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PRESERVATION AND PAINTING - MEETING THE ENVIRONMENTAL CHALLENGE

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PRESERVATION AND PAINTING - MEETING THE ENVIRONMENTAL CHALLENGE

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INTRODUCTION

The twin objectives of reducing Unit Production Cost (UPC) and Life Cycle Cost (LCC) are of long standing within the Ministry of Defence (MOD). The reduction of LCCs has assumed particular importance within the Royal Navy as it is intertwined with the need to reduce the maintenance effort required from ships' companies and to increase availability. Thus, in the field of preservation and painting improved and longer lasting coatings are constantly sought. Some of these coatings primarily provide protection against corrosion while others provide operational attributes eg anti-fouling or non-skid properties.

The technological challenges have been increased by the increasing requirements of environmental and occupational hygiene legislation. The Ministry of Defence is, of course, committed to the protection of the environment and of its workforce. This paper will only address occupational hygiene matters where they coincide with environmental issues.

Taking a positive approach, the challenge has also presented the opportunity to increase the pace of modernisation in products, processes and working practices and to achieve rationalisation of products. MOD's role has been 'proactive' as MOD is, arguably, the major shipowner having painting undertaken in the UK, and is especially affected by the impact of environmental legislation on the painting process.

THE LEGISLATIVE FRAMEWORK

It will be helpful to list here the major pieces of legislation which have required responses from the MOD and from the Marine Painting Industry at large. These are:

1. The Control of Pollution Act (COPA) 1974.
2. The Food and Environment Protection Act 1985.
3. The Water Resources Act 1989.
4. The Eighth Amendment to the European Commission Marketing Directive 76/769/EEC, 21 December 1989.
5. The Environment Protection Act (EPA) 1990.

There is also a proposal from the Commission of the European Communities for a Council Directive concerning the placing of biocidal products on the market, COM(93)351 final SYN 465.

The various UK Acts are 'parents' to Regulations and Orders which implement the requirements perceived to be necessary for the achievement of the desired environmental objectives. The MOD has been fully engaged in discussions between the 'users' and the regulators in many cases. The objective is, of course, to maximise environmental protection at an affordable cost without crippling operational capability.

All the legislation listed has imposed restrictions upon the marketing and use of anti-fouling paints, principally, but not exclusively, upon those containing Triorganotin compounds. The EPA 1990 also allows for the regulation of Volatile Organic Compounds (VOCs) in paints and for controls upon painting processes. The principal regulations affecting painting and preservation processes are briefly set out at Annex 1.

ANTI-FOULING PAINTS

Under the Control of Pesticides Regulations (Food and Environment Protection Act 1985) the Advisory Committee on Pesticides (ACP) makes recommendations to Ministers concerning the continuing registration of biocidal products. As part of this process, the Health and Safety Executive (HSE) is conducting a progressive review of non-agricultural biocidal products. Of particular interest to MOD is the Review of the Environmental Effects of Triorganotin Compounds and the Review of Copper Compounds Used in Antifouling Products. These reviews are being conducted by the ACP's Environmental Panel, ad hoc meetings of which the author attends as an 'invited specialist'. Much of the reviews' data concerning the effects of shipyard operations upon the environment is provided by MOD from the results of its own environmental monitoring programmes.

The measures taken to contain shipyard effluents (the Royal Yards have lead the way in this) and the programmes to monitor the long-term levels of Tributytin (TBT) in the environs of the Royal Yards and to monitor the effects of individual shipyard operations have been extensively reported (references 1 and 2 are examples). The monitoring of shipyard operations now includes analysis for dissolved copper. Work to identify the most efficient and economical means of monitoring 'integrated' levels of copper in the marine aquatic environment is being undertaken for MOD by the Defence Research Agency (DRA) and CAPCIS (a University of Manchester Institute of Science and Technology company).

MOD's long-term TBT monitoring programme is designed to demonstrate the trends in levels of TBT in the environment through the use of bioaccumulation techniques. The levels of TBT measured in the flesh of the oyster spat used for this work can only be approximately related to average concentrations in the water. However, the author considers the technique to provide a valuable indication of trends and of the efficiency (or otherwise) of the package of measures taken to reduce levels of TBT in the marine environment. Summary reports for the levels of mean tissue TBT content measured in Crassostrea Gigas (C Gigas) in esturial sites 'remote' from Rosyth Royal Dockyard (RRD), Devonport Royal Dockyard and Her Majesty's Naval Base Portsmouth are shown in Figures 1, 2 and 3 respectively. Figures 4 and 5 give summary reports for levels in the non-tidal and tidal basins in RRD. General trends are encouraging.

However, the statutory Environmental Quality Standard (EQS) for TBT in controlled seawaters is 2 ng/litre. An approximate bioaccumulation factor of 10,000 can be used to estimate average levels. Thus, in 1993, the last year for which a complete set of data is available, levels in the Forth were in the order of 5 ng/litre.

The National Rivers Authority (NRA) and Her Majesty's Inspectorate of Pollution (HMIP) cannot grant consents for discharges which will cause the EQS to be exceeded. It is readily apparent that consents are difficult to obtain, even though the concept of a mixing zone in the vicinity of a shipyard could allow consents to be issued for certain discharges at a concentration of 200 ng/litre. However, controls exercised by HMIP will be site specific and the dispersion of discharges may need to be modelled. The controls imposed upon shipyard operations involving TBT-Copolymer anti-fouling paints (the only type of TBT anti-fouling products used by MOD for some years) result in additional costs: some selected figures relating to the wash down of the anti-fouling paint on the hull of a typical frigate are given in Table 1.

Treatment of the effluent and subsequent discharge is an option. MOD sponsored the development of a pilot plant with a capacity to treat 250 litres of effluent: a schematic layout of this plant is at Figure 6, while Table 2 shows results typically achieved during the trials. Flocculation and settling of the suspended solids removes significant quantities of TBT. The liquor treated in the plant was run-off water collected immediately beneath the hull, whereas the liquor to be treated following a typical shipyard operation could be expected to have a lower concentration, levels of 1.9×10^3 - 7.3×10^4 ng/litre having been measured in samples taken from dock culverts.

The contractor who developed the plant has been licensed to market the technology. No plant has yet been sold, although Devonport Management Ltd (the operators of Devonport Royal Dockyard) have purchased a plant from Sweden, and have obtained a discharge consent from the NRA.

While the greatest potential sources of TBT pollution are perceived to be shipyard operations (hydro-washing, coating removal, paint application), the EQS can be exceeded eg at Sullum Voe where there is significant shipping activity but no shipyards. Hence, as part of the overall package of measures to protect the environment there are moves to seek international agreement on maximum permissible leaching rates - a figure of 4 $\mu g/cm^2/day$ is frequently quoted. If there is to be agreement on any figure, there must be an internationally recognised, repeatable and reproducible, laboratory method to determine leaching rates. The ASTM SMT 56B method is generally held to produce inconsistent results but is often advanced as, at least, the basis of a standard method of determination. As the availability of anti-fouling paints giving the performance required by the Royal Navy is considered to be essential, the rectitude of any regulatory procedure is of more than passing interest. Accordingly, the Defence Research Agency (DRA) has been tasked to conduct an extensive laboratory programme to evaluate the ASTM procedure and any modifications which will ensure repeatability. The HSE is sponsoring similar work which will be undertaken by the Ministry of Agriculture, Fisheries and Food and by the Plymouth Marine Laboratory. Thus, reproducibility will also be assessed. As considerable replication of samples and determinations are necessary to assure statistically acceptable results, the DRA's programme is not expected to complete before the end of 1995.

As responsible ship owners, MOD would wish to limit its use of TBT-Copolymer paints to those with the minimum TBT content and leaching rate consistent with assured performance. Although the paint companies' literature would suggest that for the speeds appropriate to Destroyers and Frigates ie 18 knots and upwards the 'slow polishers' should be used to reduce the leaching rate and to extend the life of the coating, the normal pattern of usage of our ships results in periods of "inactivity" during which faster polishing rates are required to achieve protection. These faster polishing rates are also considered to be beneficial in accelerating the removal of any fouling when the ship gets underway. In fact, the most reliable of the TBT-Copolymer paints used has a leaching rate of some 2.7 to 27 μg/cm^2/day at speeds from 1 to 20 knots (manufacturers figures).

TBT is an EC 'Red List' substance and a 'Schedule 1' substance under the EPA 1990. Copper, principally in the form of Cuprous Oxide, is generally considered to be the most immediately practical alternative to TBT as an anti-fouling biocide. It is, however, a List 2 substance under Council Directive 76/464 EEC and both the North Sea Conference of Ministers 1990 and the Paris Commission for the Prevention of Pollution from Land Based Sources seek the reduction of discharges of, inter alia, copper into the aquatic environment. The EQS for copper in the marine environment is 5 μg/litre (dissolved copper). The use of copper as an anti-fouling biocide is now the subject of a review by the HSE.

Copper, principally in the form of cuprous oxide, is present as a biocide in all anti-fouling paints used on ships of the Royal Navy - this is readily apparent from an examination of Figure 7, which lists the biocides present in a number of anti-fouling paints either in use or approved for use. Thus, the change in copper burden in the environment resulting from any moves to eliminate the use of TBT should not be great. For example, a "five year" TBT copolymer scheme from one manufacturer will, on a typical frigate's underwater area of 2,300 m^2, have a mass of some 1400 kg of CU_2O. A three year "tin free" system from the same manufacturer will contain about 930 kg CU_2O. The leaching rates quoted for Copper by the manufacturer are broadly similar. Ignoring differences in lengths of refit arising from changes in docking cycles, it will be apparent that a change from TBT-Copolymer paints to Erodible "tin free" paints should not result in a significant increase in the input of copper to the marine environment. The relative importance of anti-fouling paint as a source of copper pollution has yet to be established, but is thought to be minor.

A modification of ASTM SMT56B is being considered for determination of leach rates for copper. Quite apart from refinements - the method was developed by one manufacturer to suit his particular requirements and laboratory facilities - required to enable the method to be advanced as a standard, determination of the leaching rates of organic biocides need to be developed. Once analytical techniques which will detect and measure these organic biocides have been found, experimental techniques will need to be assessed. Techniques which produce concentrations of TBT or copper amenable to accurate analysis might not give the same results with organic biocides.

Initial Assessment of Anti-Fouling Coatings

Tin-free erodables are, in one major respect, a retrograde step in technology. The TBT-Methacrylate "back bone" in TBT-Copolymer paints hydrolyses reliably and predictably, releasing biocide at a rate dependent, inter alia, upon the ships speed. Most, if not all, "tin free" erodables use a soluble resin (natural or synthetic) technology. Reliable erosion is, in some cases, questionable or non-existent. Hence, laboratory methods to assess erosion and distribution of biocides through the paint film, are being sought. Anti-fouling performance will be assessed on the exposure raft.

The DRA and CAPCIS have been giving consideration to the techniques needed to examine the paint films. To date, the DRA has undertaken defect analysis of a failed "tin free" coating and analysis of a successful (4 years life) "tin free" coating using various microscopic analysis techniques. Scanning Electron Microscopy (SEM) was used to map individual coats of paint, while qualitative elemental analysis was undertaken using Energy-Dispersive X-Ray microanalysis (EDX) to determine the composition of the material in each of the coats of paint. Analysis of the cross-section of the coating using X-Ray Photoelectron Spectroscopy (XPS/ESCA) determined the presence and chemical state of elements - organic biocide was 'tracked' by the sulphur molecule - and X-Ray linescanning and mapping was carried out to plot the spatial distribution of selected elements across the whole paint scheme.

It is planned that a large number of replicates of anti-fouling coatings should be 'rotored' in sea-water for 3 months. Some samples will be examined by micro-analytical techniques to determine erosion, depth of leached layer, and distribution of biocides, while others will be placed on the exposure raft to assess subsequent anti-fouling performance. The scope of this programme is currently being revised - early ambitions exceeded the capacity of the anti-fouling exposure raft - and analytical options assessed.

VOLATILE ORGANIC COMPOUNDS

The UNECE Protocol setting a target of cutting emissions of volatile organic compounds (VOCs) by 30% from 1988 figures by the year 1999 was ratified by the UK in June 1994. Under the EPA 1990, a number of Secretary of State's Process Guidance Notes setting targets for VOCs in products and placing controls on processes have been issued, setting out the contributions to be made by sections of industry. Process Guidance Note PG6/23 sets requirements and procedures for, inter alia, manufacturing industry.

Shipbuilding is held to be 'manufacturing' whereas ship repair and conversion are not. Strictly speaking, therefore, the Royal Navy's maintenance operations could be claimed to be outwith the regulations. However, quite apart from it being difficult to envisage this situation continuing in perpetuity, it is difficult to envisage a situation where one range of products is used at new build and a further range of very different products is used for maintenance. Moreover, the Expert Panel on Air Quality Standards has recommended an Ozone standard which would require a 75-80% cut in VOC emissions rather than the current 30% commitment. Accordingly, the Directorate of Naval Architecture (DNA) has established a target for 85% of coatings specified to be 1998 VOC compliant by the end of 1995.

Table 3 records the principal VOC definitions for 1996 and 1998 compliance. It can be seen that the 1998 figures have been altered from time to time following discussions between the British Coating Federation (BCF) and the Department of the Environment (DOE). The most recent proposals are still the subject of discussion, and DNA's objective remains a VOC level of 250 gm/litre for primers and 420 gm/litre for 'top coats' - the term 'top coat' is taken to include anti-fouling paints.

In fact, in some areas, such as ballast tanks and reactor compartment finishes, products with a VOC content of less than 250 gm/litre have already been introduced and are being used in the later boats of the VANGUARD Class.

A typical ballast tank coating has a declared VOC content of 175 gm/litre and may be applied at temperatures down to 10°C. These products are intended for application by airless spray, and are not so easy to use in situations requiring brush application.

Weatherwork finishing paint and interior finishing paint are high usage products and reduction of VOCs in these products will make a major contribution to the reduction of airborne pollution. Water-based products are under evaluation for these applications, and a further aim is to achieve commonality between weatherwork, surface ship interior and submarine interior systems. Hence, suitable products are evaluated for all three applications, requiring that the paints meet requirements for fire characteristics and submarine atmospheric control. Not all water based products are suitable for all three applications, however. The submarine interior application is of considerable importance: the principal solvent in the two pack epoxy currently used is 1-Methoxypropan -2-ol (1, 2, 4 - Trimethylbenzene, Xylene, and a mixture of isomers are also present) which has an Occupational Exposure Limit (OEL) of 300 ppm for a 15 minute (average) exposure and an OEL of 100 ppm for an 8 hour time weighted average. These OELs are very difficult to achieve in a submarine interior when paint is applied at a practical rate. In service maintenance is virtually impossible.

One acrylic product has been in use in Royal Fleet Auxiliaries for some years, and is being evaluated as a weatherwork finish, although its comparatively low sheen (approximately 50 units using an Erichsen 60° gloss meter) could be a drawback. This product has also been applied to 2 compartments in HMS GRAFTON and is about to be tried on various areas of the internals of SSBN 07.

By no means all problems are solved by a change to water-based products, of course. Although the ventilation requirement for occupational hygiene reasons is greatly mitigated, air flow is required to enable water to evolve from the curing coating at an optimum rate. Obviously, humidity is critical but air flow is considered to be more important than temperature alone. Surface cleanliness is more critical than for the application of the existing alkyd products.

The museum ship HMS PLYMOUTH has been used a test vehicle for the application of water based weatherwork finishes. This ship is moored at Wallasey, near the mouth of the River Mersey, and the initial application trials were conducted in March 1994. Approximately 10% of the trial area allocated for each product was cleaned to an ST3 standard using power tools. Remaining areas were detergent washed. As the ship was downwind of an unloading berth, it proved necessary to wash the surfaces with fresh water daily to remove surface contamination. The weather was as might have been expected for the time of year - the air temperature varied from 6-15.5°C, the steel temperature from 5.5-15°C, and the Relative Humidity from 55-94%.

At high humidity and with little air flow, coatings took up to 1½ hours to become touch dry. Rain within ½ hour of application proved to have a detrimental effect. Neither brush nor roller application could achieve the required dry film thicknesses for the water based primers, and some rust staining was evident. It was concluded that, for weatherwork, a low VOC primer would be preferable. Not all the finishing coats had reasonable brushing properties: some coatings were, of course, at an earlier stage of development than others.

Levels of gloss achieved were lower than those achieved on initial application of the current silicone alkyd weatherwork finish. However, measurements of colour and gloss some 4 months later indicated good gloss retention. The four products applied in the Autumn of 1994 showed higher initial levels of gloss. Some selected gloss levels from the PLYMOUTH trials are shown in Table 4, together with some selected figures for silicone alkyd paint on the superstructure of HMS NORFOLK: these latter readings were taken before and after a deployment to the South Atlantic.

A full-scale trial of water-based finish in an operational ship is under consideration. An earlier trial in HMS COVENTRY was of limited success only, the constraints of surface cleanliness and weather conditions not being fully appreciated at that time.

VOC compliant weather and flight deck coatings are under initial evaluation in HMS BRISTOL, a harbour training ship. Certain products show promise, and it should soon be possible to proceed to an initial trial in an operational ship.

One paint evaluation programme of particular interest is that to find a VOC compliant replacement for the chlorinated rubber finish used in the reactor compartments of nuclear submarines for the past 30 years or more. VOC compliance was merely one of a lengthy list of requirements, but this requirement, together with severe limitations on trace elements and certain pigments, limited the number of candidate coatings offered for evaluation. The most severe test requirement was the evaluation of the paints in a "Design Basis Fault (DBF) Simulation" test - also referred to as the Loss of Coolant (LOCA) test. The terms were undertaken to a commercial standard for the Nuclear Power Generating Industry as this was (relatively) conveniently available. The test profile is shown in Figure 7. Only one candidate paint passed this test - it was, in fact, a ballast tank coating already in use, overcoated with a water-based epoxy to improve the decontamination characteristics.

The most scientifically challenging requirement was the determination of the thermal conductivity of the coating, especially as it was required to be determined at 200°C, in a steam atmosphere at 5 bar pressure. There is no standard method for determining the thermal conductivity of thin films, and the technique found to be available does not use a steam atmosphere. The technique used was the determination of thermal diffusivity using the heat pulse or laser flash technique. The thermal conductivity is calculated from the relationship

$$k = \alpha \rho Cp$$

where k is the thermal conductivity, α is the thermal diffusivity, ρ is the density and Cp is the specific heat at constant pressure. The specific heat is determined using Differential Scanning Calorimetry (DCS).

Determination of thermal conductivity in air has been determined and the thermal conductivity calculated. A test rig is being modified to measure thermal diffusivity in a steam atmosphere at 200°C and 1 bar pressure. Measurements will also be made in argon, a more usual-and cheaper-method, to establish whether or not the steam atmosphere affects the results obtained.

POWDER COATINGS

This environmentally friendly process cannot -yet- be used to coat a ship! The use of Fire Retarded Polyester powder coatings for component parts is an option now incorporated in the appropriate Naval Engineering Standard. Epoxy powder coated components are often to be found in equipments procured from industry.

SURFACE PREPARATION

Coating removal and surface preparation present further environmental challenges, and merit a paper in themselves. Suffice it to say that MOD, in close co-operation with industry, is constantly assessing the cost effectiveness and environmental credentials of all the techniques which are evolving.

SUMMARY

Meeting the environmental challenge to the painting process in a cost effective manner while continuing to deliver the performance required of the coatings of warships and submarines has provided, and will continue to provide, a stimulus to the development of new products and processes.

REFERENCES

1. D M ALLISON AND L J SAWYER, OCEANS '87, HALIFAX, NOVA SCOTIA, VOLUME 4, pp 1392-1397.

2. D ALLISON, N GUEST, AND J F D STOTT, MONITORING AND CONTROL OF DOCKYARD ACTIVITIES INVOLVING TBI-CONTAINING PAINTS, 3RD International Organotin Symposium, Monaco, April 1990.

Any views expressed are those of the author and do not necessarily represent those of the Ministry of Defence or HM Government.

ANNEX 1 - THE LEGISLATIVE FRAMEWORK

THE CONTROL OF POLLUTION ACT 1974

In 1986, regulations made under COPA restricted the retail sale of TOT paints to copolymer paints containing less than 7.5% tin in the dry film and free association paints containing less than 2.5% tin in the dry film.

In 1987, regulations made under COPA banned the retail sale of all anti-fouling paints containing TOTs and the sale of TOT anti-fouling treatments for aquaculture applications.

THE FOOD AND ENVIRONMENT PROTECTION ACT 1985

The Control of Pesticide Regulations (COPR) were made under this Act in 1986. On 1 July 1997, under the aegis of COPR, the full control on sale, supply, storage, advertisement and restrictions of use of TOTs to vessels over 25 metres in length came into operation. Anti-fouling products, even "non-toxic" low surface energy products, must be registered with the HSE.

THE WATER RESOURCES ACT 1989

Section 85 (Offence of Polluting Waters) states that "a person contravenes this section if he causes or knowingly permits any poisonous, noxious or polluting matter or any solid waste matter to enter any controlled waters." Controlled waters include dockyard basins and water within 3 miles of the shoreline.

Discharges require consents to be issued by the NRA.

THE EIGHTH AMENDMENT TO THE EC MARKETING DIRECTIVE, 76/769/EEC, 21 DECEMBER 1989

The Eigth Amendment introduced an EC wide ban on the application of TOT anti-fouling paints to vessels less than 25 metres in length.

THE ENVIRONMENT PROTECTION ACT 1990

EPA 1990 is wide ranging and requires, inter alia, the keeping of records of substances, and quantities thereof, discharged. Processes using Schedule 1 substances are subject to Integrated Pollution Control (IPC) by Her Majesty's Inspectorate of Pollution (HMIP). TBT is a Schedule 1 substance.

HMIP are due to issue, following discussion of draft versions, a "Chief Inspectors Guidance to Inspectors, Environment Protection Act 1990, Process Guidance Note IPR 6/1, The Application or Removal of Tributyltin or Triphenyltin Coatings." This will require operators to apply to HMIP for authorisation - a distinction is made between "existing processes" and "new processes". IPC is exercised on all aspects of shipyard operations involving TOT coatings, including VOC emissions and waste disposal. The aim in upgrading existing processes is to attain the appropriate control parameters by, generally, no later than 31 January 2000. The operator will be required to implement a compliance monitoring programme.

Waste Management Regulations, imposing a Duty of Care, have been introduced.

Secretary of State's Guidance Note PG6/23(92) introduces controls on VOC emissions for most painting processes (some, eg road vehicle finishing, are covered by separate Guidance Notes). Only users of 5 tonnes or more solvent or 20 tonnes or more of paint per annum are affected (at present). Basically, to comply with the requirements users will have to demonstrate that solvent emissions are less than 50 mg Carbon per cubic metre of air or use compliant coatings.

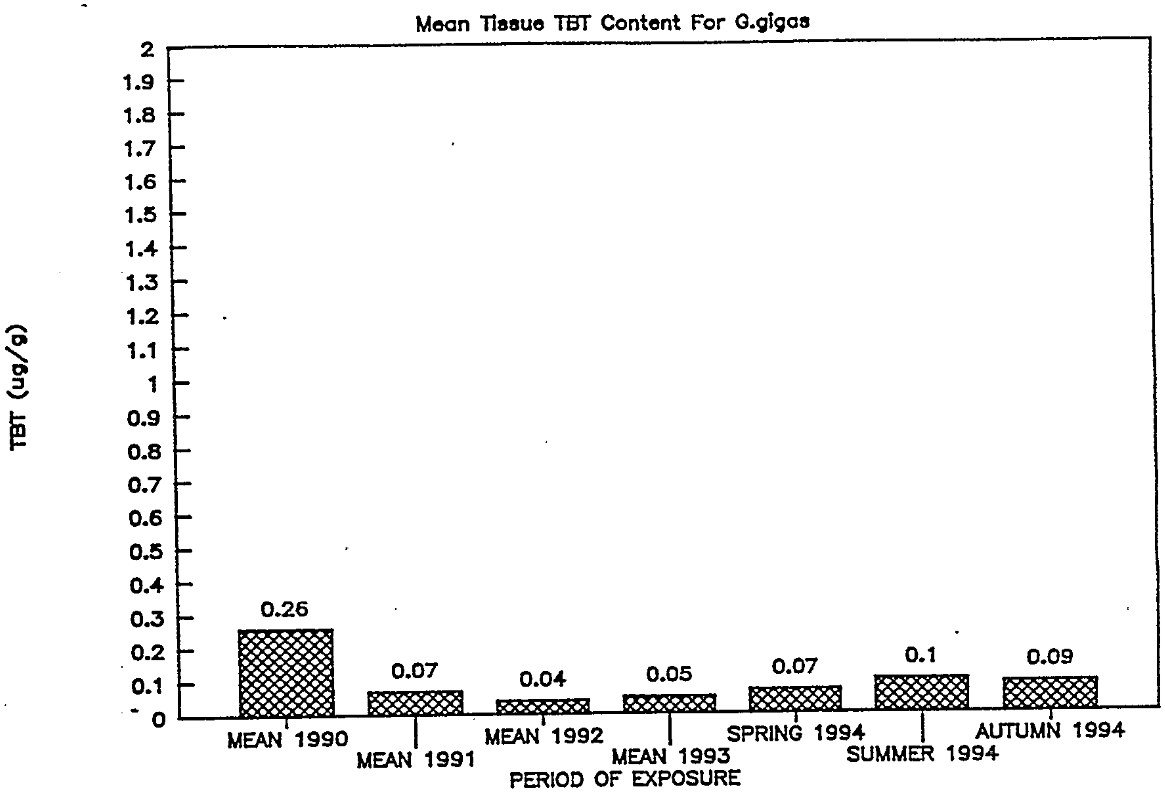

FIGURE 1

Rosyth Royal Dockyard - Integrated TBT Levels, Esturial Areas

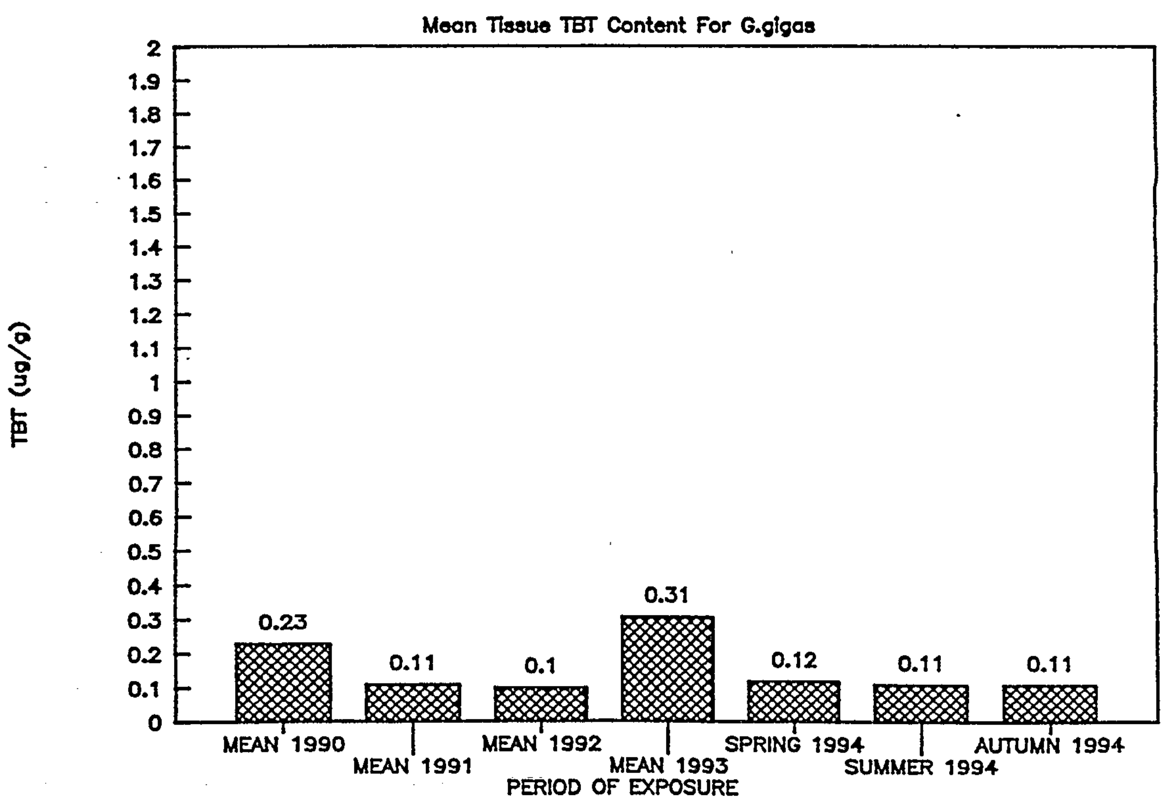

FIGURE 2

Devonport Royal Dockyard - Integrated TBT Levels, Esturial Areas

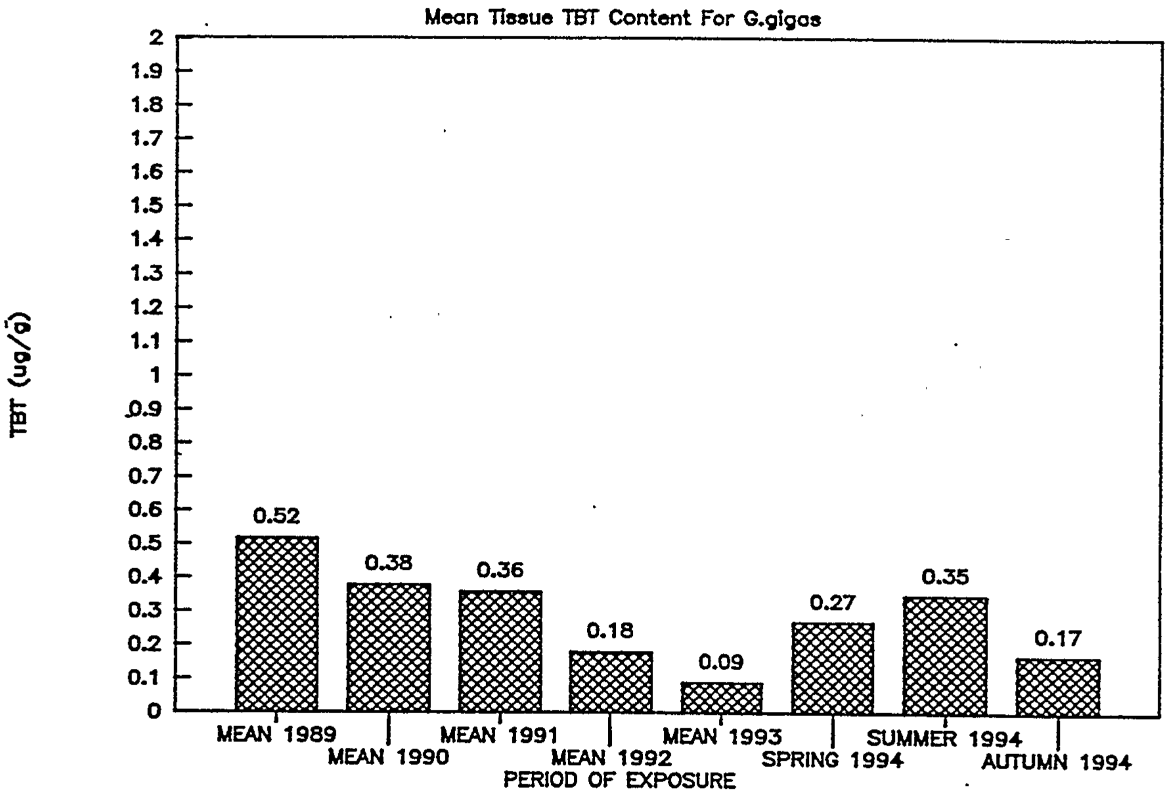

FIGURE 3

HM Naval Base Portsmouth - Integrated TBT Levels, Portsmouth Harbour

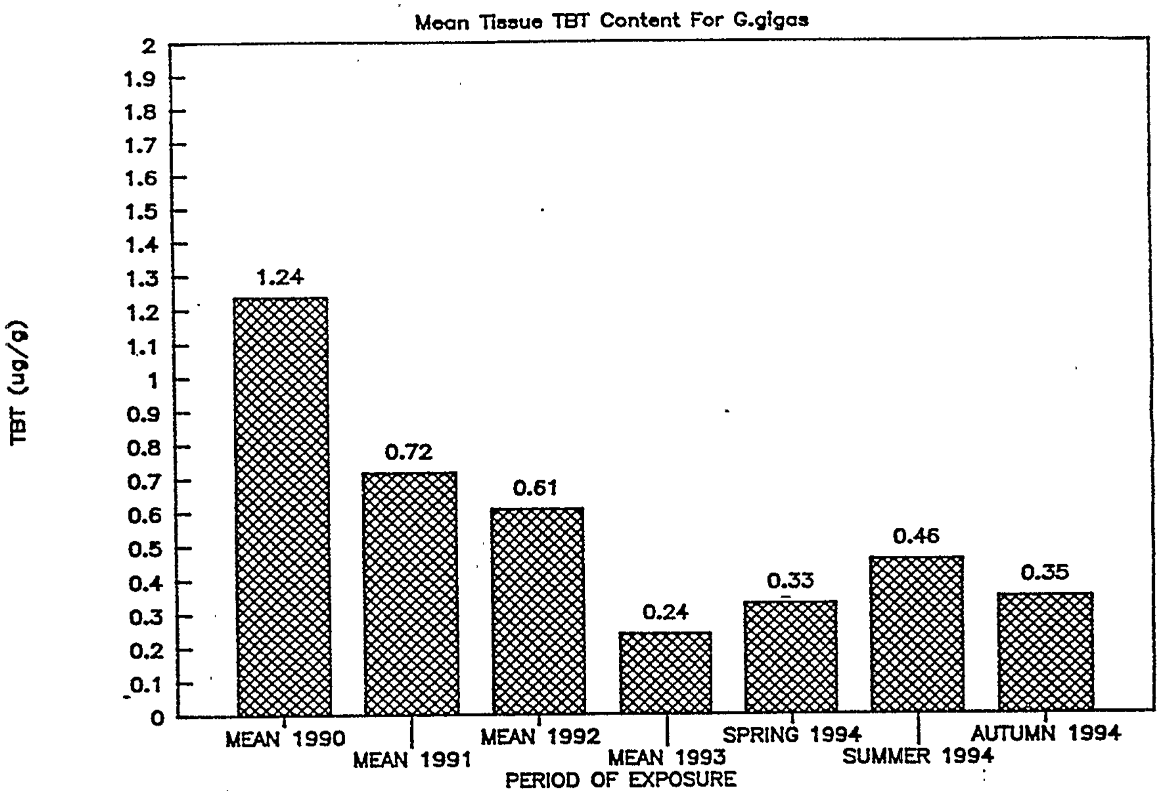

FIGURE 4

Rosyth Royal Dockyard - Integrated TBT Levels, Dockyard Basin

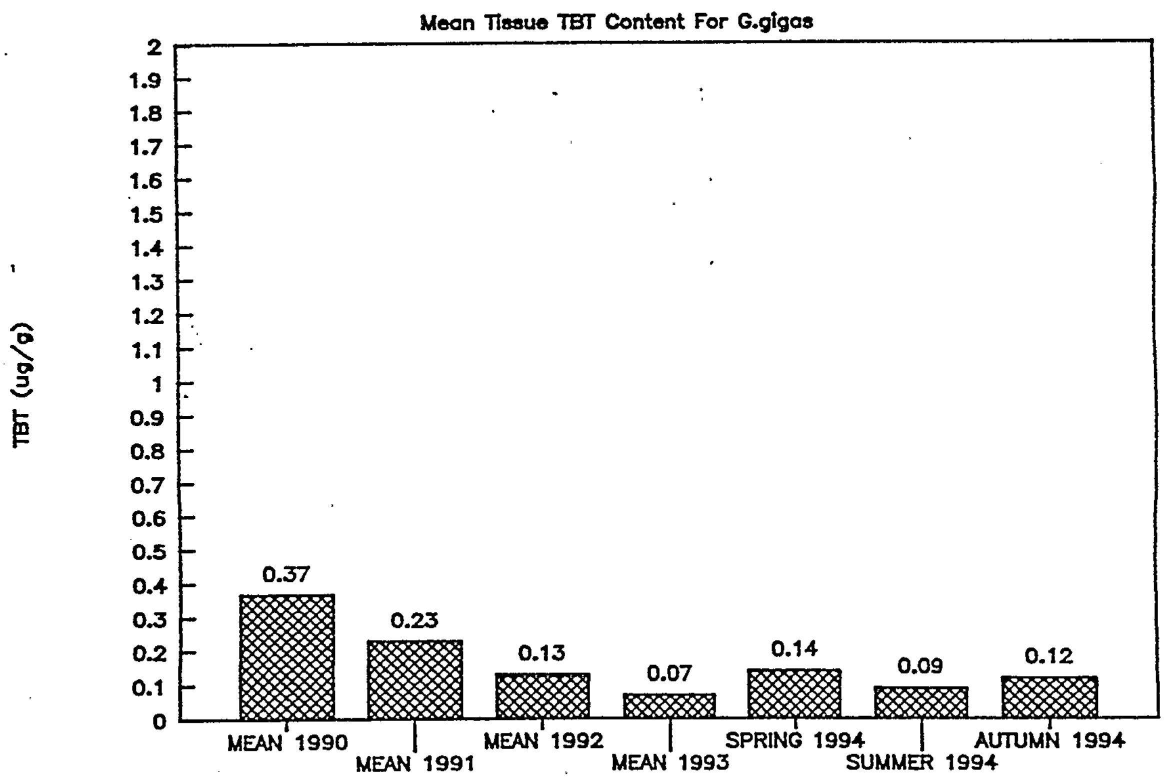

FIGURE 5

Rosyth Royal Dockyard -Integrated TBT Levels, Yard Tidal Area

DOCK PREPARATIONS FOR CONTAINMENT	2.5 MANWEEKS
SENTRIES, ETC, DURING WASHDOWN	2.5 MANWEEKS
FRESH WATER USED	60,000-75,000 litres
DAILY HIRE OF 20 TONNE ROAD TANKER	£1000-£3000 Approximately
NOTE: Actual cost of road tankers is dependent upon the distance of the disposal site from the yard, and hence the number of trips per day, or days per trip, involved.	

TABLE 1

SOME ADDITIONAL COSTS INVOLVED IN CONTAINING THE EFFLUENT FROM THE WASH-DOWN OF THE HULL OF A TYPICAL DESTROYER OR FRIGATE

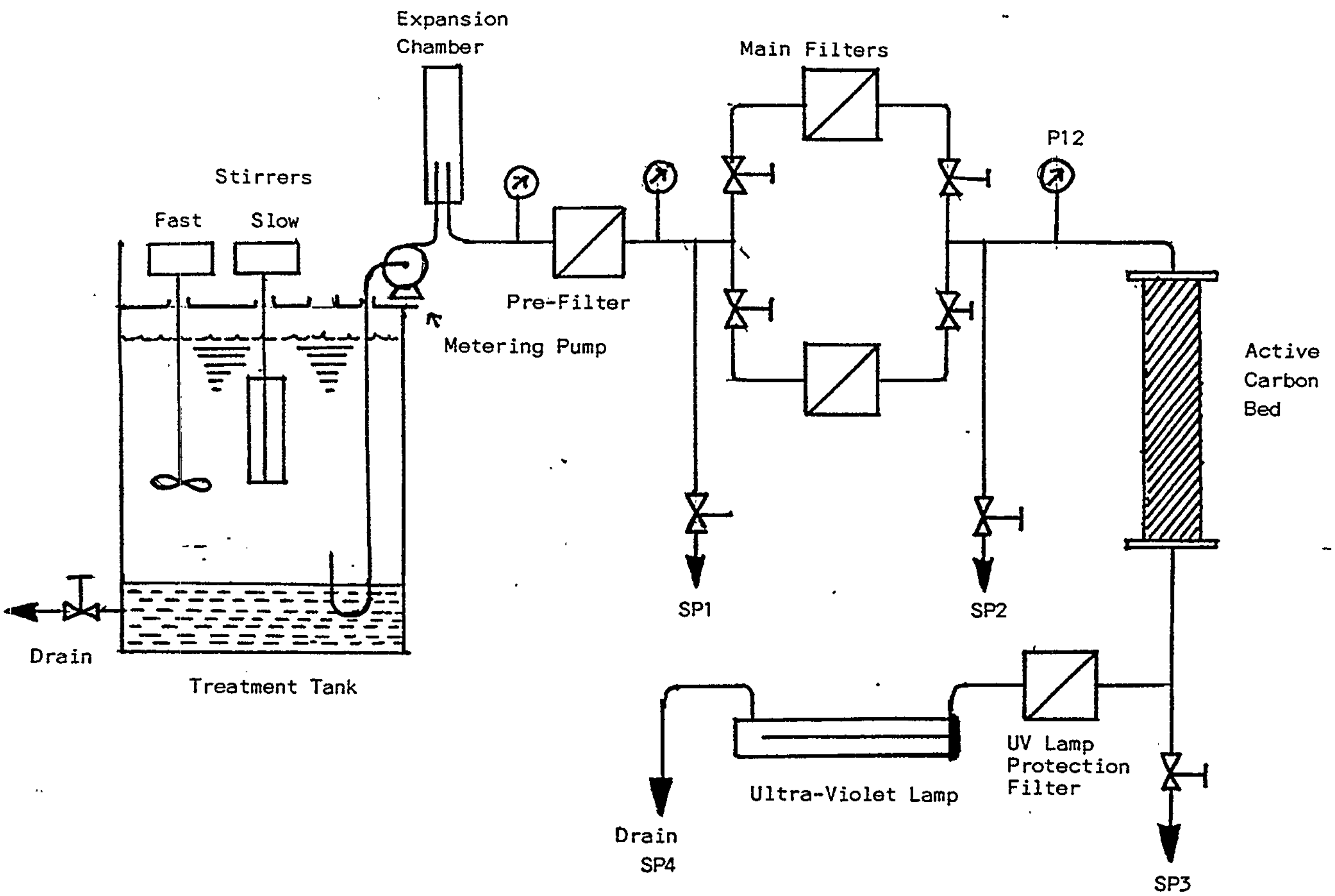

FIGURE 6

Pilot Scale TBT Removal Plant - Schematic Arrangement

SAMPLE POINT	TOTAL TBT ng/ltr	SUSPENDED SOLIDS PPM
RAW	2420500	380
SP1	1044300	0.8
SP4	49	3.6

TABLE 2

Typical Results from Pilot Scale Plant

FIGURE 7 SOME ANTI-FOULING PRODUCTS AND THEIR CONSTITUENT BIOCIDES

BIOCIDE / ANTI-FOULING PRODUCT	SEAMATE HB66	SEAVICTOR 50	SEAGUARDIAN	NAUTIC H1 7690	OLYMPIC-H1 7661	GRASSLINE M396	GRASSLINE ABL M349	ENVOY TF400 & TF500	SEAFLO Z-100LE -HS	TFA 10	INTERSMOOTH HISOL BFA 954/956	INTERSMOOTH BGA 530
CUPROUS OXIDE	●	●	●	●	●	●	●	●	●	●	●	●
ZINC OXIDE	●	●						●		●		
4,5-DICHLORO-2-N-OCTYL -4-ISOTHIAZOLIN-3-ONE		●										
2,3,5,6-TETRACHLORO-4-(METHYL SULPHONYL) PYRIDINE						●		●				
2,4,5,6-TETRA CHLORO ISOPHTHALONITRILE										●		
DICHLOROPHENYL DIMETHYLUREA										●		●
2-METHYLTHIO-4-TERTIARY-BUTYLAMINO-6-CYCLOPROPYLAMINO-5-TRIAZINE					●			●				
CUPROUS THIOCYANATE								●				
TRIBUTYLTIN ACRYLATE							●					
TRIBUTYLTIN OXIDE	●			●			●		●		●	
TRIBUTYLTIN METHACRYLATE	●			●					●		●	
ZINEB											●	

PRODUCT TYPE	VOC COMPLIANCE LEVEL, gm/litre				
	INITIAL PROPOSALS		1ST REVISION	2ND REVISION	MARCH 1995 PROPOSALS
	1996	1998	1998	1998	1998
METAL AIR DRYING COATING	400	250			
SHOP/HOLDING PRIMER				780	780
PRIMER			250	250	
TOPCOAT			400	420	
UNDERWATER ANTI-CORROSIVE, ONE PACK					560
UNDERWATER ANTI-CORROSIVE, TWO PACK					450
ANTI-FOULING TIE COATS					550
ANTI-FOULING TBT-COPOLYMER					450
ANTI-FOULING TIN FREE POLISHING					400
NON POLISHING TRADITIONAL ONE PACK ANTI-FOULING					450
BALLAST TANK COATINGS					400
BALLAST TANK COATINGS, WINTER WORKABLE					450
CARGO TANK COATINGS					475
POTABLE WATER TANK COATINGS*					350*
ONE PACK ABOVE WATER PRIMERS					520
ONE PACK ABOVE WATER FINISHES					560
HIGH TEMPERATURE RESISTANT COATINGS					600
TWO PACK ABOVE WATER PRIMERS					350
TWO PACK ABOVE WATER FINISHES					420
* LIMIT REPRESENTS AVERAGE FOR PRIMER (250) + TOP COAT (420) SYSTEM					

TABLE 3

PROPOSALS FOR VOC LEVELS IN COMPLIANT COATINGS

SHIP AND PRODUCT	60° GLOSS LEVEL			
	NOV 93	JUN 94	OCT 94	DEC 94
<u>HMS PLYMOUTH</u>				
LEAST GLOSSY MATERIAL		13.8	13.2	
ACRYLIC MATERIAL, STARBOARD		15.9	18.2	
ACRYLIC MATERIAL, PORT		49.5	52.0	
SILICONE ALKYD, LAUNDRY		39.5	#	
SILICONE ALKYD, BOMB ROOM		60.4	60.4	
WATER BASED SILICONE ALKYD		NA	50.0	
WB PAINT, SPRAYED		NA	80.2	
WB PAINT, BRUSHED		NA	47.6	
WATER BASED EPOXY		NA	67.4	
NOTE: # OVER-PAINTED				
<u>HMS NORFOLK</u>				
SILICONE ALKYD, LOWEST INITIAL GLOSS	34.0			29.1
SILICONE ALKYD, HIGHEST INITIAL GLOSS	78.0			58.0
SILICONE ALKYD, LEAST CHANGE	52.1			52.0

TABLE 4

GLOSS LEVELS MEASURED IN HMS PLYMOUTH AND HMS NORFOLK

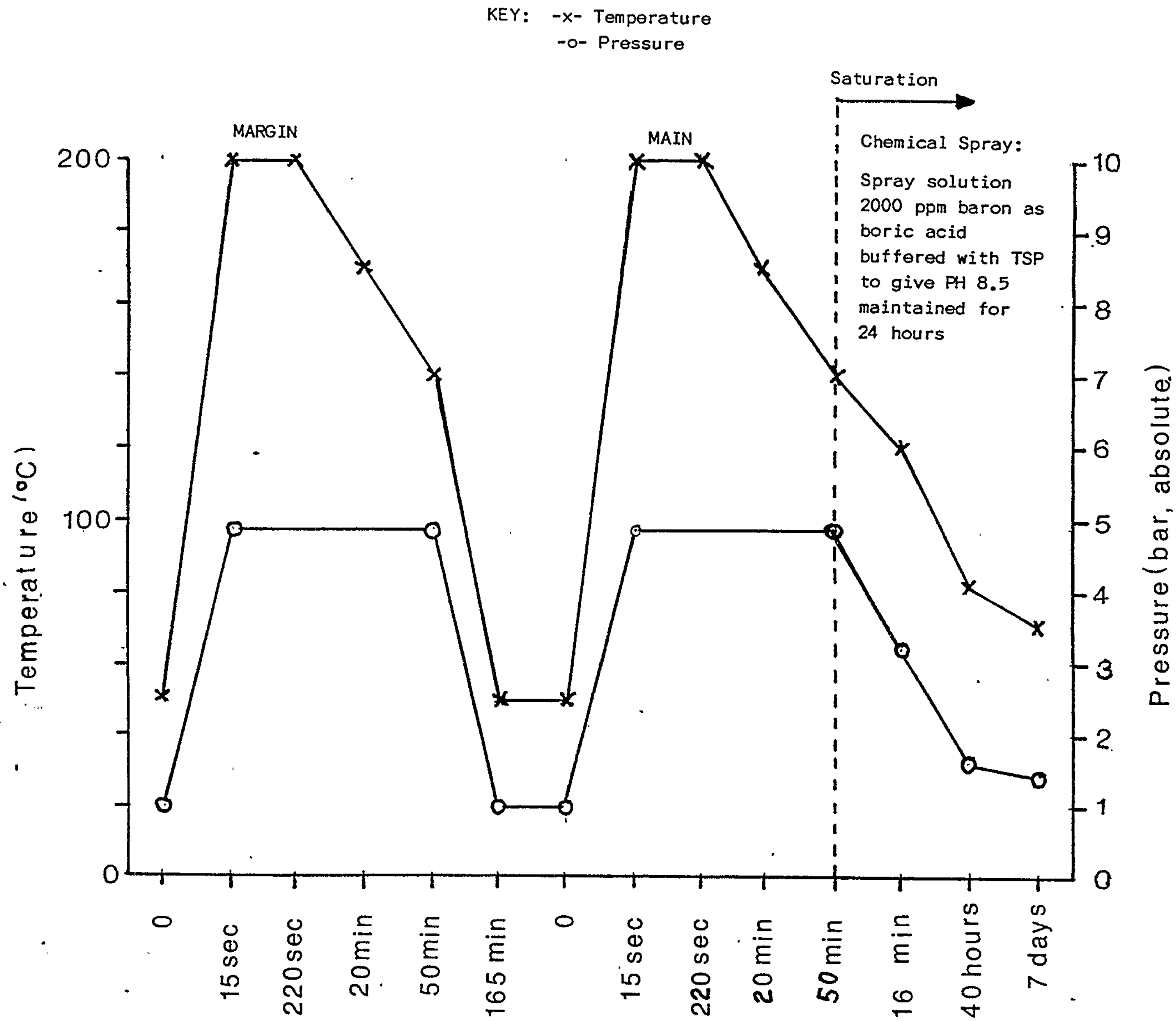

FIGURE 7

Temperature/Pressure Profile for Design Fault Basis (DBF) Environment Simulation