SS GREAT BRITAIN: CONSERVATION AND ACCESS — SYNERGY AND COST

David Watkinson and Matthew Tanner

ABSTRACT
Conservation and access are integrated within a unique scientifically-researched, cutting edge, desiccated storage system for preserving the iron hull of Brunel's steamship ss Great Britain. As part of the visitor attraction, conservation develops a synergy with the ship that effectively contributes to preservation costs by enhancing visitor experience and numbers. The ethical implications of a desiccation preservation strategy are discussed and the measures taken to mitigate its carbon footprint considered. The cost of conservation to society in energy terms is broached.

THE PROBLEM

As the first iron-hulled ocean-going screw-driven liner, whose innovative structure provided the blueprint for modern day hull design, the ss Great Britain is an international technological milestone. "It is impossible to imagine a more important survivor of our 'heritage' in terms of her significance in the industrial, economic and social development of Britain" [1]. Launched in 1843 and ending her life as a hulk in the Falkland Islands, she was returned to Bristol in 1970 and placed in the original dry dock in which she was built. Analysis of the hull estimated its current life span as 25 years before it became structurally unsafe for visitors [2].

The ethical question as to whether conservation of the ship is justified was addressed using the approach of Kerr [3] in a report commissioned to examine the importance of the ship's historical, technological and cultural contexts [4]. The resulting evidence-based argument advocated that preservation of the ship and its surrounding dock was of international importance. Survival of the original iron hull was central to any conservation plan. This was addressed in a second report that assessed the instability of the ship and considered conservation strategies [2]. The challenge was to identify a sustainable preservation strategy for an iron ship 99 m (324 feet) long that was infused with chloride, while retaining visitor access.

CHOOSING A CONSERVATION METHOD

Conservation treatments should not be applied without evidence that demonstrates their theory works in practice. Consequently the ss Great Britain Trust refused to be distracted by non-evidence-based conservation procedures, however attractive they may have appeared, and commissioned a study that rigorously assessed current iron conservation options [2].

This discounted much-used chloride removal techniques said to stabilize chloride-infested iron, as there is no published quantified evidence to suggest that they do anything other than enhance stability of iron. The amount of chloride remaining in iron after treatment is unquantifiable, which means post-treatment environmental control is necessary to counter corrosion threats posed by this residual chloride [5–7]. Washing treatments also pose technical and environmental challenges when used on a large scale. Removing chloride from the ss Great Britain by aqueous alkali extraction would require disposal of millions of litres of alkali [8]. Any chemical leakage during *in situ* treatment of the iron hull would enter the listed dry dock and be likely to seep into the adjacent river basin. Even with stringent design controls, permission from the Health and Safety Executive to undertake such treatments would be difficult to obtain. There is also a significant energy requirement to treat a large object like a ship, as temperatures of 60°C must be maintained for up to 80 days to optimize chloride extraction efficiency in alkali [9, 10]. Removal of chloride by electrolysis presents similar problems of scale, residual chloride and disposal of electrolyte solutions. It is also physically a high-risk strategy for heavily corroded iron. Passive protection using impressed current was not feasible due to discontinuities in the hull and differing potential between iron plates and various metal repairs [11].

The iron hull can be left with its chloride undisturbed deep within the metal and its corrosion layers, if corrosion is controlled by removing other components essential to the corrosion process. Eliminating oxygen from the hull environs was impractical from both visitor access and technological standpoints. The report concluded that for a large chloride-infested, corroded iron hull desiccation was the only preventive conservation option that was technically attainable and offered good visitor access [2]. Once no corrosion points are identified and maintained, desiccation provides a safe preservation system.

Desiccation: a conservation context

Desiccation has a financial and environmental cost. Active desiccation of large spaces like museums, galleries and stores requires significant amounts of energy to power a mechanical desiccation plant. These are designed readily to achieve target humidities that are dynamically monitored by electronic sensors. By quickly detecting failure to maintain target humidity they facilitate a rapid response to rectify the fault responsible. This makes desiccation potentially a safe storage system with easy visitor access.

Even small-scale passive micro-desiccation creates an environmental imprint by using hundreds or thousands of polyethylene boxes to house small objects with silica gel desiccant. Box production, silica gel manufacture and regeneration energy contribute to carbon footprint and there is significant financial cost in the form of staff time used to inspect and maintain the dry environments. Good management and significant availability of conservator time is essential for this system to succeed, which means in reality it can be a high risk strategy. Even when inspected, the internal environment of boxes is difficult to measure accurately using the inexpensive humidity sensitive paper strips sealed inside them [12]. Objects could sit in aggressive environments for years if management fails.

Energy expenditure and carbon footprints are subject to increasing attention in politics, the press and media, which means the environmental impact of large-scale environmental control of collections is open to close scrutiny. Should energy-hungry and polluting conservation options be implemented, even if the cost of rejecting them decreases the life span of an object? It may be that the whole balance of conservation needs to be reassessed relative to energy expenditure. Instead of ideal conditions that reduce decay to a minimum rate, it may be necessary to define more clearly the life span of objects and calculate their rates of decay relative to energy expenditure. For some materials, even the most environmentally-friendly conservation options may still produce a significant environmental footprint. Many questions remain to be addressed. What is the balance between preservation and environmental impact? At what point should cost and environmental impact influence the goals of conservation? Even if an initial high financial cost can be met with available resources, will future running costs either be financially sustainable or environmentally justifiable? The role of conservation in society must be robust enough to overcome its environmental impact. Education, enlightenment, cultural awareness and entertainment must be balanced against their cost in non-renewable energy and their ensuing carbon footprint. Is it possible that conservation is too closely scrutinized relative to energy expenditure in other areas of the heritage and leisure industries, as well as the workplace? By comparing conservation with other energy consumers is it possible to provide a crude 'value justification' for conservation? Aspects of these questions are considered in relation to the preservation of the ss Great Britain.

DESICCATION DESIGN

In choosing desiccation, responsibility was accepted for its carbon footprint. It was now important to examine how this footprint could be minimized. One long-term advantage of desiccation is that while its environmental impact cannot be reversed, it can be stopped by switching off the plant and deciding not to continue the preservation process. It is also an entirely reversible and non-interventive procedure, as there has been no chemical or physical interference with the hull, other than removal of free and adsorbed water. Consequently, treatment by a more cost-effective method is possible at any time if one is developed. Switching off the desiccation equipment leaves the hull much as it was the day it was desiccated.

The level of desiccation maintained will impact on the carbon footprint; the drier the environment the more expensive the cost of the desiccation plant and the greater its energy needs. Research was commissioned to identify both 'no corrosion' points and corrosion rates for chloride-infested iron as a function of relative humidity. These data would be used to design the desiccated environment and explore options for minimizing carbon footprint. Laboratory modeling of the corrosion mechanisms occurring within the chloride infested hull as it desiccates identified the relative humidities at which corrosion slowed and then ceased. At temperatures of 20°C corrosion ceased below 15% relative humidity, was negligible at 20% and did not produce a significant impact until 25% [13, 14]. A decision whether to prevent or minimize corrosion could be made using these figures, which would impact on design cost, fuel requirements and the ongoing carbon footprint.

Although the conservation ideal is to prevent decay, this concept should not create a rigidity of thought that prevents a pragmatic assessment of the conservation equation. Preventing decay may be either theoretically unattainable or limited by circumstance relating to factors such as management, budget and access. Data from the corrosion research program empowered the ss Great Britain team to carry out cost benefit analysis for differing desiccation designs, taking into account finance, environmental impact, visitor access and corrosion rate.

Projects rely upon successful grant applications for their underpinning; capital and conservation goals must be linked to the finite amount of money that can be raised. Besides value for money, grant awarding bodies require evidence that goals are viable in both the short and long term. Peer-reviewed corrosion research provided evidence for the success of the conservation methodology [15], and future funding for desiccation was built into the project as part of the visitor entrance fee. The best overall cost benefit analysis for the envelope design produced a preservation goal that specified a life span for the ship of at least 100 years, based on a target relative humidity of 20% (±3%) at 16 to 20°C. This was slightly above the no corrosion point identified by research [13]. A lower operational humidity would have required a more expensive outlay and a higher fuel consumption that would raise the carbon footprint of the preservation strategy.

Transferring conservation theory into practice relied upon design of the desiccation plant and protective envelope, future fuel costs, good public access and sufficient visitors to fund the fuel bills. The design of the protective envelope influences the amount of energy required to achieve the target relative humidity and defines the carbon footprint of the project. Money available for future operating costs was calculated using a conservative estimate of visitor numbers. Ironically, although fuel consumption is likely to be the most predictable component within the preservation equation, it is the least certain in terms of future cost.

Table 1 Examples of desiccation design options and operational parameters. Due to energy adjustments direct comparisons should only be made between options 1 and 2 or 3 and 4 [16].

Design parameters and controlled areas	*Option 1 Flooded waterline plate and glass enclosure over hull*	*Option 2 Waterline plate and glass enclosure over hull*	*Option 3 Flooded waterline plate*	*Option 4 Waterline plate*
Visitors:				
Ship	200	200	150	150
Dry dock	64	64	50	50
Water temperature	12°C	N/A	12°C	N/A
Maximum wetted area of dock	20 m^2	20 m^2	65 m^2	65 m^2
Controlled environment	15 ±5%	15 ±5%	20 +3%	20 +3%
Estimated annual running costs	£57541	£87750	£41815	£55062

Envelope design

Design of the envelope was considered in relation to energy expenditure, aesthetic merit and visitor experience. It required testing of new and innovative ideas and materials prior to their inclusion within a design. A number of schemes were considered and their running costs calculated relative to projected visitor numbers, area of freestanding water in the dock and operational temperature and humidity (Table 1).

An envelope around the whole ship and its masts was rejected outright as costly to build and maintain, with a negative aesthetic impact on both the Bristol skyline and the ship. A scheme to roof the dock with a glass waterline plate in conjunction with encasing the hull within a close fitting glass sandwich with a desiccated interior was deemed to be aesthetically intrusive to the line of the ship. This would detract from the visitor experience, which may ultimately reduce revenue and influence survival of the ship.

A unique and novel envelope design was chosen, which provided a horizontal glass roof between the dry dock edge and the hull waterline, Fig. 1. This waterline plate is flooded to a

Fig. 1 Artist's impression of the controlled envelope.

Fig. 2 Flooded waterline plate glass roof.

Fig. 3 Desiccated dock area underneath flooded waterline plate.

depth of 50 cm to create the visual effect of a floating ship, while the hull 'beneath the water' was visible to visitors who descended into the dock, Figs 2 and 3. This dock area and the interior of the ship were desiccated. At deck level double doors minimize environment interchange and energy loss between the controlled interior of the ship and the atmosphere. The exterior of the heavily corroded lower hull, which the survey had shown was infused with chloride, lay within the desiccated dry dock envelope [2]. The exterior of the relatively uncorroded upper hull was stripped to the metal surface and treated with a rigorous coating regime developed and designed by Robert Turner of Eura Conservation [8].

This design offers a breathtaking visitor experience designed to generate visitor income. While Brunel's ship is obviously a powerful magnet for visitors, large numbers of people also come to see the conservation system in action. Incorporating conservation into the visitor experience realizes its income generating

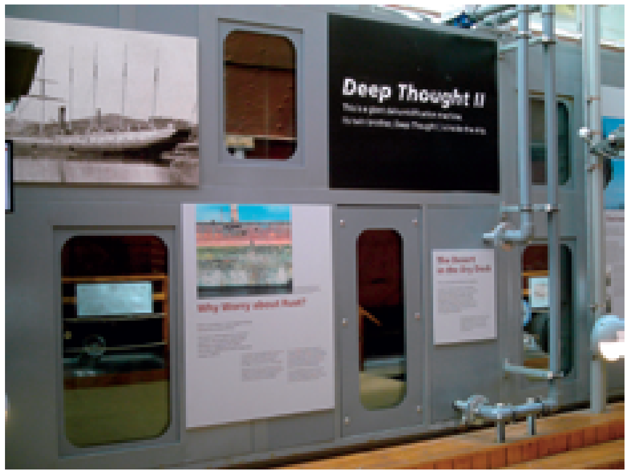

Fig. 4 One of two desiccation plants.

Fig. 5 Access for partially abled visitors via funnel.

potential. The environmental control technology and hardware is visible within the dry dock and visitors see this in action, Fig. 4. The ability to effectively 'walk underwater' while viewing the hull and its associated conservation technology is a vital part of the visitor package, along with the appearance of a floating ship from the dockside. This envelope design allows visitor access to all parts of the ship and wheelchair access is via a lift in the funnel shaft, Fig. 5.

The success of this symbiotic relationship between preservation and access generated first year visitor numbers that exceeded predictions by 54%. Throughout the conservation work there were 'hard hat' tours and the ship never closed to visitors. This

Table 2. Effect of flooding the waterline plate on energy conservation [16].

	Dock water cooling	*Conventional air cooled refrigeration*
Capital cost	£6700	£142700
Maintenance per annum	£5563	£8653
Energy p.a.	£1650	£12148
CO_2 emission kg year^{-1}	15600	115853
Percentage renewable energy	21%	0%

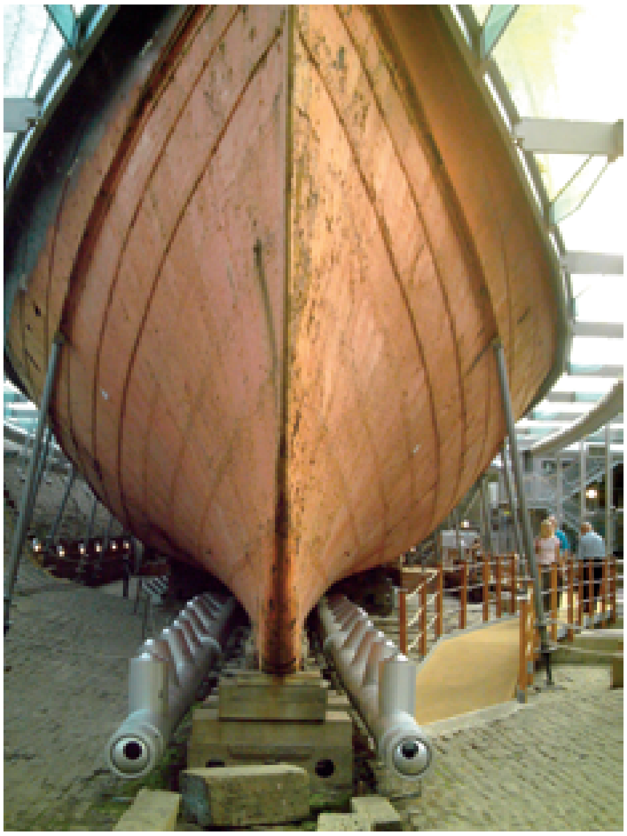

Fig. 6 Desiccated air ducted over the hull.

produced an atmosphere of expectation that boosted visitor numbers immediately following completion of the work. Reviews and visitor comments reflect the success of the preservation package: "… an example of museum excellence" (*Museums Journal*); "Outstanding at every level — this is visual poetry!" (Lord Winston, Chairman of the Gulbenkian Prize judges 2006); "It is the best museum I've ever been to precisely because it never feels like a museum at all. All museums should be like this" (Jimmy Wilson, London). This envelope design also has a number of advantages for limiting energy use and plant requirements.

Energy saving

Flooding the glass roof creates insulating properties and reduces solar gain, which produce significant energy saving. The water to flood the roof is taken from the adjacent harbor and is filtered, recycled and maintained at a consistent depth to prevent warm weather evaporation. This provides a cooling effect on the environment below it, where two large desiccating plants operate, and avoids the need for mechanical chilling in the desiccation system. Compared to an unflooded roof, a 20% energy saving is made, Table 2.

Further energy saving is made by channeling the desiccated air to where it is most needed on the hull surface. Air at 0 to 3% relative humidity is directed over the iron hull within the controlled space, Fig. 6. Away from the hull, surface air may be

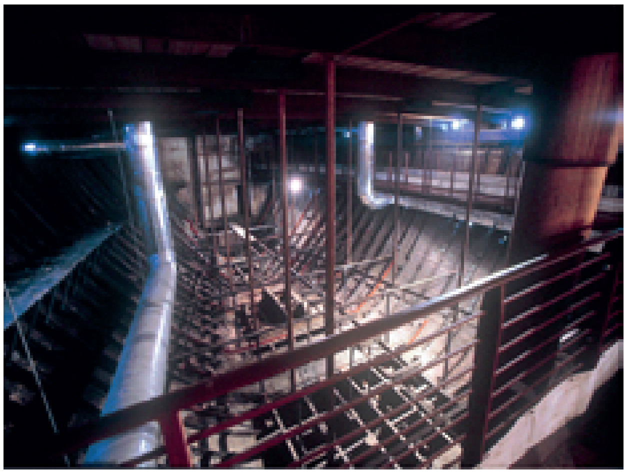

Fig. 7 Desiccated area inside ship exposing original structure of hull.

above the target 20% relative humidity. Twelve sensors sited at various points on the hull surface and within the dock record the environment for assessment and control of the desiccation plant. Other energy savings are made at a more mundane level, with over 1000 light bulbs being exchanged for low energy bulbs that save approximately 80% of the lighting energy bill as compared to tungsten bulbs.

Visitor experience and income generation

Reconstructions and displays on board show the full history of the ship. Visitors can see the hull construction in sections of the ship unchanged since its time as a hulk in the Falklands, Fig. 7. There are reconstructed areas showing steerage accommodation for emigrants to Australia and first class berths representing the ship as an ocean going luxury liner. Replica moving engines built to Brunel's original design are installed. Reconstructions offer no conservation problems in relation to the desiccated environment. Materials can be chosen to suit the conditions and if they respond badly to low relative humidity they can be replaced. No part of the original iron structure was drilled or defaced during the conservation program [2]. Only later additions to the hull were used to attach fittings mechanically. A pragmatic approach to income generation includes the holding of weddings and banquets on the ship. The galley is purpose-designed to support this, as it is separately ventilated and is sealed from the ship to prevent moisture ingress. The integration of the ship into the local community is clear from its popularity for weddings.

CONSERVATION IN OPERATION

Relative humidity readings reveal the overall success of the system, with hull sensors recording values from 15 to 25% with minimal fluctuations, Fig. 8. No system is proof from plant malfunction, but any failure to attain the prescribed conservation relative humidity is immediately detected by sensors and action can be taken. Such proactive systems have considerable advantages over passive conservation options like coatings and chloride extraction without environmental control. When these systems fail there is no early warning, only the symptoms of failure guide the conservator. By this time much damage may have occurred. Over-design of the desiccation plant has allowed it to cope with the larger than predicted numbers of visitors and water ingress through the sides of the dry dock. In high summer, internal temperatures in the controlled space may exceed the target values, but relative humidity was at the prescribed level. A recent leak from a faulty expansion seal on the glass roof dripped water into the dock, but this did not influence the operating relative humidity on the hull surface.

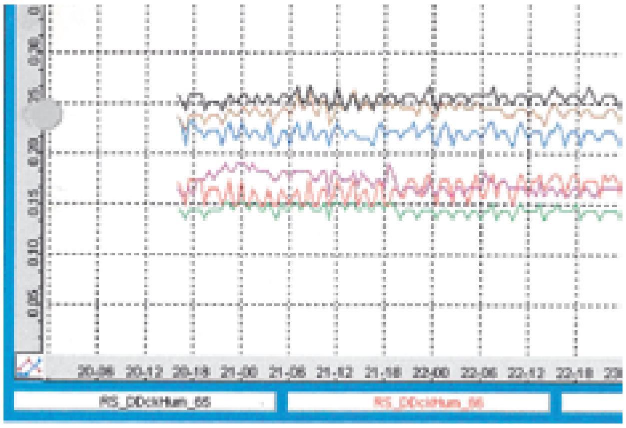

Fig. 8 Sensors show grouping within 15 to 25% relative humidity about the 20% target.

One unforeseen cost factor was the massive gas price rise in the winter of 2006–2007. The political and financial factors creating this could not have been predicted, but since the plant will only operate on gas there could be no turning back from the chosen conservation option. This factor and increased visitor numbers led to a fuel bill that was over double the expected amount. The carbon footprint slightly exceeded estimates, but its financial cost increased significantly beyond predictions. Based on the total time that the target relative humidity has been reached or exceeded and by using evidence derived from visual inspection and photographic recording of the hull condition, conservation is a success.

DISCUSSION

Whether creating a significant carbon footprint to preserve an object of international cultural significance is justified remains beyond the scope of this short paper. The currency of culture has many different forms. However, comparisons can offer a tangible context for the preservation of the ship. The ss Great Britain's yearly gas bill of £62000 is roughly equivalent to that of 120 semi-detached houses with an average annual gas bill of £500. Further calculation based on four persons per household reveals that 500 people are kept warm and fed for a year, while during the same time the ss Great Britain warmed and entertained 200000 visitors and preserved the ship. In terms of outcomes and energy expenditure, preserving the ss Great Britain seems to compare well with energy expended on heating homes.

The ship and dock are now a registered museum that occupies 14000 cubic feet (*c*.400 m^3). A museum, art gallery or office block of comparable size with air-conditioning will equally expend large amounts of energy. Routine energy use is unlikely to be subject to the same level of ethical scrutiny as the unusual desiccation of the ss Great Britain. Yet, in its favor, the ship is an object of world cultural importance to rival the contents of the most high profile museums. Ethical arguments to support the carbon footprint of the ss Great Britain are strong, when compared to air conditioning of office buildings. Beyond these immediate justifications a look into the future reveals the challenge of mitigating the financial impact of rising fuel costs on the preservation program. Access charges can be raised to match inflation, but increases in fuel prices are likely to outstrip this. This challenge can be addressed in several ways.

First is the realization that ship preservation only consumes part of the museum energy bill. A survey has identified a baseline from which resource savings can be measured [17]. These include the possible use of wind turbines to generate power. A local company has already been granted planning permission to erect three turbines. The ss Great Britain could use surplus energy from these and apply to build its own turbines. Within the environmentally-controlled dock, a full review of heat loss via the dock walls, energy effects of water ingress and optimization of energy pump and gas burner efficiency will provide routes for reducing in-system heat loss. Away from the ship a wide range of energy savings are possible and include fridge chillers, halogen lights and installation of Sunpipes for lighting and convection within buildings. The grade two listed dock offices offer less scope for instituting energy efficiency measures. Choosing an energy supplier that uses significant amounts of hydroelectric power will ethically reduce the carbon footprint.

A second less preferable approach involves matching corrosion control to budgetary constraints. Underpinning corrosion research allows conservation of the hull to be quantified as a function of relative humidity, thereby facilitating pragmatic management decisions regarding both the degree and cost of the corrosion control delivered. As fuel prices rise, expenditure could be kept static, but at the cost of reducing corrosion control by incrementally raising operational relative humidity. Even a 1% changes from the current 20% target can save on fuel. Above 25% relative humidity corrosion begins to become more appreciable [13, 14], but in contextual terms, humidities above this value still deliver significant corrosion control measured as the life of the hull. In effect, degree of preservation would be matched to available finance. This is a monetary manifestation of risk management. It could be speculated that this type of decision will face all museums in the future, as it is debatable if the exchequer will continually raise grants to public museums in line with fuel costs and many museums are high energy consumers.

This final comment need not sound a note of future gloom. Rather it recognizes an adjustment of the preservation equation to meet a changing world and signals a need for conservators to become comfortable with future decision-making strategies. Museums should not lose sight of their importance and their right to utilize energy, just as an office block commercially exerts its right to energy consumption. Overall, there is an energy price for everything, which may be big or small according to the project. Having identified an evidence-proven conservation route and minimized its carbon footprint, the question remains, "What price culture?"

ACKNOWLEDGMENTS

Thanks to Heritage Lottery Fund for finance and to Robert Turner of Eura Conservation.

REFERENCES

1 Greenhill, B., and Allington, P., *The first Atlantic Liners*, Conway Maritime Press, London (1997).

2 Turner, R., Tanner, M., and Casey, S., *Conservation plan for the Great Western Steamship Company Dockyard and the ss Great Britain. Volume 2 — Condition report and recommendations for the ss Great Britain,* ss Great Britain Trust (1999) (unpublished), http://www.eura.co.uk/ssgb (accessed April 2005)

3 Kerr, J.S., *The Conservation Plan. A Guide to the Preparation of Conservation Plans for Places of European Cultural Significance*, The National Trust of Australia (1996).

4 Cox, J., and Tanner, M., *Conservation plan for the Great Western Steamship Company Dockyard and the ss Great Britain,* Vol. 1, *ss* Great Britain Trust (1999) (unpublished).

5 Watkinson, D.E., 'Chloride extraction from archaeological iron : comparative treatment efficiencies', in *Archaeological Conservation and its Consequences,* ed. A. Roy and P. Smith, International Institute for Conservation, London (1996) 208–212.

6 Watkinson, D.E., 'Degree of mineralisation: its significance for the stability and treatment of excavated ironwork', *Studies in Conservation* **28** (1983) 95–90.

7 Selwyn, L.S., and Argyropoulos, V., 'Removal of chloride ions form archaeological wrought iron with sodium hydroxide and ethylene diamine solutions', *Studies in Conservation* **50** (2005) 81–99.

8 Watkinson, D., Tanner, M., Turner, R., and Lewis, M., 'ss Great Britain: teamwork as a platform for innovative conservation', *The Conservator* **29** (2005) 73–86.

9 North, N.A., and Pearson, C., 'Washing methods for chloride removal from marine iron artifacts', *Studies in Conservation* **23** (1978) 174–86.

10 Skinner, T., 'The treatment of archaeological iron by the alkaline sulphite method', in *Conservation of Iron*, ed. T. Bryce and J. Tate, National Museum of Antiquities of Scotland (1980).

11 Jones, D., *Principles and Prevention of Corrosion*, Macmillan, New York (1992).

12 Daniels, V.D., and Wilthew, S.E., 'An investigation into the use of cobalt salt impregnated papers for the measurement of relative humidity', *Studies in Conservation* **28** (1983) 80–84.

13 Watkinson, D., and Lewis, M., 'ss Great Britain iron hull: modeling corrosion to define storage relative humidity', in *Metal 04 Proceedings of the International Conference on Metals Conservation*, ed. J. Ashton and D. Hallam, National Museum of Australia, Canberra (2004).

14 Watkinson, D., and Lewis, M., 'Desiccated storage of chloride contaminated archaeological iron objects', *Studies in Conservation*, **50** (2005) 1–12.

15 Watkinson, D., and Lewis, M., 'The influence of atmospheric moisture on the corrosion of chloride contaminated iron', report submitted to ss Great Britain Trust and Heritage Lottery Fund (2001) (unpublished).

16 WSP, *Report on Simulated running costs for desiccation of the ss Great Britain* (unpublished).

17 Forsyth, S., *2007 Baseline Review Checklist*. *Envolve*, internal report commissioned by ss Great Britain Trust (2007) (unpublished).

AUTHORS

David Watkinson graduated in archaeological conservation from University College London Institute of Archaeology in 1975. Following work in museums he moved to Cardiff University, where he taught conservation and researched iron treatments for an MSc. He is currently a senior lecturer at Cardiff University responsible for BSc and MSc artifact conservation courses and a care of collections MSc. He has researched and published widely on metals, glass, object treatments and conservation education, with a focus on iron corrosion and conservation. He is an FIIC, ACR and FSA. Address: School of History and Archaeology, Cardiff University, Colum Drive, Cardiff, CF10 3EU, Wales, UK. Email: watkinson@Cardiff.ac.uk

Matthew Tanner gained a BSc and MPhil within maritime archaeology before entering the museum and heritage sector as a maritime specialist. After managing the fishing collections at the Scottish Fisheries Museum he became curator of maritime technology at the Merseyside Maritime Museum. Later he moved to the ss Great Britain Trust, where he headed the team that won £7.74 million from the Heritage Lottery Fund for the conservation and regeneration of the ss Great Britain. He sits on the Technical Committee of the National Historic Ships Committee, and is honorary secretary of the Association of Independent Museums. Address: Brunel's ss Great Britain, Gas Ferry Road, Bristol BS1 6TY, UK. Email: matthewt@ss-great-britain.com