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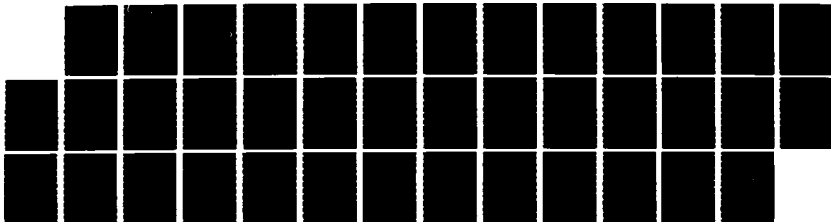
REPORT ON AN OVERSEAS VISIT TO ATTEND THE CDSO
(COMMONWEALTH DEFENCE ORGA. (U) MATERIALS RESEARCH LABS
ASCOT VALE (AUSTRALIA) J J BATTEN MAY 86 MRL-R-997

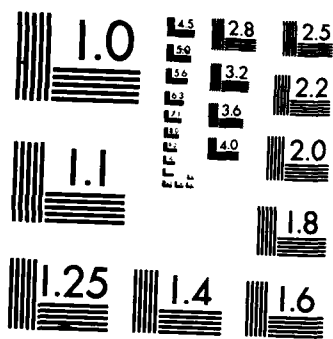
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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

MATERIALS RESEARCH LABORATORIES

MELBOURNE, VICTORIA

REPORT

MRL-R-997

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REPORT ON AN OVERSEAS VISIT TO ATTEND THE CDSO CONFERENCE
IN THE UK AND TO VISIT DEFENCE ESTABLISHMENTS IN
THE UK AND THE USA

J.J. Batten

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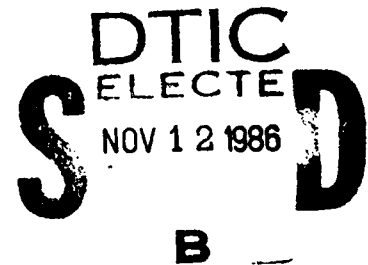
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**DEPARTMENT OF DEFENCE
MATERIALS RESEARCH LABORATORIES**

**REPORT
MRL-R-997**

REPORT ON AN OVERSEAS VISIT TO ATTEND THE CDSO CONFERENCE
IN THE UK AND TO VISIT DEFENCE ESTABLISHMENTS
IN THE UK AND THE USA

J.J. Batten



ABSTRACT

The main purpose of the visit described here was to attend the Commonwealth Defence Science Organisation Conference that was held in Brighton, UK, from the 13-17 May 1985, and to present a paper at that conference.

After the conference, visits were made in England to the Admiralty Marine Technology Establishment (Holton Heath), to the AMTE Dockyard Laboratory at Portsmouth, to the Royal Armament Research and Development Establishment at Fort Halstead, to the Royal Aircraft Establishment at Farnborough, and to the Corrosion and Protection Centre at the University of Manchester. In the USA, the Naval Surface Weapons Center at Maryland, the Naval Research Laboratory at Washington, the David Taylor Naval Ship Research and Development Center at Annapolis, and the Army Materials and Mechanics Research Center at Boston were visited.

The main purpose of these visits was to establish contacts at the scientific level, examine research programs and facilities related to corrosion research, and to relate these to the research and consulting activities being undertaken by the Corrosion Control Group at MRL. Another purpose was to discuss specific TTCP co-operative programmes with my counterparts in the above establishments. An extended version of the CDSO lecture was presented on several of these visits.

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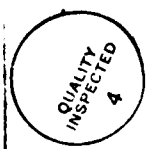
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REPORT ON AN OVERSEAS VISIT TO ATTEND THE CDSO
CONFERENCE IN THE UK AND TO VISIT DEFENCE
ESTABLISHMENTS IN THE UK AND THE USA

1. INTRODUCTION

This report describes the results of a visit to the UK and USA during the period 13th May to the 5th June, 1985. The purposes of the visit were:-

- (a) To attend the Commonwealth Defence Science Organization Conference, Brighton, UK, 13 May - 17 May 1985. The theme of the Conference was "The Operation of Weapon Systems and Platforms in Harsh Environments". During the Conference I presented the paper "Using Design to Minimise Corrosion in Harsh Environments".
- (b) To visit a number of Defence Establishments in the UK and the USA that undertake research and consulting activities associated with corrosion problems experienced by their Services.
- (c) To visit the Corrosion and Protection Centre of The University of Manchester Institute of Science and Technology.
- (d) To exchange knowledge/information on the latest developments in the science of corrosion control at the above research establishments. In particular to discuss the following TTCP co-operative programmes:
 - (i) PTP-1, "Corrosion and Protection of High Density Penetrators".
 - (ii) PTP-1, "Gun Barrel Erosion".
 - (iii) PTP-1, "Corrosion Testing of Aluminium-Lithium Alloys" (proposed).
 - (iv) PTP-4, "Corrosion Testing of Ion-Implanted Ball Bearings".

2. THE COMMONWEALTH DEFENCE SCIENCE ORGANIZATION CONFERENCE

2.1 Information about the CDSO

The CDSO is a body whose main purpose is to promote the advancement of defence science throughout its member countries. Among the ways this is achieved are: the exchange of information, visits of scientist and experts between member countries, and the arrangement of Meetings and Symposia. Membership is drawn from Commonwealth countries and currently comprises representatives from Australia, Bangladesh, Canada, Ghana, India, Malaysia, Mauritius, New Zealand, Nigeria, Papua New Guinea, Singapore, Sri Lanka, Tanzania, Trinidad and Tobago and the United Kingdom. (The United States of America is accorded official observer status at CDSO Conferences.)

The CDSO is organised by an Executive Committee consisting of:

Professor R.O.C. Norman (UK)
Professor P.T. Fink (Australia)
Dr D. Schofield (Canada)
Dr V.S. Arunachalam (India)

2.2 Conference Details

The conference, which was held at the Bedford Hotel, Brighton, UK, during 13-17 May 1985 was attended by 56 delegates from ten of the member Commonwealth countries. Australia was represented by Professor Fink, Dr Adams, Dr Batten, Major Goold, Major General James, Brigadier Mackenzie-Orr, and Dr Tregellas-Williams. The theme of the conference was "The Operation of Weapon Systems and Platforms in Harsh Environments". The conference programme is given in detail in Appendix A1 and the list of attendees at the meeting is given in A2. It will be seen from the Appendices that at this highly successful meeting thirty-four papers related to the theme of the conference were presented (nine from Australia). Most of the papers generated lively discussion and out-of-session comment.

The first two days of the conference were concerned with "Problems of the Human Operator" and consisted of 18 papers that can be summarised as follows:-

- (a) The effect of the environment (e.g. limited space, noise, vibration, tiredness caused by prolonged periods of concentration, etc) on the efficiency of sonar operators, pilots, etc to perform their respective functions.
- (b) The effect of protective clothing, or the weight of his equipment, on the effectiveness of a fighting soldier.

Wednesday, 15 May, consisted of a trip to the Royal Armament Research and Development Establishment, Fort Halstead.

The final two days of the conference were devoted to "Problems of Materials", and I presented the first paper on this theme. Sixteen papers were presented on a wide range of topics, viz.

- (a) the effect of harsh environments on metals, plastics, and explosives, and
- (b) assessment of the use of results from accelerated testing procedures in predicting actual service-life.

Most of these papers were very informative and useful. The paper I presented from MRL highlighted the strong link between the design of an article and its resistance to corrosion. The paper generated considerable interest and response among the delegates.

I found the opportunity to exchange scientific information and establish contacts with other Defence scientists afforded by this CDSO conference to be of great value, and continued Australian support is strongly recommended.

3. TECHNICAL VISITS - UNITED KINGDOM ESTABLISHMENTS

3.1 Visit to Admiralty Marine Technology Establishment (Holton Heath)

3.1.1 Aim of visit

To discuss research and consulting activities associated with the use of metals and alloys in the marine environment. In particular, to discuss their work on the Cathelco Antifouling System.

Contact: Mr John Rowlands (Corrosion Section, Metallurgy and Ceramics Division)

3.1.2 Information about the Establishment

The Admiralty Marine Technology Establishment (Holton Heath) (AMTE[HH]) has a varied programme which ranges from research into analytical chemical techniques, through investigations of the performance of materials in operational use in the Fleet, to the provision of support to naval dockyards. It has an important function to solve current problems in materials science and to achieve greater cost effectiveness in the selection of materials for use in the marine environment.

The research programme of the Metallurgy and Ceramics Division of AMTE(HH) is concerned with structural, physical and mechanical aspects of ferrous and non-ferrous metals and alloys, ceramic materials, corrosion and allied phenomena.

3.1.3 The visit

Corrosion research being undertaken embraced laboratory studies and large-scale rig testing. Dynamic cavitation and impingement in seawater systems were being investigated in pipe rigs. This most impressive system is used for comparing the erosion behaviour of different metals and coatings. Although not really a research tool, it is an excellent way of comparing metal/coatings one against the other.

Corrosion fatigue and the stress corrosion cracking of metals and alloys in a marine environment were also being studied, together with simple exposure corrosion, crevice and bimetallic corrosion. Zero resistance ammetry was being employed to study galvanic corrosion. Potentiostatic and potentiodynamic techniques were being used for general study of passivation and protective film breakdown and repair, as well as the influence of impressed current cathodic protection on stress corrosion and corrosion fatigue behaviour.

Concerning the Cathelco Antifouling System, this was considered as not being very effective - of doubtful use. It was interesting to learn that the system had now been changed, namely the Cu/Al anode had been replaced with an all-copper anode, a position reached by Australia quite independently. The use of chlorine for antifouling purposes was considered more effective. Irrespective of which antifouling system was being used, it was believed that it was not required when the ship was in deep water but was required when in coastal waters.

Discussions were held on the possibility of collaborative research programmes, or the attachment of Corrosion Control Group staff to AMTE(HH) - possible topics included using chlorination for antifouling purposes, three dimensional effect in Cathodic Protection systems, and mathematical modelling of corrosion processes.

3.1.4 Overall impressions

In recent times this Establishment had suffered severe cuts in staff (e.g. its Corrosion Group had gone from a staff of 12 to 3) and, as a consequence, morale appeared to be low. Most of the research is now contracted out - mainly to Southampton University - and this appears not to be working well at all. It would appear that such research is more expensive than doing it yourself and it is less reliable. Often the research you want done, isn't done.

3.2 Visit to Admiralty Marine Technology Establishment - Dockyard Laboratory, Portsmouth

3.2.1 Aim of visit

To discuss corrosion problems of mutual interest to the RN and RAN, and inspect their outdoor exposure site at Eastney.

Contacts: Mr Gilbert Newcombe (Deputy Superintendent)
Mr Arnold Bloom (Head, Chemistry Section & Biology)

3.2.2 Information about the Dockyard Laboratory

The Dockyard Laboratory is part of the Division "Fleet and Dockyard Support" of AMTE. This division is centred on the Dockyard Laboratory at Portsmouth and maintains outstations in the other Royal Dockyards at Chatham, Devonport and Rosyth, as well as at Eastney about five miles from the main site at Portsmouth. The scientific staff consists of chemists, metallurgists and biologists, whose main function is to maintain an on-site facility for process monitoring and diagnosis of materials failure in service. These diagnostic activities cover corrosion, failure of metallic components, degradation of coatings and other non-metallic substances and bio-deterioration of materials. These activities lead directly to programmes of remedial research and the provision of a specialist advisory service to ship design authorities.

In the longer term, the expertise assembled into this multi-disciplinary team is used to pursue part of the Royal Navy's materials basic research programme. For example, on the metallurgical side, the development of high-strength corrosion resistant non-ferrous alloys for critical ship applications is coupled with complementary work on techniques for the fabrication and repair of components made from them.

3.2.3 The visit

The main points to arise from discussions held in the morning were:-

- (a) The RN has banned the use of Cd-electroplate.
- (b) The RN is phasing-out the use of chromate conversion coatings.
- (c) The RN is using Crennel zinc anodes for its cathodic protection systems. They have moved away from the use of aluminium anodes because of inconsistent results.
- (d) Ultimately the Cathelco Antifouling System will be replaced with a system based on chlorine.

The afternoon was spent at the Eastney outstation at Langstone Harbour. This comprehensive natural exposure facility has both atmospheric and submerged test sites. Providing a marine environment largely free from pollution, this site has achieved international recognition and in addition to meeting the needs of Defence establishments, is available on a commercial basis to outside customers.

The facility is located on an isthmus, thus it is an easy matter to use once-through sea water on exposure racks that have salt water streaming over panels to test the corrosion resistance of different coatings and metals. In the harbour itself the facility has five rafts for testing samples submerged in seawater. In all, a most impressive natural exposure facility.

3.3 Visit to Royal Armament Research and Development Establishment, Fort Halstead

3.3.1 Aim of visit

To discuss research and consulting activities associated with corrosion problems experienced by the army; in particular, to discuss the TTCP-PTP-1 operating assignment "Corrosion and Protection of High Density Penetrators" with the assignment leader (Mr J.T. Heron). It was also hoped to discuss the TTCP-PTP-1 operating assignment "Gun Barrel Erosion".

Contacts: Mr Tom Heron (Armament Materials Division (xM4))
Dr Dennis Turley (MRL, on attachment to RARDE)

3.3.2 Information about RARDE

The Royal Armament Research and Development Establishment is primarily concerned with research, design and development in the field of conventional armaments for all three Services. It is one of the largest research and development establishments in the Ministry of Defence and is the lead in land service R&D.

An important part of the programme of the Armament Materials Division is the carrying out of basic studies into the critical performance factors of materials for weapon systems. Teams are engaged on research into new melting and fabrication techniques and erosion-resistant steels for gun barrels; special materials required for armour-piercing shot; long-term storage and environmental protection of service stores; and the design and construction problems associated with non-metallic, high-pressure gun barrel manufacture.

Specialist groups provide the essential feedback mechanism for in-service failures and manufacturing defects to be investigated and reported back to the designers.

3.3.3 The visit

Most of the day was taken up with discussions on the corrosion and protection of high density penetrators. Mr Heron described the work they have done on a sintered tungsten-nickel-copper alloy that is used in UK penetrators. They have found that this alloy suffers severe corrosion under warm, damp conditions. This corrosion requires high humidity, preferably condensation conditions, in order to occur. A RH above 90% is required for any significant corrosion to occur. A bar of the alloy stored under normal (dry) laboratory conditions will remain uncorroded indefinitely, but as lack of condensation cannot be guaranteed under normal storage conditions some form of protection must be applied. The corrosion mechanism is believed to be essentially a simple bimetallic reaction, and this results in the leaching out of the tungsten particles.

A large number of protective schemes have been examined. These included a number of paints and lacquers but they provided only poor to moderate protection. Metallic coatings such as electroless nickel, tin, cadmium and zinc were found much superior. Of these, cadmium was by far the best, but was rejected on environmental grounds. A zinc coating, electrodeposited from a cyanide bath, was the preferred substitute but a non-cyanide bath was recommended for production, again on environmental grounds.

Ion vapour plated aluminium was also found to be very good but lack of a commercial plant limits its application.

The TTCP programme required the UK (and the other participating countries (i.e. USA and Australia)) to study the candidate alloys. However it became clear during the discussion that the UK intended to cease work on W-alloys in favour of depleted uranium (DU) which they believed they could make stronger and tougher. At this stage they have not tested the tungsten USA- and Australian-alloys, and have done only a limited amount of work on DU.

On Australia's part, I discussed the work we have done which involves electrochemical polarisation measurements, and more detailed studies of the kinetics of the corrosion reactions for two UK alloys, one USA alloy and the Australian alloy. Because of the rather detailed study Australia has undertaken, I formed the impression that the UK would be happy to leave this more detailed investigation in our hands, and that the UK would rely on our results for this study.

With regard to the handling and machining of DU, it was interesting to observe that the British regarded it as a radioactive material and treated it accordingly (i.e. a special room was used, operators were required to wear a complete set of overclothes, tests were conducted for residual radioactivity after removing these overclothes and washing, and so on).

Finally, a short period was spent with Dr Dennis Turley (on attachment from MRL), who was in the process of commissioning a new Ion Vapour Deposition (IVD) apparatus. With regard to work on gun-barrel erosion, when the CDSO visited RARDE as part of the CDSO Conference, a presentation was made to that group on the work being done on gun-barrel erosion. At this, it was

stated that new techniques for electroplating adherent crack-free chromium deposits on gun barrel bores to reduce erosion had been successful.

3.3.4 Overall impressions

Just as with AMTE(HH), RARDE has suffered severe cuts in staff (Corrosion Group, staff reduced from 8 to 4) and this has had an adverse effect on staff morale.

3.4 Visit to The Royal Aircraft Establishment, Farnborough

3.4.1 Aim of visit

To discuss research and consulting activities associated with corrosion problems experienced by the Air Force.

Contacts: Dr R.E. Miller (Superintendent, Non-Structural Materials Division)
Dr Chris Smith (Head, Corrosion Section)

3.4.2 Summary of discussion with Dr Chris Smith

This discussion took the greater part of the day, and the main points to arise from it were as follows:-

- (a) The mechanism of the chromating reaction is being studied, under contract, by UMIST (see Section 3.5). This investigation is concerned with mechanisms of the inhibition of the corrosion of aluminium and its alloys by chromate species; such chromates may be incorporated in paint films and/or present in aqueous environments.
- (b) There is a need to replace chromate in paint primers and in solutions used to pre-treat aluminium and its alloys - for environmental reasons.
- (c) Both RAE and MRL have an interest in testing, for corrosivity, the cleaning compounds used for aircraft surfaces. The RAF use the specification TS 10281, "Compounds, Cleaning, for Aircraft Surfaces". It was interesting to learn that the prescribed test (copy of specification supplied) required the detection of an increase in mass of a panel by no more than 1 mg, or a decrease in mass of no more than 5 mg. As the RAAF have found - this sort of requirement is difficult to detect. It is for this reason that Corrosion Control Group MRL hope to develop an electrochemical test to replace the above test - as requested in the RAAF letter to MRL dated 5th March 1980 where the request was for MRL to develop "a viable objective quantification test". The equipment developed in our corrosion monitoring work has reached a sufficient standard that this objective can now be achieved

in the laboratory. However transfer of the technology to a RAAF-base environment may be difficult. The process requires simplification.

- (d) The RAF has a requirement to replace cadmium-electroplate on high strength steels with an electroplate that is acceptable environmentally.
- (e) British Aerospace are undertaking research for RAE, under contract, to study the effect of different pre-treatments on paint adhesion.
- (f) Salford University are conducting research, under contract, on ion plating in an attempt to produce denser coatings with good adhesion. They are interested in Al/Zn alloy coatings (5% Zn) and have found that the method used for cleaning the surface is most important. These coatings will be assessed by outdoor exposure at Eastney (see 3.2.2, 3.2.3).
- (g) McDonald Douglass are undertaking research, under contract, on IVD in an attempt to reduce the porosity of the coating. One technique used has been to shot-peen after plating to reduce porosity, and then to chromate.
- (h) In collaboration with AERE Harwell, a study is being made of the effect of ion-implantation on the fretting of Ti- and Al-alloys. They are also studying the effect of ion-implantation of Yttrium on titanium gas turbine blades.
- (i) UMIST are also conducting research, under contract, on the ion-implantation of Al-alloys with aluminium.
- (j) Dr Smith expressed considerable interest in the research we are undertaking in an attempt to improve the corrosion resistance of Zn-electroplate through alloy plating.
- (k) We discussed the proposed TTCP co-operative programme on the use of Al/Li alloys for aircraft. Another use for this alloy could be to reduce the weight of the Sabot for long-rod penetrators.

3.4.3 Summary of discussion with Dr Bob Miller

Dr Miller spoke on the run-down in the number of staff of the Establishment and the effect this can have on staff morale.

3.4.4 Overall impressions

As with AMTE(HH) and RARDE, they have found at RAE that "contracting research out to Universities doesn't work" - they don't do the work you want them to do.

3.5 Visit to the Corrosion and Protection Centre, University of Manchester Institute of Science and Technology (UMIST)

3.5.1 Aim of visit

To discuss corrosion topics of mutual interest and, in particular, to discuss the work they are doing on the atmospheric corrosion of sintered metals. A further purpose of the visit was to present an extended version of the lecture I presented at the CDSO Conference.

Contacts: Dr S. Turgoose (Lecturer in Corrosion Science and Engineering)
Dr G.A.M. Sussex (Post-Doctoral Research Worker)

3.5.2 Information about the Centre

The UMIST Corrosion and Protection Centre was established in 1972 after the Hoar Committee on Corrosion and Protection had focussed public attention on the cost of corrosion, and the savings possible using existing knowledge. These were estimated at 1,365 million pounds sterling and 310 million pounds sterling per annum respectively in 1971.

The overall UMIST objective was the establishment of an interdisciplinary Centre, which would encourage specialists from different academic disciplines to cross their traditional boundaries to work in relevant areas of corrosion and protection. The Centre has three main areas of activity in corrosion and protection, namely teaching, research, and advisory and testing services for industry.

3.5.3 The visit

(a) The lecture, "Using Design to Minimise Corrosion in Harsh Environments" was well received. Attendance numbered at least fifty. Questions extended the duration of the lecture from one hour to $1\frac{1}{2}$ hours.

(b) The research on "The Atmospheric Corrosion of Sintered Metals", being done by a Research Student (Peter J. Aylott) was of considerable interest to Corrosion Control Group at MRL. The sponsor for the work was the Ministry of Defence (in fact, the work was being done for Mr Tom Heron of RARDE [see section 3.3.3]). The aim of the research was to identify the mechanisms whereby certain sintered metals corrode under conditions of high humidity.

In the study two galvanic couples between tungsten and nickel based alloys were made under aqueous conditions. The two nickel alloys (Ni70Cu30 and Ni50Fe50) were coupled to pure tungsten in a 1% sodium sulphate solution under stagnant conditions at 25°C. The change in galvanic current with time was monitored using a zero resistance ammeter, galvanic potential measurements were made relative to calomel.

The tungsten nickel-copper couple gave anodic products on each electrode, with the tungsten being predominantly anodic. The tungsten nickel-iron couple gave anodic products on the nickel-iron only.

It was stated that the work was concerned with a study of the atmospheric corrosion of the two sintered tungsten alloys 90%W, 7.5%Ni, 2.5%Cu and 90%W, 5%Ni, 5%Fe. It is claimed that the above galvanic study was chosen to represent a close approximation to the alloy phases present in the sintered tungsten alloy. My personal feeling is that I don't believe the above claim to be true, for the binder phase in the sinter will contain an appreciable quantity of dissolved tungsten (probably 25-30%). Thus the couple, pure tungsten and the binder in the sinter, could be quite different from the couple, pure tungsten and the above pseudo-binder.

(c) Other (short) discussions:

(i) Corrosion monitoring (Dr J.L. Dawson)

Dr Dawson is the Supervisor at UMIST for the following research projects:

- Dewpoint corrosion in coal fired power stations
- Localized corrosion monitoring
- Engineering aspects of dewpoint corrosion
- Underground corrosion of ductile iron pipes

For these investigations corrosion coupon and corrosion monitoring techniques were developed. The monitoring technique used digital voltmeters and microprocessors to follow the corrosion process.

(ii) Stress corrosion cracking (Dr R.A. Cottis)

Dr Cottis is the Supervisor at UMIST for the following research projects:

Stress corrosion cracking of an austenitic stainless steel
The electrochemistry of stress corrosion cracking
The kinetics of hydrogen evolution on steel in alkaline solutions
The influence of crevice conditions on hydrogen uptake by steels
Stress corrosion and hydrogen embrittlement of armoured conveyor steels
The influence of applied cathodic potential on the hydrogen embrittlement of an armoured flexible conveyor steel
The influence of corrosion on fatigue crack initiation in steels

Dr Cottis has found that with some steels, the presence of a crevice can passivate the remainder of the steel (Pub. in Proc AIME Symp. "Localized Crack Chemistry and Mechanics in Environment Assisted Cracking", Philadelphia (1983)).

4. TECHNICAL VISITS - ESTABLISHMENTS IN THE UNITED STATES OF AMERICA

4.1 *Visit to US Naval Surface Weapons Center, Maryland, USA*

4.1.1 *Aim of visit*

To discuss research and consulting activities associated with corrosion problems experienced by the Navy, to discuss the proposed TTCP-PTP-1 Operating Assignment "Corrosion Testing of Aluminium-Lithium Alloys", and to deliver an extended version of the CDSO lecture.

Contacts: Dr Carl E. Mueller (Head, Electrochemistry Branch, Research and Technology Department, Materials Division)
Dr Chester M. Dacres (Head, Corrosion Technology Group)
Mr Amarnath (Dave) Divecha

4.1.2 *Information about NSWC, Maryland*

The Naval Surface Weapons Center is the Naval Materials Command's largest research and development center. The Center is at two sites, one at Dahlgren in Virginia, the other at White Oak in Maryland. The mission of the Center is to support the Navy's Surface Forces as "the principal RDT and E

center for surface ship weapons systems, ordnance, mines and strategic systems support". In carrying out this mission, NSWC performs warfare analysis, research, design, development, test and evaluation, systems integration, and fleet engineering services.

The principal function of the Research and Technology Department is the support of development programs throughout the Center. Towards this end, the technical programs are based upon anticipated future needs of the Center. Because of this, most of the work results in the development of highly mission oriented capabilities and facilities.

The mission of the Electrochemistry Branch is to maintain a broad technology base in the materials and electrochemistry of batteries, and to support the NSWC and the Navy by providing electrochemical power sources for naval weapons.

4.1.3 The visit

(a) **The lecture**, "Using Design to Minimise Corrosion in Harsh Environments" was attended by about 35 to 40 people and this included Dr Mueller and Dr Dacres. With the discussion, it lasted about $1\frac{1}{4}$ hours.

(b) **Battery research** (Dr Chester Dacres)

The significance of this work is that virtually every US naval weapon, ordnance item, or communications device depends for its operation on some source of portable power. Today, and for the foreseeable future, this power is provided most often by electrochemical batteries.

Electrochemical batteries today are needed to power devices that perform the following general functions in weapon systems:

- * Detection
- * Fuzing, safety, and arming
- * Guidance and control
- * Propulsion (weapons and vehicular)

General requirements for their batteries include high energy density, long (uncontrolled) shelf life, short start-up times, reliability, safety, the capability to operate over wide ranges of temperature, and extreme ruggedness.

However, it is anticipated that future weapons will need power sources where energy densities are much higher than present ones. They will need higher reliability, better voltage regulation, and infinite (uncontrolled) shelf life. Indeed, the battery needs of the new "smart" weapons will have to be satisfied by new battery technology. It is believed that this new technology will be based primarily on the use of lithium as the anode material. In electrochemical systems, this metal (the lightest metal known) exhibits exceedingly high energy.

Batteries based on lithium anodes promise energy densities four to five times higher than present technology can provide. This new technology, however, also necessitates a completely new approach to batteries. Most new battery materials used are air and moisture sensitive, therefore not only R&D but manufacturing also has to be carried out in specially constructed inert atmosphere glove boxes or dry rooms (1% relative humidity). Some materials are toxic and therefore special procedures have to be observed in use and disposal as well as in fabrication. Finally, the use of highly energetic materials packaged into very small space increases the danger of explosion should malfunction of these batteries occur. Thus the successful exploitation of promising new lithium battery technology will require careful attention to assure the safety of Service personnel.

The research of the Electrochemistry Branch included the following:

- (i) Low-rate, long-life primary batteries, such as the Leclanche dry cell, the alkaline MnO_2 , the alkaline Hg systems, and the Li-organic or -inorganic solvent systems.
- (ii) High-rate primary batteries, such as the thermal (molten salt) and the AgO/Zn systems.
- (iii) High-rate secondary batteries, such as the AgO/Zn system.
- (iv) A study of the electrochemistry of the Li/SO₂ and Li/SOCl₂ electrochemical couples.

The Electrochemistry Branch would welcome the setting-up of a TTCP collaborative programme on battery research, in particular with the aim of controlling the irreversible deterioration of battery electrodes and thus extending their shelf life.

(c) **Aluminium-Lithium Alloys (Mr Dave Divecha)**

A detailed presentation was made to me outlining the properties of Al/Li alloys. This clearly supported the need to carry out a comprehensive evaluation of the corrosivity of this alloy. It is proposed to address this problem through a TTCP round-robin testing programme. The aim of this programme will be to exchange, evaluate and compare USA and UK candidate lithium-bearing aluminium alloys for defence applications, where lower density and higher stiffness may be exploited. The nations that will participate in this programme are USA, UK, Canada and Australia.

The current high strength aluminium alloys used in aerospace and other military applications are being supplemented by lithium-bearing aluminium alloys which have approximately 10% lower density and 10% higher modulus. These alloys were developed independently in the USA and the UK. They are most attractive for future aircraft designs and also offer the possibility of direct replacement in existing designs to give increased life and performance.

The development of these alloys has reached an advanced stage with airframe manufacturers already using the alloys as a means of increasing performance, comparable with the use of composites, yet retaining the lower costs and manufacturing technique of conventional metal technology.

Three goals have been set for alloy development:

- (i) To produce a medium strength alloy.
- (ii) To produce a high strength alloy.
- (iii) To produce a low strength alloy with damage tolerance.

The UK industry has reached production status for a medium strength Al-Cu-Mg-Li alloy, and the US industry has developed a high strength Al-Cu-Li alloy. Both countries are developing alloys and treatments to develop other properties. Typical compositions are 3%Cu, 2%Li, 0.15%Zr or 2.5%Li, 1.2%Cu, 0.7%Mg, 0.12%Zr.

The question can be asked why does the inclusion of these alloying elements improve the properties of Al/Li alloys. While Cu is thought to increase strength, the desirable maximum percentage of Li is thought to be 3%. It is considered by PTP-1 that the time is appropriate for Defence establishments to have first-hand experience of the mechanical behaviour and performance of these alloys in order to assess their suitability for specific applications and to derive the maximum exploitation of the benefits they offer. It is clear that the susceptibility of these alloys to general corrosion, crevice corrosion and stress corrosion cracking will need to be ascertained.

(d) **Inspection of the Surface Evaluation Facility at NSWC**

The Surface Evaluation Group is under Dr Ronald Lee, who demonstrated the instrumentation in the facility to me.

The Naval Surface Weapons Center has equipped and staffed the Surface Evaluation Facility to provide a unique Navy capability for determining surface properties. The Facility engages in a full-spectrum approach to the Navy's materials problems through three major functions.

- * Development of new materials and devices is supported through programmatic studies of surface-related problems in collaboration with the scientists and engineers working on the primary development project.
- * Research on the fundamental properties of solid surfaces maintains a forefront expertise in surface science.
- * Analytical Services are provided for short-term trouble-shooting of materials problems within the Navy R&D community and in the Fleet.

The instrumentation of the Facility includes:

(i) Physical Electronics 590A Scanning Electron Microprobe (Super-SAM)

The Facility's 590A Super-SAM is currently the DoD's most advanced capability for the elemental analysis of extremely small volumes ($3 \times 10^{-17} \text{ cm}^3$).

The 590A presents high magnification images (1,000x) both as electron micrographs and as maps of the distribution of the elements on the surface. Composition as a function of depth is obtained by computer controlled ion bombardment.

(ii) Kratos ES300 X-Ray Photoelectron Spectrometer (XPS)

The ES300 XPS identifies both the atomic composition of a surface and the way the atoms are chemically bonded together. The NSWC instrument incorporates a unique combination of features which facilitate the analysis of propellants, explosives and high vapor pressure materials.

(iii) Multi-Technique System

This unique system features two types of Appearance Potential Spectrometers (APS) for obtaining information about the electronic structure at specific atomic sites in the surface. These spectrometers, which are available in only a few laboratories in the world, are in a vacuum chamber which is also fitted with Auger Electron Spectroscopy (AES) and X-Ray Photoelectron Spectroscopy (XPS).

(iv) AMR 1000A Scanning Electron Microscope (SEM)

The AMR 1000A provides all of the features of a modern SEM including the elemental analysis capability of the accessory Energy Dispersive Analysis of X-Rays (EDAX). Useful magnifications range from 5x to 50,000x.

The mission of NSWC presents the Surface Evaluation Facility with an extremely wide range of applications of surface analysis. Typical of these applications include the following:

- (i) Trident Missile Propellants: Problems related to the uniformity of burn rate were being clarified through the determination of the molecular structure of propellants - both as compounded and at the burn interface.
- (ii) Lithium Battery Safety: Lithium batteries have been withdrawn from essential service in the Fleet due to severe explosion hazards. The Surface Evaluation Facility has made significant contributions towards the solution of this problem by means of surface analysis results which revealed previously unsuspected aspects of the chemistry of lithium battery electrodes.

- (iii) **Composite Materials:** Uncontrolled variables in the manufacture of metal matrix composites are producing unacceptable fluctuations in strength and corrosion resistance. The Facility's capability for analyzing extremely small volumes is being used to identify the reasons for poor fiber-matrix bonding and chemical degradation so the manufacturing technology can be better controlled.

4.2 *Visit to Naval Research Laboratory, Washington*

4.2.1 *Aim of visit*

To discuss research and consulting activities, associated with corrosion problems experienced by the Navy, to discuss the TTCP-PTP-4 Operating Assignment "Surface Modification - Corrosion Resistant Bearings by Ion Implantation", and to deliver an extended version of the CDSO lecture.

Contacts:

Dr Robert Brady	(Polymeric Materials Branch, Chemistry Division)
Dr Fred A. Smidt	(Head, Materials Modification and Analysis Branch, Condensed Matter and Radiation Sciences Division)
Dr Graham Hubler	(Materials Modification and Analysis Branch)
Dr Jim W. Butler	(Consultant (Ion Beam Applications), Condensed Matter and Radiation Sciences Division)

4.2.2 *Information about NRL*

The mission of NRL is to conduct a broadly based multidisciplinary program of scientific research and advanced technological development directed towards new and improved materials, equipment, techniques, systems and related operational procedures for the Navy. To this end, part of its mission is to initiate and conduct scientific research of a basic and long-range nature in scientific areas of special interest to the Navy. Two other main areas of work are, firstly, to conduct exploratory and advanced technological development deriving from or appropriate to the scientific program areas, and secondly, to furnish a scientific consultative service for the Navy.

4.2.3 *The visit*

(a) **The lecture, "Using Design to Minimise Corrosion in Harsh Environments"** was attended by about 35 to 40 people. Again there was quite a lot of discussion after the presentation.

(b) **The TTCP Operating Assignment (Dr Fred Smidt)**

This operating assignment arose when it was discovered that corrosion of bearings was occurring in storage for both the US Navy and the

Royal Australian Navy. Research and development work at the Naval Research Laboratory and at other places had established the effectiveness of ion implantation of metals and alloys for selected corrosion resistance applications.

Co-operative activities were conducted in support of the TTCP-PTP-4 assignment on Surface Modification : Corrosion Resistant Bearings by Ion Implantation. The assignment was undertaken in response to the above-mentioned need to reduce the extent of damage caused by corrosion of bearings during storage. The assignment specifically addressed the need for improved corrosion resistance in high performance gas turbine bearings fabricated from AISI M50 and 52100 steels. Previous studies conducted by NRL had demonstrated the efficacy of an ion implantation treatment with Cr to improve the corrosion resistance of M50 steel.

The assignment involved evaluation of a similar Cr implantation treatment for M52100 steel with participation by Canada, the USA (at both NRL and the Army Materials and Mechanics Research Center at Watertown) and Australia (MRL). NRL provided implantation of test samples.

The work carried out by the Americans indicated that implantation by Cr was effective in providing complete protection in the simulation test for both M50 and 52100 steel and an increased threshold for pitting corrosion in buffered sodium chloride solution.

The Canadians, on the other hand, found significantly less resistance to corrosion than reported by the Americans in the buffered chloride pitting corrosion test. The Australian results supported those of the Canadians. There was a consistency between the Australian and Canadian results, which were, in the case of the Cr implanted sample, grossly different from the American results.

It is clear that the above difference in results needs further investigation, and it was with this in mind that I wished to discuss these results with Dr Smidt of NRL, who is the leader of the operating assignment. It was concluded that the corrosion test result was sensitive to variables such as chloride concentration and scan rate. It was further concluded that the environment used by the Australians and Canadians was too aggressive and did not simulate the relatively mild corrosive environment of the bearing compartment. It was agreed that we in Australia would repeat our work but this time use a much milder corrosive environment. It was further agreed that these results would be available in time for the next PTP-4 meeting (July 1985).

(c) **Linac Facility** (Dr Jim Butler)

This facility is in the Condensed Matter and Radiation Sciences Division, a division where a broad program of basic and applied research is conducted on the fundamental properties of materials and on the interaction of various types of radiation with matter. Damage produced by radiation, ranging from laser and x-ray beams through charged and neutral particle beams in the megavolt region, is studied. Techniques to utilize radiation for

beneficial modification of materials (e.g. ion implantation) are also developed.

This facility is used for studying the effect of fast-moving ions on materials (e.g. plastics), with a view of simulating the damage that is likely to happen to these materials in an atomic blast.

(d) **Visit to the Chemistry Division (Dr Robert Brady)**

This division conducts both basic and applied research in the fields of electrochemistry, combustion, polymeric materials, and related fields. Specialized programs within the three main fields include corrosion, fire suppression, and coatings.

My main contact at NRL was Dr Robert Brady, and he was concerned with producing non-slip paints for aircraft decks. These were tested with respect to their non-slip capability and the degree of protection they afforded the underlying metal. It was quite clear that considerable success had been achieved in both these regards.

4.3 Visit to the David Taylor Naval Ship Research and Development Center at Annapolis

4.3.1 Aim of visit

To discuss research and consulting activities associated with corrosion problems experienced by the Navy and to deliver an extended version of the CDSO lecture.

Contact: Mr A.G.S. (Terry) Morton (Branch Head, Marine Corrosion, Physical and Mechanical Metallurgy Division, The Ship Materials Engineering Department)

4.3.2 Information about DTNSRDC

The DTNSRDC is the US Navy's principal research, development, test and evaluation Center for naval vehicles. The Center consists of two laboratories, namely the Carderock Laboratory and the Annapolis Laboratory of about 1000 and 500 people respectively. The Center at Annapolis has two major technical departments

- * The Propulsion and Auxiliary Systems Department
- * The Ship Materials Engineering Department

The Ship Materials Engineering Department at Annapolis is the US Navy's primary research and development organization for ship materials. It is involved in assuring that the design and construction of naval vessels is

accomplished with the most suitable materials and also provides support to the fleet in the solution of operating and maintenance problems.

This department consists of five technical divisions as outlined below:

* **Physical and Mechanical Metallurgy Division**

In this division research is conducted on metallic materials, characterization of their engineering properties, and development of new concepts for advanced naval applications. Under study are high strength steels, titanium, aluminium, and a variety of specialty alloys, as well as high temperature and superconductive materials. Studies are made of metals in the marine environment, including corrosion and ways to minimize it, and fatigue and fracture under static and dynamic loading in various environmental conditions.

* **Fabrication Technology Division**

The advanced fabrication technology program of this division focuses on new combinations of materials and how products are formed, cast and welded.

* **Chemical and Physical Processes Division**

A major responsibility of this division is the improvement of fresh water systems, fuels, lubricants, bearings and related materials used to operate Navy equipment.

* **Non-Metallic Materials Division**

A wide variety of non-metallic materials are being investigated under several major programs, including corrosion control, energy conservation, reduction of ship detection and vulnerability, and fire damage prevention. The materials include paints, coatings, plastics and rubbers.

* **Environmental Protection Division**

This division is the US Navy's lead laboratory for ship-board pollution abatement programs. Specific problem areas concern the disposal of bilge and ballast oily wastes, industrial, domestic and solid wastes, propulsion or solvent air emissions, as well as toxic and hazardous materials. Noise abatement is another concern.

4.3.3 The visit

(a) **The lecture**, "Using Design to Minimise Corrosion in Harsh Environments" was well attended and extremely well received - this is hardly surprising when you take into consideration the program of the Physical and Mechanical Metallurgy Division.

(b) Overview of the Marine Corrosion Branch (Mr Morton)

Basic research (6.1)

- * H₂ embrittlement The study of the diffusion of hydrogen in metals is being undertaken at a university by a Ph.D. student.
- * Cu-Ni films

Exploratory development (6.2)

- * Metal matrix composites Al-based composites using graphite/SiC. Cu-based composites using reinforced Al₂O₃. Purpose of the composite is to improve the mechanical properties. Work on anodising and thermal spraying for corrosion control.
- * Thermal Spray behaviour Study of degree of protection against the composition of the wire. When Al or Al/Zn is sprayed on steel this produces a coating that tends to be porous. This can lead to corrosion due to a bimetallic effect unless the coating is sealed. This can be done using paint. The coatings tend to be used topside. Maybe could be used immersed if sealed.
- * Impedance of paint films Work associated with means of preventing underfilm corrosion. Also used to study the rate of corrosion of the substrate.
- * Galvanic corrosion Work aimed at studying galvanic corrosion prediction using long- and short-term polarization curves.
- * Elevated temperature materials Studying the properties of ceramic coatings.
- * SCC test methodology Work aimed at studying the influence of test procedures, e.g. crack opening. Study of the effect of cathodic protection (zinc anodes) on SCC.
Study of the effect of water and salt.
Metal used is HY100, this is a heat treated HY80.
- * HSLA-80 Study the corrosivity. This is a low C steel, easily welded. Since no heat treatment is needed, fabrication is much cheaper.

suggestion that before you can determine the influence of the thickness of the coating, the influence of different ways of putting on the coating, and different coatings, it is necessary to get rid of the high spots on the surface, i.e. it is necessary to smooth it. I also suggested that for a study of the corrosion of the basis metal, a study of the penetration of the coating by water and oxygen would be a help. This could be done using labelled molecules.

(e) **Exposure of US Test Panels at JTTRE (Dr Denise Aylor)**

Through the auspices of TTCP, MRL (Metallurgy Division) agreed to arrange to have some panels exposed at JTTRE. Unfortunately, through the vagaries of both postal systems, letters between the two laboratories were taking an inordinate time to reach each other (nearly three months), with the result that often the letters would cross, and this made organizing the trial difficult. The meeting with Dr Aylor and Mr Morton was aimed at resolving the situation.

The following points summarize this discussion:

- (i) Panels should be at 20°C to the horizontal and face north.
- (ii) The basis metal is 6061 aluminium with SiC whiskers. The aluminium sheet is formed by powder metallurgy.
- (iii) When uncoated, panels appear to get crevice corrosion between the Al and SiC whiskers.
- (iv) The coatings are:
 - 1st - thermal spray coating of Al (Pure); thickness 7-10 mil
 - 2nd - an organic coating
 - 3rd - an organic coating
 - 4th - an organic coating
- (v) Inspection
 - (A) Look for blistering or lack of adhesion between coatings.
 - (B) Look to see if hardening, powdering or crazing of the organic layers has occurred.
 - (C) If the blister is whole, don't cut it open to see where the separation is. Leave that for Dr Aylor to do.
 - (D) If blister is not whole, ascertain the layers between which it formed.
 - (E) Take photographs of the panels and/or use visual inspection, to observe blisters.
- (vi) There are three different types of samples, four of each.

(vii) Exposure

- (A) Two of each, hot/wet, cleared and not near the sea.
- (B) Two of each, near the sea, not immersed or in the splash zone but close enough to get some salt deposition.

(f) **Comparison of Relative Corrosivities of Marine Environments**
(Mr Morton)

This survey is being organized by ASTM Sub-committee G-1.09 on Corrosion in Natural Waters.

Objective: It is the intent of this task group to apply ASTM G52-76, Standard Recommended Practice for Conducting Surface Seawater Exposure Tests on Metals and Alloys, to compare the relative corrosivities of marine environments around the world. The corrosion data generated from this program will be compiled for distribution to the participants and publication as a baseline reference.

The chairman of Committee G1 is Dr T.S. Lee and, subject to the approval of higher management at MRL, I agreed to his co-ordinating the Australian participation in this survey.

(g) **Corrosion of Ball Bearings** (Mr Morton)

The US Navy did have a storage problem with ball bearings. The packaging specification was improved and now the US Navy appear not to have such a storage problem.

4.4 Visit to the Army Materials and Mechanics Research Center, Boston

4.4.1 Aim of visit

To discuss research and consulting activities associated with corrosion problems experienced by the Army. Also to discuss the TTCP-PTP-1 Operating Assignment "Corrosion and Protection of High Density Penetrators" with the American Key Person (Mr Milton Levy).

Contacts: Dr Eric Kula (Chief, Metals Research Division)
Mr Milton Levy (Chief, Surface Behaviour Branch, Metals Research Division)

4.4.2 Information about AMMRC

The Center consists of three Laboratories:

- * Mechanics and Structural Integrity Laboratory
- * Organic Materials Laboratory
- * Metals and Ceramics Laboratory

The composition of the Metals and Ceramics Laboratory is as follows:

- * Metals Research Division (Dr E.B. Kula)

Physical Metallurgy Branch
Mechanical Behaviour Branch
Surface Behaviour Branch (Mr M. Levy)
Metal Matrix Composite Branch

- * Ceramics Research Division
- * Process Research Division
- * Prototype Development Division

The Purpose of AMMRC:

"As specialists in materials and solid mechanics, to support the Army by managing and conducting priority technical programs and communicating information in a timely manner, enabling the Army to develop, procure and maintain required systems."

This is summed up in their motto:

"Better Materials for Tomorrow's Army"

4.4.3 The visit

(a) Computerized Electrochemical Scanning System (Miss Nancy Kackley)

This system is used for examining the quality of welds and for determining the porosity of coatings (Sn, Al flame sprayed coatings, crevicing with stainless steels). The system is very useful for determining the quality of coatings, and is used for QA purposes for that reason. The quality of the weld is judged by examining the potentials across it.

Miss Kackley has submitted the work to MIT for a M.Sc. degree. Best resolution in the work was about 0.25 mm.

(b) **TTCP-PTP-1 Operating Assignment** (Milton Levy, Frank Chang and Richard Brown)

The USA is looking for 10-20 years storage life for this ammunition. They have studied several American W-based candidate alloys but have not commenced work on the 2 UK alloys or the Australian alloy although they have received the samples.

In their work, the corrosion behaviour of the high density tungsten alloys was studied by electrochemical potentiostatic polarization methods and by weight loss measurements in full immersion tests. The results indicated that a 97W-2Ni-0.7Fe-0.3Co alloy was the most corrosion resistant. The data also indicated that copper as an alloying element accelerates corrosion of tungsten alloys. Both general dissolution and localized attack at grain boundaries were observed.

The Americans have tried to protect these alloys from corrosion using ion implantation of Cr, or Mo, or Ti, but without a great deal of success. The British have found electrodeposited zinc, cadmium or tin, or ion vapour deposited aluminium satisfactorily protects the basis metal under warm, damp conditions, and it is the intention of the Americans to use these electrodeposited coatings.

On my part, I then made a very detailed presentation of the work we have done at MRL in the round-robin corrosion testing programme (1 USA, 2 UK, 1 AUS alloy). I also left them with a copy of a summary paper that I had prepared for the visit. They expressed considerable interest in the results.

In summary, therefore, it would appear that in the round-robin corrosion testing programme involving the USA, the UK and Australia, that Australia is the only country that has, to date, carried out corrosion tests on the candidate alloys from other countries.

(c) **Long-term Storage of Chemical Munitions** (Mr Levy)

The US Army maintains a stockpile of chemical munitions to be used as a deterrent. These toxic chemical munitions are basically conventional rounds of ammunition which contain toxic-agent-filler in lieu of explosive filler. Both unitary and binary systems of chemical munitions are used. However container material compatibility with agents, from the point of view of long-term storage, appears to be becoming a serious problem for surveillance inspection of nerve gas (GB) filled Weteye bombs has revealed several that are leaking because of corrosion of the Al 6061/Al 4043 weld alloy system. Another problem with these chemical munitions is associated with GB-leakage in 105 mm, GB-gas, M360 projectiles.

I inspected these rounds and participated (albeit in a small way) in the metallurgical examination of these leaking chemical munitions from the stockpile.

In the Weteye bomb, leaks had been observed at a weld in the fill port area. Metallurgical examination revealed crevice corrosion with a preferential attack of the silicon constituent in the weld metal. The corrosion was exacerbated by the original design of the fill port area and the associated weld. Electrochemical studies were also being done, and these were indicating that fluoride ions in the agent were responsible for the corrosion.

In the 105 mm GB projectiles, leaks were found only in those rounds with a two-piece brazed burster tube. Metallographic examination revealed that leakage was associated with a poor brazed joint, containing porosity and incomplete penetration. Corrosion of the steel burster tube occurred at the brazing alloy-steel interface. Upon exposure to the atmosphere, hydrolysis of the agent occurred, and further corrosion was noted at the site of elongated sulphide stringers of the resulphurized steel end plug.

Thus, in both systems, leakage was associated with welded or brazed joints, either an improper joint design or an inadequate brazed joint. Exposure to the atmosphere caused hydrolysis of the agent and a more intense corrosion.

The investigator of this corrosion problem, Mr Levy, was very irate that the meeting of TTCP-PTP-3 Ad Hoc Study Group 105, "The Chemical Survivability of Materials", held in Australia in August 1983, considered only the survivability of metals from the point of view of exposure to chemical agents during training or in conflict. It did not consider the problem of the long-term storage of these chemical agents which he felt was of equal or greater importance.

Mr Levy intends to propose that a TTCP-PTP-1 collaborative programme be commenced to determine the compatibility of chemical agents, particularly those involving binary weapon systems, with candidate metals such as tantalum.

APPENDIX A1

COMMONWEALTH DEFENCE SCIENCE ORGANISATION CONFERENCE

THE OPERATION OF WEAPON SYSTEMS AND PLATFORMS IN HARSH ENVIRONMENTS

PROGRAMME

MONDAY, 13 MAY

Chairman - Professor R.O.C. Norman (UK)

Address of welcome by the Rt Hon Adam Butler, MP, Minister of State for Defence Procurement (UK).

Session 1

Human aspects of the design of Army tactical data processing systems.

Mrs M.K. Carver, Mr A.L.C. Quigley & Mr N.A. Traylen (UK).

Interactive decision support systems for combat.

Major P.R. Ferguson (Australia).

Session 2

Computer-aided detection and tracking for surface ship sonars.

Dr I.G. Liddell (UK).

The use of simulation for passive sonar display design and operator training.

Mr M.J. Smith (UK).

Session 3

Video-game technology in training research.

Mr K. Ellis & Miss C. Heaton (UK).

A low-cost approach for training simulators.

Mr L. Magee (Canada).

Session 4

Man or mule? A look at load carrying equipment.

Lt Colonel K. Czoran (Australia).

Training flight simulator technology : DRDO experience and future plans.

Dr V. Srinivas (India).

TUESDAY, 14 MAY

Chairman - Mr K.G. Hambleton (UK)

Session 5

Delusions of adequacy: protective clothing on peace-time military exercises.
Mr R.C. Osczevski (Canada).

Protective clothing and thermal stress.
Dr D.J. Smith (UK).

The development of guidelines on the heat stress imposed by personal protective military clothing.
Mr C.Y. Gooderson (UK).

Session 6

Morale and motivational research in the Indian Armed Forces.
Dr L.P. Sen Mazumdar (India).

Retention Studies in the UK Regular Army.
Mr D. Dennison & Mr J. Kingdom (UK).

Session 7

Casualties in training - realism vs acceptable casualty levels.
Brigadier M.H. Mackenzie-Orr (Australia).

Explosive Ordnance Simulators - are they really cost effective?
Wg Cdr N. Alexander (Australia).

Session 8

The effect of environmental factors in aircrew performance.
Dr B. Ellis (UK).

The interaction of vehicle agility with pilot workload and task performance for battlefield helicopters in the nap-of-the-earth environment.
Dr G.D. Padfield (UK).

Impulse noise measurement, effects, protective measures, personnel monitoring.
(Mr N. Seabrook (Australia)).

WEDNESDAY, 15 MAY

Visit to the Royal Armaments Research and Development Establishment, Fort Halstead, Sevenoaks.

THURSDAY, 16 MAY

Chairman - Mr N.H. Hughes (UK)

Session 9 Using design to minimise corrosion in harsh environments.
Dr J.J. Batten (Australia).

Corrosion protection of land Service equipment.
Mr J.T. Heron & Mr J. Roberts (UK).

Session 10 Determination of the effective service-life of Variable
Depth Sonar tow cable on Canadian ships.
Dr J.R. Matthews & Dr B.F. Peters (Canada).

Modelling of bi-metallic corrosion in sea-water systems.
Mr J.C. Rowlands & Mr D.J. Astley (UK).

Session 11 The weathering of non-metallic materials.
Mr A. Davis (UK).

Lifeing and deterioration of polymeric materials.
Mr E.E. Gunn (UK).

The effects of the marine environment on the mechanical
properties of polymers.
Dr R. Lane et al (UK).

Session 12 Assessment of the service-life of weapon systems and their
components.
Dr R. Bird (UK).

Correlation of equipment failure in the field with
component reliability in design for assessment of provision
for spares.
Brigadier B.N. Kapoor (India).

Analytical techniques for the management of reliability
growth programmes.

Mr J.A. Hunt (UK).

Methods for calculating the number of spare parts required
to support the operation of weapon systems.
Major B.E. Hough (Canada).

FRIDAY, 17 MAY

Chairman - Professor R.O.C. Norman (UK)

Session 13 Assessment of the degradation in the quality of in-service
naval armament stores.
Lt Cdr C.J. Templeton (Australia).

The effect of climatic conditions on the storage life of the CRV7 rocket motor.

Mr D.L. Smith, Mr P.G. Harris, Mr A. Ouellet & Mr D.P. Morris (Canada).

The effect of local environment on some Indian weapons and ammunition.

Mr N.S. Venkatesan, Mr A. Krishna & Mr G.S. Dhami (India).

Session 14

Some Australian experiences of environmental design and serviceability problems with rocket motors and ammunition. Dr W.G.P. Robertson (Australia).

Ammunition design to withstand hot/dry climatic extremes. Major J.J. Goold (Australia).

APPENDIX A2

COMMONWEALTH DEFENCE SCIENCE ORGANISATION

CONFERENCE, 13-17 MAY 1985

LIST OF PARTICIPANTS

Australia

Professor P.T. Fink
Dr J.S. Adams
Dr J.J. Batten
Major J.J. Goold
Major General W.B. James
Brigadier M.H. Mackenzie-Orr
Dr J. Tregellas-Williams

Bangladesh

Brigadier E.H. Khan

Canada

Mr P. Solnoky
Major B.E. Hough
Dr L.E. Magee
Dr J.R. Matthews
Mr R.J. Oszcewski
Mr D.L. Smith

Ghana

Lt Col Seth Obeng
Major F.A. Apegyei

India

Dr V.S. Arunachalam
Brigadier K.K. Karayi
Dr V. Srinivas

Malaysia

Professor Dr Noramly Muslim

New Zealand

Surgeon Commodore A.G. Slark

Nigeria

Col I.O. Williams

Singapore

Mr Wu Tzu Chien
Mr Koh Wee Liam
Mr Wang Kang Ming

United Kingdom

Professor R.O.C. Norman
Mr K.G. Hambleton
Professor P. Hancock
Mr N.H. Hughes
Mr D.E. Humphries
Mr D.A. Fanner
Dr R.G. Loasby
Mr A.L. Oliver
Dr R. Bird
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Mr K.G.G. Corkindale
Dr A. Davis
Mr D. Dennison
Dr B. Ellis
Mr K. Ellis
Mr C.Y. Gooderson
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Mr J.A. Hunt
Dr R. Lane
Dr I.G. Liddell
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Mr T.D. Reed
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Mr M.J. Smith
Mr E.C. Tupper

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