# THE PRACTICAL APPLICATION OF CORROSION DATA TO STORAGE FACILITY DESIGN

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## ABSTRACT

Corrosion data developed for the British Advanced Gas Cooled Reactor (AGR) Program were used by National Nuclear Corporation (NNC) to design a dry spent fuel storage vault with passive, environmentally controlled air cooling. This paper describes the development of the corrosion data and their use in the storage facility design.

Conventional weight gain techniques used to determine the effects of humidity on various corrosion mechanisms do not yield, in general, corrosion data adequate for conditions of interest in the AGR program.[1] Specific tests were developed and carried out to satisfy the program needs.

The tests indicated that freedom from corrosion occurs below a critical relative humidity at the metal surface. The results and conclusions of these tests provide a convincing argument for the suitability of carbon steel containers for the long-term storage of spent fuel and high level waste.

## CORROSION AND CHEMISTRY CONSIDERATIONS

The major concern with respect to corrosion in a cooling air environment is the potential enhancement of atmospheric corrosion by the presence of pollutants in the atmosphere. The collection of such pollutants on metal surfaces provides the potential for the formation of aggressive solutions should wetting of the surface occur. Wetting can arise either by direct condensation or by the less obvious absorption of moisture present in the atmosphere due to the hygroscopic nature of the contaminants. Preston and Sanyal studied the influence of various salt deposits on atmospheric corrosion of carbon steel at 25°C.[2] They established the relative humidity above which some common contaminants wetted and produced short-term corrosion data for relative humidity levels up to saturation; critical relative humidities were also quoted for other salts. Table I shows typical critical relative humidities quoted by these authors and weight gain versus percent relative humidity for three of the salts studied are reproduced in Fig. 1. Consideration of the critical relative humidity data shows that some of the constituents of seasalt, namely calcium and magnesium chloride, have the lowest critical relative humidities of common contaminants. Because a dry fuel store constructed in the UK would be located by the coast, soundly based atmospheric corrosion data was vital for seasalt contaminated steel surfaces. Such data was not available in Ref. 2.

TABLE I

Percent Relative Humidity Above Which Some Salts Absorb Water (data given in Ref. 1).

| Salt | % Relative Humidity at Which Moisture Absorbed |
|---|---|
| $KCl$ | 80 - 90 |
| $NaCl$ | 58 |
| $MgCl$ | 33 |
| $CaCl_2$ | 31 |
| $NH_4Cl$ | 50 - 60 |
| $FE\ Cl_3$ | <<70 |
| $(NH_4)SO_4$ | 60 |
| $FeSO_4$ | <60 |

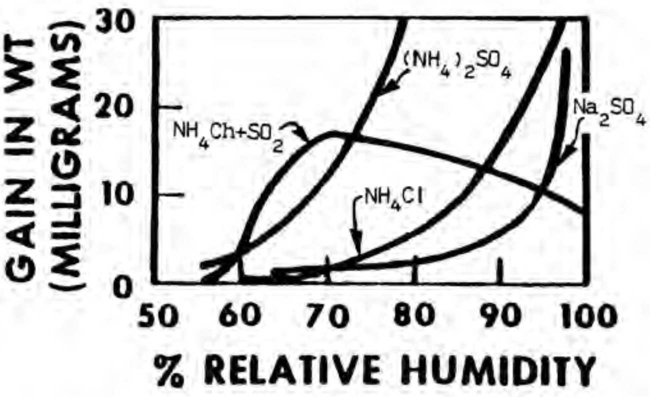

Fig. 1. Weight Gain vs Percent Relative Humidity for Three Seasalts.

However, NNC had already developed the necessary expertise to undertake research in this area as a result of work undertaken under Central Electric Generating Board (CEGB) and South of Scotland Electric Board sponsorship to support the British AGR Program. The carbon dioxide coolant in these reactors has been shown to contain trace levels of both ammonium chloride and ferric chloride which are known to collect on low temperature areas of the coolant circuit. The coolant contains a few hundred VPM of moisture and, hence, there was the potential for wetting of such chloride contaminated low temperature surfaces during normal operation with the attendant risk of corrosion. Components which were likely to be at risk from such corrosion had mostly been fabricated from carbon steel, although there were some austenitic steel items in such areas.

It was essential to establish with very great precision the critical relative humidities of these salts under normal coolant conditions so that a tolerable upper value for the coolant moisture level could be accurately established. It was also necessary to include tests in the air atmosphere representative of man-access conditions so that the required relative humidity control for such periods could be fully assessed. A suitable technique was therefore developed by NNC to permit such precise critical relative humidity data to be generated. This technique also allowed corrosion currents to be measured while the relative humidity was increased in carefully controlled steps.

Basically, the equipment consists of a cell comprising helical steel and platinum electrodes separated by polyimide (Figs. 2a and 2b) which is placed on a temperature controlled specimen table in a pressure vessel. The pressure vessel is filled with either air or high pressure $CO_2$ with a known controlled moisture level. The temperature of the specimen is varied to provide local changes in relative humidity. A corrosion current flows between the electrodes when moisture is absorbed onto the salt contaminated surface. A typical change in corrosion current with relative humidity is shown in Fig. 3; the salt in this case being ferric chloride.

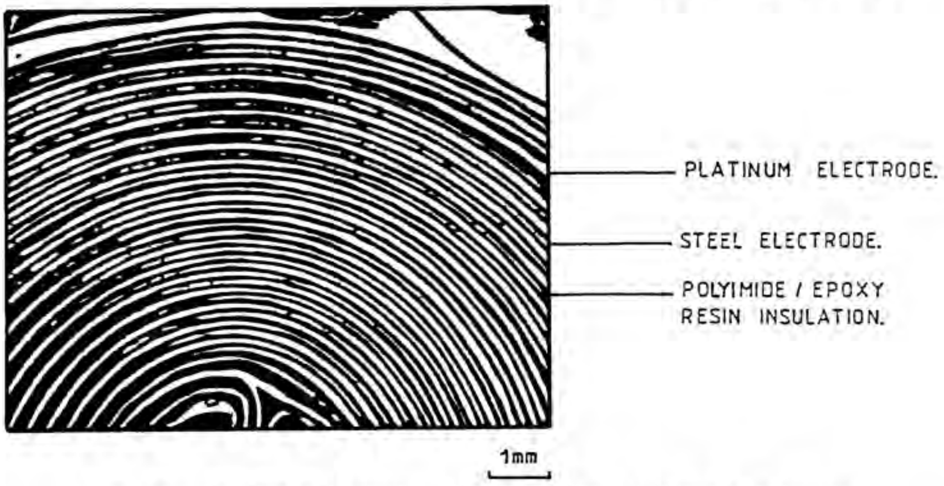

Fig. 2a. Surface of Corrosion Cell Showing Different Electrodes.

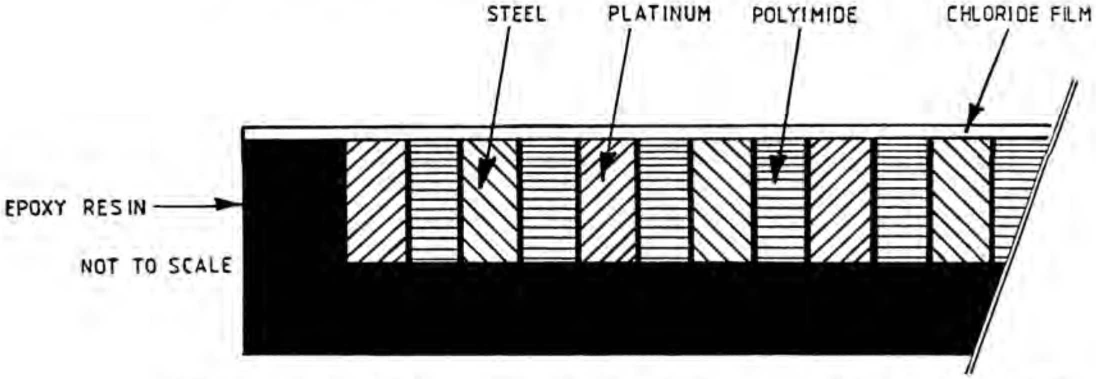

Fig. 2b. Schematic Representation of Section Through Part of the Corrosion Cell Showing Electrodes in Relation to Chloride Film.

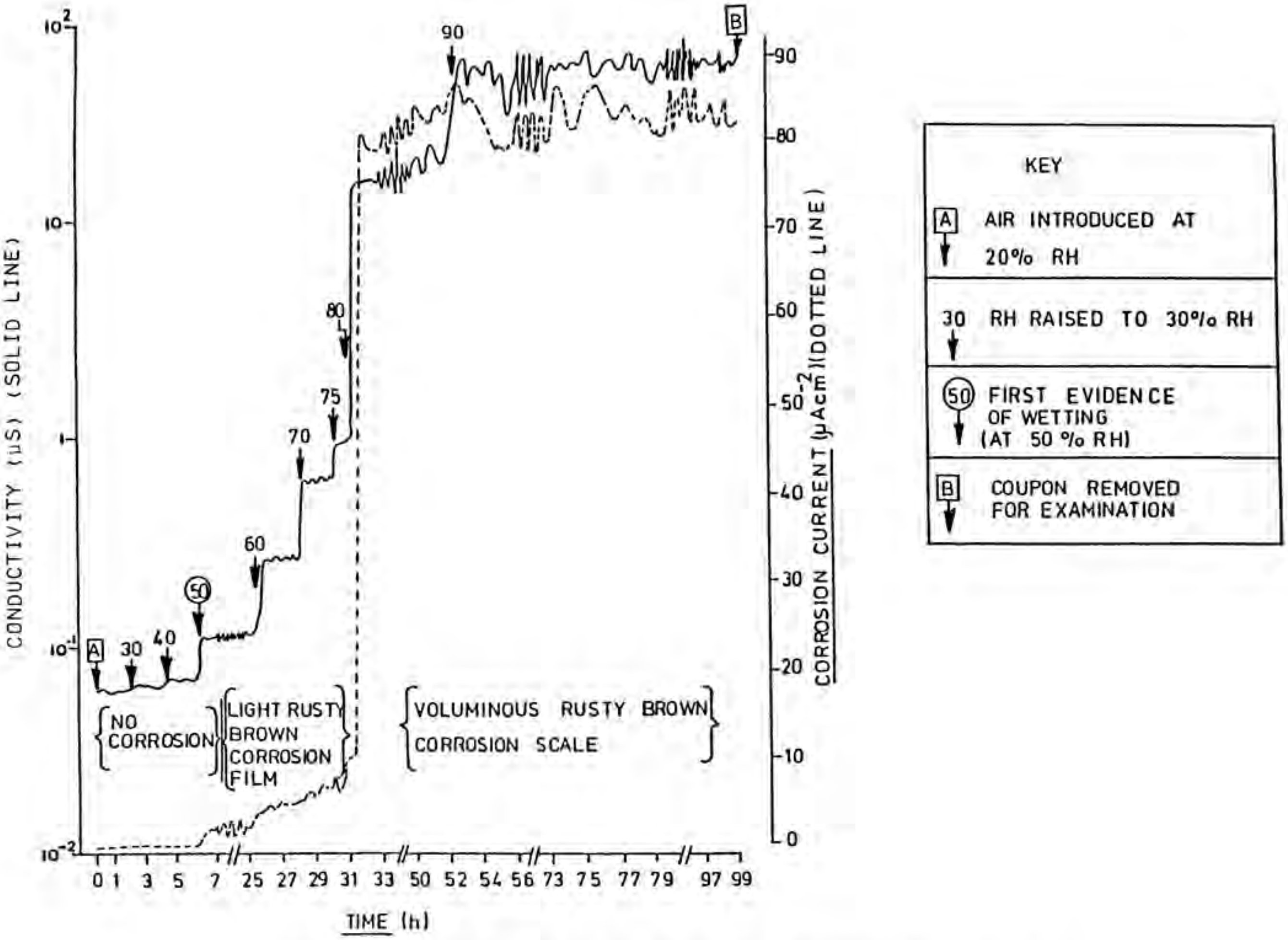

Fig. 3. Conductivity and Corrosion Current vs Time Plots for Mild Steel Corrosion Cell Coated with Ammonium Chloride and Exposed to 600 psia Air Containing 500 vppm Moisture.

## VAULT DESIGN

NNC, provided with these test data, designed a dry spent fuel storage vault with passive, environmentally controlled air cooling. The basic design of the facility includes use of a concrete vault module, with a number of vertical channels in a square matrix, that accommodate containers holding the fuel or vitrified high level waste. These are cooled by a direct air flow induced by natural draft. The relative humidity of the cooling air is lowered to below the critical point by mixing with the warm outlet air. This mixing is accomplished with a specifically designed venturi built into the vault module.

The facility is designed to receive irradiated fuel in a cask with a wet or dry environment. The equipment and procedures for unloading, washing, decontaminating, handling, and inspecting the cask are similar to those used at existing power plants and storage facilities. The fuel is moved from the shipping cask, dried, inspected, prepared for storage, and placed in a storage container by equipment in a hot cell. The hot cell contains special seals that maintain the outside of the cask and the container free of radioactive contamination. The containers are sealed by welding. No inerting of the container atmosphere is required to prevent fuel corrosion. Only under the special circumstances of waterlogged fuel pins is inerting required to prevent corrosion on the interior of the container. The size of the container is such that it can be conveniently handled and is suitable for accommodating fuel elements of different design. Stainless steel is not considered to be the best material; low carbon steel with good welding properties is preferred. Two fuel containers are loaded in each channel. The lower ends of the channels are set above the floor, the interspace being the air inlet mixing plenum. The resultant temperature rise of air in the annulus between the container and the channel tube produces natural-draft forces sufficient to induce convection cooling of the container wall, maintaining the enclosed fuel at an acceptable temperature. The space between the top of the channels and the underside of the vault roof provides outlet mixing and prevents the formation of hot spots on the concrete surfaces. The design allows a portion of this air to be recirculated to the inlet to preheat the incoming air and maintain temperatures in the channels at the level required to guarantee corrosion protection. Recirculation is induced by venturi-type recirculation ejectors, driven by natural-draft forces. The recirculation ejectors are constructed by using special forming during the concrete pours of the storage vault and are fitted with fabricated stainless steel nozzles as shown in Fig. 4. A very important feature of the design is that there are no moving parts or special linings within the vault.

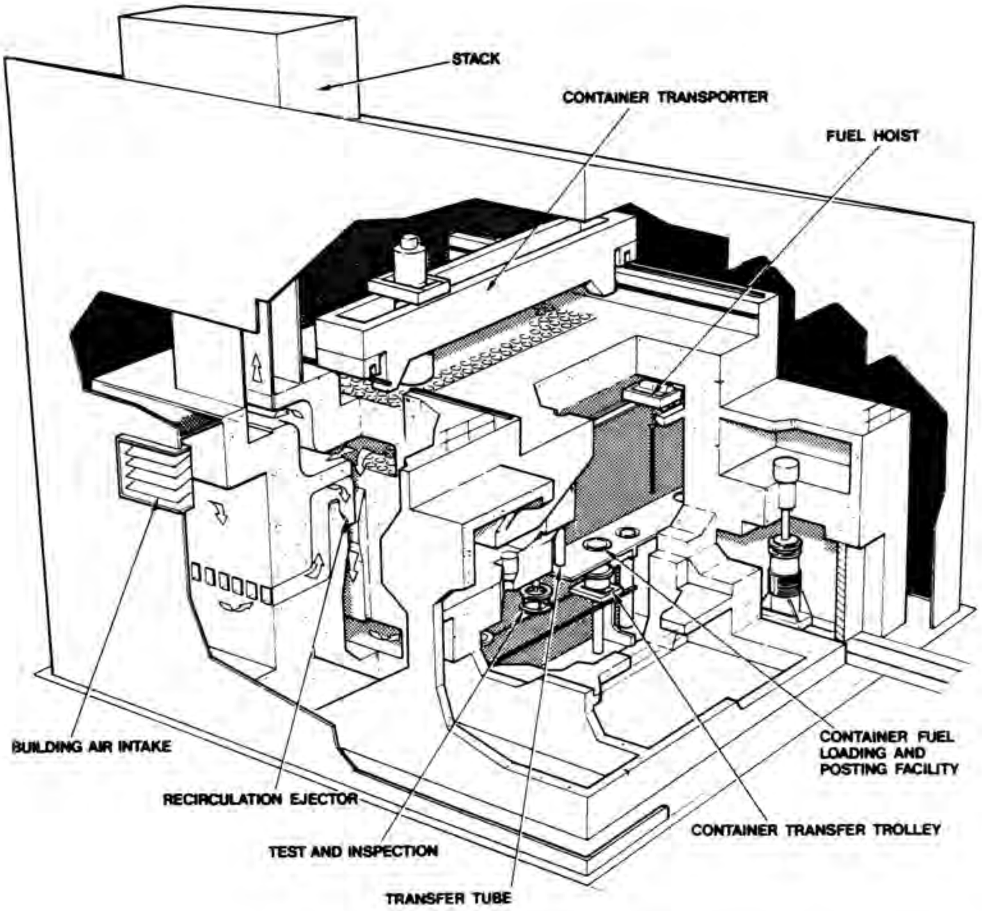

Fig. 4. PWR Dry Fuel Store

The transfer of heat by conduction, convection, and radiation from the fuel to the container wall varies with the type of fuel assemblies. In addition, the amount of preheat required for the inlet air varies with the maximum design ambient air temperature and humidity. The stack height, venturi configuration, and annulus gap between the fuel container and channel can be adjusted to suit any site ambient condition or fuel type.

The vault design continues to provide fuel cooling and environmental control as long as sufficient decay heat remains in the fuel to produce the required natural-draft forces. Ultimately, the vault may be sealed off to form a closed natural-circulation loop, via a heat pipe cooler, if necessary. The ability to seal off the vault makes this method of storage very attractive, especially for very long periods.

## CONFIRMATION TESTING

The mechanical design of the facility has been proven in model, full-scale flow, and wind tunnel testing. The long-term performance of the vault and its ability to prevent corrosion of material has been and continues to be the subject of ongoing test and evaluations by NNC. Corrosion testing of low carbon steel samples at various relative humidities has been under way since August 1983. The short-term nature of the available AGR corrosion data (up to 28 days) made long-term corrosion predictions of plant behavior difficult. Longer-term (12 months) corrosion tests were, therefore, initiated on both carbon and austenitic stainless steel specimens. At this stage, tests specific to the dry fuel store were also included, under CEGB sponsorship. The specimens in the Dry Fuel Store Program were exposed only to the air environment and the surface contaminant was seasalt due to the likely coastal location of the dry fuel store. The ferric chloride data produced for the AGR man-access situation could also have been relevant to the dry fuel store since iron chlorides could form as a consequence of corrosion in the presence of seasalt.

The long-term tests under AGR coolant conditions used the moisture control method developed for the relative humidity determinations, but tests in the air atmosphere relied on saturated salt solutions to control relative humidity. Corrosion monitoring in these long-term tests has been achieved by a combination of weight loss determinations on descaled specimens, plus detailed optical metallography to provide a realistic basis for extrapolation of corrosion behavior over full plant life. The AGR work was undertaken at 28°C while the dry fuel store studies were carried out at 25°C and 50°C; relative humidities investigated have covered the range 33 to 80 percent. This laboratory program has, therefore, furnished us with sufficient data to assess the corrosion behavior of both carbon steel and austenitic stainless steel dry fuel store components for any potential cooling air inlet conditions.

The conclusions of our testwork are that both carbon steel and austenitic stainless steel have good general corrosion resistance when exposed to the design conditions. However, some pitting does develop and this is greater for the austenitic stainless steel. Such steels rely on a thin tenacious oxide layer for their corrosion resistance, and the local destruction of the film by chloride causes deep pitting in moist environments. This mechanism is thought to have operated in these tests. Carbon steel is, therefore, the preferred material for components for which local penetration would be unacceptable (i.e., the containers) and, because of its cheapness, is the preferred material for the vault channels and general structures. However, austenitic stainless steel is considered the most appropriate for the venturi ejectors since it is important to maintain the surface profile so that the flow characteristics are essentially unchanged; very localized pitting does not influence this choice.

Finally, the container material needs to be sufficiently corrosion resistant to all potential internal container environments. Although fuel is dried prior to containerizing, the containers evacuated prior to receiving fuel, and, subsequently, argon filled before the final closure weld is made, it is necessary to consider the consequences of any process faults. Although it is extremely unlikely that either air or moisture would remain in the containers, the design must account for this situation.

The $\gamma$ dose associated with the fuel will convert any moisture and air present inside the container into nitric acid.[3] Assessment of carbon steel corrosion has been undertaken by calculating the amount of nitric acid formed, the amount of oxygen available for reaction, and then determining the quantity of metal which could be consumed. These calculations have been undertaken for a container that has not been argon filled, a container with waterlogged fuel pins, and finally for the highly unlikely case of a container having a leak. The calculations have confirmed that the container has adequate thickness to withstand any such corrosion.

The results of design and testing to date are directly applicable to most locations throughout the world. Only minor physical dimensional changes are required and these can be accomplished without invalidating the development or confirmation test. The application of this knowledge of the corrosion of low carbon steel provides a reasonable long-term storage alternative for storage of commercial spent fuel and high level waste.

## REFERENCES

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