but this time in any system and aggressive environment and for any materials. Thus the topics of the Proceedings, HIGH TEMPERATURE CORROSION and Protection of Materials III, differ somewhat from those for the earlier two

Proceedings, continuing an evolution in the Symposium topics which mirrors the changing priorities of the community.

The majority of the papers submitted fell into one of the following sixteen themes:

1. Mechanisms of Oxidation and Oxide Scale Growth (12)
2. Advanced High Temperature Materials (4)
3. Reactive Element Effect Including the Effect of Yttrium (11)
4. Sodium Sulfate Induced Hot Corrosion Including Sulfidation (4)
5. Oxidation of Steel (2)
6. Oxidation of Intermetallics Including Titanium Aluminides and Titanium Alloys (9)
7. Techniques and Experimental Methods (6)
8. Aluminide and Modified Aluminide Coatings (5)
9. Overlay Coatings (4)
10. Effect of Surface Modification by Laser Irradiation or Ion Implantation (7)
11. Thermal Barrier Coatings (2)
12. Erosion-Corrosion (3)
13. High Temperature Corrosion in Practical (or Industrial) Systems (12)
14. Refractory Materials, and Composites Including Silicon Coatings and Silicon Based Materials (11)
15. Effect of Mechanical Factors (7)
16. Data Banks and Modelling (3)

Safe and environmentally acceptable sources of energy continued to be matters of major concern for developed and developing countries. Since the second meeting, the concern over nuclear power in the developed nations increased, particularly in regard to the eventual waste disposal problems on decommissioning. Continuing concerns over the emissions of NO_x and SO_x from coal-burning electricity generation systems had led to progressive increases in environmental limits on these emissions, with the development of control systems which had significantly increased the cost of electricity. New concerns over the release of toxic trace elements from the coal, such as mercury, arsenic, and selenium, led to further environmental control measures. The debate over the "greenhouse effect" and global warming continued, and some control over CO₂ emissions seemed likely in some countries. This, together with the impact of fuel prices, placed additional premiums on high thermal efficiency in fossil fuel-burning systems. Another factor which became more important over the years from 1986 to 1992 was the increase in the estimates of availability of natural gas, and the consequent relaxation of legislation which restricted its use in power-generating systems. Since natural gas is methane, CH₄, its combustion results in much reduced CO₂ emissions compared to coal; sulphur is either absent or can be easily removed, and there is no fuel-bound nitrogen, so that emissions of NO_x and SO_x are also greatly reduced. These factors all pointed to the growing use of high-efficiency natural gas-fired electric generating systems, which in the next few years will mostly be advanced gas turbine-based combined cycles; later, advanced fuel cells may begin to play an important role. The growth in efficiency demanded of aircraft engines driven by the high prices of aviation fuel continued. All of these factors pointed to the increasing demands that will be placed on the high temperature components of these

advanced systems, and in particular on the combination of mechanical properties and oxidation and corrosion resistance.

The apparent decrease in research in molten alkali salt accelerated oxidation ('hot corrosion') continued, although interestingly it may become a significant damage mechanism for some parts of the newer advanced industrial gas turbines in the next few years, in particular for the MCrAlY bond coats below thermal barrier coatings. There was perhaps a little more on the topic in the third Symposium than in its predecessor, although mostly concerned with operational experience and alloy improvement: there was little discussion of the mechanism of the process, which probably supports the view that the overall mechanism is now well-understood.

There was reduced interest in the effect of coatings on the mechanical properties of alloys, probably because this topic was felt to be mature. The decline in interest in the problems associated with low-grade oil-derived fuels continued, probably because the environmental control requirements make them economically undesirable.

There were several papers dealing with oxide dispersion strengthened (ODS) materials and other powder metallurgical based materials, illustrating the growing importance of this class of materials.

The oxidation behaviour of low-alloy steels, and also of higher-alloy austenitics, received somewhat more attention in this third meeting. This may be a measure of the move to increase the process temperatures in systems where these are the materials of construction, and also of the economic pressures to increase their maximum use temperatures.

As usual, the Reactive Element Effect (REE) received a lot of attention in the third Symposium. This was perhaps more of a measure of the theoretical challenge presented by the Effect than of any potential improvement in its technical application: The procedure is already well-established in practice. However, the most important technical aspect of the REE is related to the adhesion and spalling resistance of protective scales on high-temperature alloys, an important topic which is currently receiving much more attention in the high-temperature oxidation community. This was reflected by an increase in the papers related to this aspect in the third Symposium; and the suggestion that segregation of certain impurities (notably sulphur) to the oxide/metal interface is important in weakening an inherently strong interface, originally proposed almost simultaneously by Ikeda in Japan, Smeggil in the USA, and Lees in the UK, continued to generate much discussion.

In the Preface to the Second Symposium, we noted that our understanding of the metal/oxide adhesion and the nature of the metal/oxide interface was poor, and we hoped that the next Symposium would address this topic in more detail. One paper reviewed the current situation in some detail, but relatively few other contributions were received relating to this important topic.

In both of the previous Symposia, we commented on the lack of papers dealing with the development of an understanding of the fundamental mechanisms of mixed oxidant corrosion. Once again, there was little concerned with this topic, although a few papers described practical situations where these processes were important. Several papers reported research on the sulphidation of a wide range of materials, ranging from very low sulphur partial pressures to pressures close to one bar. This was perhaps a little surprising, since in relatively few practical processes are materials exposed to sulphur in the absence of other oxidants, but it

may reflect an interest in the part process in the technically important areas of sulphidation/oxidation, or carburisation/sulphidation/oxidation corrosion.

Interest in the high-temperature oxidation and corrosion of intermetallics continued to grow. What was interesting is that the range of intermetallics of interest had increased: the iron and nickel-base aluminides were first joined by titanium aluminides, but also refractory metal intermetallics appeared to be becoming important. Indeed, after a lapse of several years the oxidation and corrosion behaviour of refractory metals, and zirconium and titanium, was again becoming of interest. This appears to be driven by advanced aerospace systems, including very high speed civilian transport aircraft.

More interest in advanced materials, including non-oxide ceramics, ceramic and metal-matrix composites, and carbon-based composites probably also represented an impetus from the aerospace industry, and searches for materials for the next generation of advanced gas turbines. For similar reasons, the interest in thermal barrier coatings, and their degradation by oxidation and corrosion (typically of the metallic bond layer between the coating and the substrate) continued to grow.

The more-conventional area of metallic coatings again was one of the largest in the Symposium, in terms of the number of papers presented. However, once again the number of these relating to quality control, inspection, remaining life assessment and repair techniques was less than the importance of these aspects would appear to warrant.

The important area of the interaction between corrosion and mechanical properties continued to receive significant attention. This included both the interaction of corrosion with creep, for example; and the interaction with wear processes such as erosion.

Several papers described high temperature corrosion experience in practical systems, and outlined the complex mechanisms involved. This was a most important development in this third Symposium compared to the previous two. Since the incidence of corrosion in industrial systems is a sensitive matter, it has often been treated in the past as a matter of commercial confidentiality, and the increased willingness of manufacturers and users to share their experience is very encouraging.

Finally, a group of papers reviewed the progress in establishing data banks for high temperature oxidation and corrosion.

THE TRENDS OF THIS SYMPOSIUM

The aim of the present Fourth International Symposium on High Temperature Corrosion and Protection of Materials held at Les Embiez, May 20-24, 1996, is essentially the same as for its predecessors, that is to say, to update our knowledge of the degradation processes of high-temperature materials related to chemical interactions with the environment on the one hand, and to analyse the methods used to combat this degradation, particularly through protective coatings and surface treatments, on the other. However, in a further move to continue the broadening of the range of environmental interactions considered by these Symposia, the minimum temperature range of interest was lowered to 400°C. In the meantime, the presentation of the papers in this Proceedings breaks with the usual, (and sometimes tedious) presentation following the usual series of themes found in any Conference on High Temperature Corrosion and Coatings. In this conference we have introduced an

approach in which the papers presented are arranged to follow the life of the materials under the attack of a corrosive environment, from diagnosis of the attack, to the identification of the problems of materials degradation and to the approaches developed to address the solution of these problems. This has resulted in the following six chapters of the Proceedings.

1. Fundamentals of high temperature corrosion and special experimental technics (including Metals and Alloys - Intermetallics - Special Experimental Technics)
2. The Failure of the Protective Oxide (including The Oxide-Metal Interface:, Stress Generation, Oxide Cracking, and the Reactive Element Effect - Interactions Between Corrosion and Mechanical Stress or Strain - Wear and Erosion-Corrosion)
3. Some Examples of the Problems (including Industrial Applications; Complex Alloys in Complex Environments - Corrosion in the Liquid State)
4. How to Overcome These Problems? (including Coatings (Other than TBC). - Ceramics - Ceramic Matrix Composites)
5. The Next Step : Thermal Barrier Coatings.
6. Data banks (Data Generation, Databases and Expert Systems)

Safe and environmentally acceptable sources of energy, at the lowest possible cost, continue to be matters of major concern for both developed and developing countries. In the developed nations, the concern over the environmental impact of nuclear power, particularly in regard to the disposal of high activity waste and the problems of decommissioning, continues to be a major issue. However, the concerns over the emission of hazardous wastes such as oxides of sulfur and nitrogen, and fine particulate matter from fossil fuel fired systems, have if anything increased over the last four years, as have concerns about the dispersion of wastes, specifically from coal-fired systems, containing materials such as arsenic, selenium, and particularly mercury. The debate over the effect of greenhouse gases, particularly CO₂, has also not clarified greatly. The view that the reserves of natural gas are much more extensive than had been believed, mentioned above in relation to the third Symposium, has developed and strengthened, encouraging further moves towards the use of natural gas as a fuel for electricity generation. The effect of this has been to make natural-gas fired high-efficiency combined cycle combustion turbines much more attractive to electricity generators than they have been in the past, and a new generation of large land-based turbines has emerged and is continuing to develop. These have steady-state inlet temperatures approaching the short-time peak temperatures in advanced aviation engines, and are hoped to attain significantly longer periods between maintenance outages and total lives. Advanced materials will be required, including very large single crystal superalloy first stage blades, with thermal barrier coatings and advanced cooling systems. Higher efficiencies of conversion are required for economic reasons, but this implies higher maximum temperatures for heat engines, and this can result in increased production of oxides of nitrogen. To remedy this, changes in the combustion system are required, and this can result in local low oxygen activities in the high temperature environments.

Electrochemical methods of generating electricity offer the possibility of high efficiencies without this being linked to a combustion process. However, for kinetic reasons these too may involve high temperatures: molten carbonate and solid oxide fuel cells are currently being developed, and these both present challenges for materials at high temperatures.

On the other hand, there has been some decrease in the interest in advanced coal conversion processes such as coal gasification, and in some of the alternative combustion processes, such as fluidized bed combustion. Combustion of biomass fuels has been receiving more attention, because these are regarded as neutral in terms of CO₂ emissions; and there is continuing interest in more efficient incineration.

For each Symposium in this series, the mixture of topics changes a little, reflecting the evolution of the subject and the changes in the industrial priorities. In this fourth Symposium, the decline in the interest in molten-salt accelerated oxidation ("hot corrosion") we noted in the third Symposium has continued; but it is possible that this may change in the future, since the corrosion at the interface between a thermal barrier coating and the MCrAlY bond coat appears to be an important issue, and molten salts may play a significant role in this. In the third Symposium, we commented that there were several papers relating to the oxidation and corrosion of ODS (oxide-dispersed strengthened) alloys, and it is interesting that this class of materials is essentially absent this year, although in engineering applications such as high-temperature heat exchangers there have been some significant developments recently.

We noted in the third Symposium that the interest in the high-temperature oxidation and corrosion of intermetallics continued to grow; and remarked on the wider range of intermetallics that were being studied. In this Symposium, there continued to be a significant interest in this class of materials. In practice, these materials have found application more in such uses as heat-treatment furnace furniture than in the more exotic aerospace applications mentioned in our Preface to the previous meeting; and their limitations appear to be more related to low-temperature hydrogen damage than high-temperature oxidation and corrosion, at least in the cases of the iron and nickel aluminides.

The conventional coatings and coating techniques continued to be subjects of interest. For the third Symposium we commented that the technically-important areas of quality control, inspection, remaining life assessment and repair techniques had received less attention than they warranted, and this continues to be true in the papers presented to the fourth Symposium, although the specialist literature shows that this field is receiving significant attention.

The significant - and welcome - increase in papers discussing high-temperature corrosion experience in practical systems, and reviewing the complex mechanisms involved which we remarked upon in the last Symposium was maintained in the current meeting.

We have been attempting to introduce important changes in the way technical meetings of this kind are run. We believe that the discussion of the ideas presented is an important part of the value of meetings of this kind: simple presentation of results can be more effectively - and certainly more cheaply! - be done through the use of printed material, perhaps in the future supplemented by e-mail. The point of collecting a number of specialists in a single place has to be the discussions between them; not simply one-on-one, but in groups. We believe that a poster session can do this much more effectively than the more conventional oral presentation; and the more challenging the ideas presented, the more this is true. It is very unfortunate that the scientific community has built up a culture in which having one's paper assigned for poster presentation is seen as being second class. At the third Symposium we therefore made a conscious effort to increase the importance of the poster sessions, to promote greater discussion of the results of investigations. In this Symposium, we went even further along this path. The number of papers presented in the oral sessions was reduced, and the time allowed for each paper was increased, to promote more plenary discussion, which

also has a significant part to play. The contributions of the speakers in limiting the lengths of their presentations, and the control exercised by the Chairpersons, allowed this to happen. The space for the poster sessions was increased to facilitate circulation, and the attendance at each of the sessions was very satisfactory. This is, in our view, the wave of the future for meetings of this kind: it is the interactions between the attendees, and the opportunity for in depth discussion of the research results presented that are the principal reasons for attending such Symposia.

This 4th International Symposium on High Temperature Corrosion and Protection of Materials was dedicated to the 85th anniversary of Professor Paul Lacombe, Honorary Chairman and former Chairman of the International Advisory Committee. One afternoon was devoted to paper presentation in his honor which included two keynotes and two papers, of which two were presented by two of his former students.

Overall, the response to the meeting continued to be very encouraging. 184 papers were selected for oral or poster presentation, and following careful refereeing, 115 were selected for publication in these Proceedings. 170 investigators from 26 different countries convened in les Embiez, including one from South Korea, one from Spain, two from Ireland, one from Morocco and one from Taiwan for participants from new countries and two from Australia, one from Brazil, seven from Japan, two from India, two from the People's Republic of China, three from Russia and one from Venezuela, for attendees coming from the farthest countries. The continuing increase of the number of papers published in the Proceedings also is a sign that this symposium has gained a premiere place in the high temperature community throughout the world. The first Proceedings of the series contained 93 papers. HIGH TEMPERATURE CORROSION II, 97 papers, HIGH TEMPERATURE CORROSION III, 105 and this volume amounts 115 papers.

Once again, this Preface cannot be concluded without paying tribute to those without whose help in organisation this Symposium would not have been held. First of all, deep gratitude is owed to the significant efforts and dedicated help of the members of the Executive Committee, including Dr. S. Alperine, Dr. Y. Bienvenu, Dr. C. Cabrillac, Dr. M. Caillet, Prof. C. Coddet, Prof. J. Desmaison, Prof. J. P. Larpin, Dr. L. Lelait, Prof. G. Moulin, Prof. B. Pieraggi, and Prof. P. Steinmetz; and to the invaluable advice of Professor Bob Rapp, who undertook the heavy task of Chairman of the International Advisory Committee and co-editor of the Proceedings. The quality of these owe much to his quality refereeing of a great number of papers. Much gratitude is due also to Dr. Gilbert Vacquier, from the Laboratoire de Physico-Chimie des Matériaux, for his continuous and efficient help in the local organisation of the Symposium. Help and assistance from other members of the administration of the Université de Provence is also acknowledged.

The considerable burden of editing the Proceedings of the Symposium was greatly facilitated by the considerable contributions of Dr. R. C. Krutenat and Dr. M. Caillet. Without their thoroughness and hard work, this Proceedings could not have been produced. Sincere thanks are also due to all the authors, who co-operated in the stringent review process; modifying their manuscripts to comply with the referees requests; and to the members of the International Advisory Committee who acted as reviewers.

Last, but not least, the support of the sponsors is gratefully acknowledged, in particular, EPRI's continuous interest in the project as well as the continuous support of E.D.F. (Electricité de France) and of the Université de Provence.

We hope that these Proceedings will justify the trust and confidence of the sponsors and of all the participants of the Symposium.

Roland Streiff
John Stringer
Symposium co-chairmen