(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 September 2001 (20.09.2001)

PCT

(10) International Publication Number
WO 01/69223 A2

(51) International Patent Classification^7: G01N 27/00

(21) International Application Number: PCT/GB01/01097

(22) International Filing Date: 13 March 2001 (13.03.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0005948.5 14 March 2000 (14.03.2000) GB
0005942.8 14 March 2000 (14.03.2000) GB

(71) **Applicant** *(for all designated States except US)*: **BRITISH NUCLEAR FUELS PLC** [GB/GB]; Risley, Warrington, Cheshire WA3 6AS (GB).

(72) **Inventor; and**
(75) **Inventor/Applicant** *(for US only)*: **HANDS, Brian** [GB/GB]; British Nuclear Fuels PLC, Sellafield, Seascale, Cumbria CA20 1PG (GB).

(74) **Agent: PAWLYN, Anthony, Neil**; Urquhart-Dykes & Lord, Tower House, Merion Way, Leeds LS2 8PA (GB).

(81) **Designated States** *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

(54) Title: IMPROVEMENTS IN AND RELATING TO INVESTIGATING CORROSION

(57) **Abstract:** The invention provides a method and apparatus intended to allow accurate monitoring of the corrosion behaviour of material when exposed to an environment. The method and apparatus are based around the field signature method. The invention particularly includes a method of investigating corrosion of a material in a given environment, the method including manufacturing a test sample from a sample of the material, providing two or more electrical contacts in contact with an internal surface of the test sample, providing an external surface of the sample in contact with the environment, measuring the voltage between two or more electrical contacts at a first time and at one or more other times, an external surface of the sample being in contact with the environment during one or more of the times, a current being passed through the sample at the time of the voltage measurement, the voltage measurements providing information about the effect of the environment on the sample with time, and wherein the internal surface of the sample on which the electrical contacts are provided is physically isolated from the environment during the voltage measurements by a seal.

IMPROVEMENTS IN AND RELATING TO INVESTIGATING CORROSION

This invention concerns improvements in and relating to investigating corrosion, particularly but not exclusively in relation to investigating corrosion potentially occurring in a body of material using field signature method based investigations.

A variety of situations, particularly in the nuclear industry, require components to be dispersed in a non-hazardous component and formed into a body of material for subsequent storage. Encapsulation of radioactive waste materials is one such example. To safely store the bodies of material over extended periods estimations must be made of the long term effects of the storage, particularly on the integrity of the body of material used to retain the hazardous material and/or shield against emissions arising therefrom.

Other situations, such as reinforcement in concrete, also need predictions of behaviour, principally corrosion, over time.

The present invention aims to provide methods and apparatus for investigating the behaviour over time of bodies of materials potentially containing a variety of components and potentially exposed to a variety of conditions in an accurate and reliable manner, amongst other aims.

According to a first aspect of the invention we provide a method of investigating corrosion of a material in a given environment, the method including

providing a sample of the material,

providing two or more electrical contacts in contact with the sample,

providing the sample in contact with the environment,

measuring the voltage between two or more electrical contacts at a first time and at one or more other times, the sample being in contact with the environment during one or more of the times,

a current being passed through the sample at the time of the voltage measurement,

the voltage measurements providing information about the effect of the environment on the sample with time,

and wherein the electrical contacts are physically isolated from the environment during the voltage measurements.

The sample of the material may be manufactured to provide a test sample.

The two or more electrical contacts are preferably provided on an internal surface of the sample.

Preferably an external surface of the sample is provided in contact with the environment. An external surface of the sample is preferably provided in contact with the environment during one or more of the measurement times.

The electrical contacts may be physically isolated from the environment by seals or covers. Individual seals or covers may be provided for one or more, even all the electrical contacts.

Preferably the internal surface of the sample on which the two or more electrical contacts are provided is physically isolated from the environment during the voltage measurements, ideally by a seal.

According to a second aspect of the invention we provide a method of investigating corrosion of a material in a given environment, the method including

manufacturing a test sample from a sample of the material,

providing two or more electrical contacts in contact with an internal surface of the test sample,

providing an external surface of the sample in contact with the environment,

measuring the voltage between two or more electrical contacts at a first time and at one or more other times, an external surface of the sample being in contact with the environment during one or more of the times,

a current being passed through the sample at the time of the voltage measurement,

the voltage measurements providing information about the effect of the environment on the sample with time,

and wherein the internal surface of the sample on which the electrical contacts are provided is physically isolated from the environment during the voltage measurements by a seal.

The first and/or second aspects of the invention may involve one or more of the following features, options or possibilities.

Corrosion of the material as a whole may be equated to corrosion of the sample. In particular the rate and/or amount of corrosion which is measured for the sample may be deemed to apply to the material as a whole in the given environment.

The corrosion investigated may occur throughout the sample and/or at one or more specific parts of the sample. The corrosion may occur due to contact between the sample and one or more components of the environment. The environment in question is preferably the external environment for the sample. The corrosion preferably arises as a result of chemical attack on the sample and/or mechanical wear on the sample in some situations. Corrosion may, but preferably has not actually occurred at the time of the first voltage measurement for the sample.

The material may be a hazardous material, particularly a solid. The material may be a radioactive material, particularly a solid. The material may particularly be uranium, preferably in elemental form. The material may be a metal, such as steel. The material may be a structural component, for instance reinforcement.

The environment may comprise one or more of any solid, liquid or gaseous components in contact with the sample or material. The environment may include one or more dissolved species. The environment may include an encapsulating material and/or concrete and/or vitreous material. The environment may include water and/or one or more acids and/or one or more alkalis and/or one or more organic liquids and/or one or more inorganic liquids. The environment may include air and/or gases produced by chemical reaction and/or decomposition of components of the environment and/or gases produced by corrosion and/or gases produced fissions. The environment may include cations and/or anions, such as might arise from solubilising of one or more components of the environment.

The environment may include the pressure and/or temperature and/or pH of the samples surroundings.

The environment may change over time. The environment may be that environment occurring within a container in which the sample is also present. One or more components may enter and/or leave and/or arise within the contained environment from the general environment, usually the ambient environment outside the container. This may particularly be the case if the container is opened or in some other way breached.

The environment may in particular be a grouting material provided within a metal container, such as a drum.

The test sample may be manufactured by taking a sample of the material and subjecting it to one or more altering processes. The manufacture may particularly involve machining or otherwise forming at least a part of the shape and/or one or more surfaces of the sample. Preferably the manufacture involves forming an internal surface for the sample, particularly an internal surface within a bore in the sample. Preferably the bore is open at one end, for instance to allow the electrical contacts to be introduced and is open or closed at the other end. The bore may have a circular cross-section. Preferably the manufacture involves forming an external surface for the sample, particularly an external surface which contacts the environment during measurements. Preferably the external surface is of circular cross-section and ideally a cylinder is defined. Preferably the separation between the internal surface on which the electrical contacts are provided and the external surface which contacts the environment is known. Preferably the separation forms a thickness.

Preferably all the electrical contacts are provided on a single mounting unit. Preferably the separation of two or more, ideally all, of the electrical contacts is fixed in one or more directions. The separation may be fixed in all directions apart from potential movement in to or out of the mounting unit. The electrical contacts may be moveable, for instance being spring loaded, perpendicular to the surface of the mounting unit, but are preferably provided in fixed locations relative to the test sample after the first current measurement.

The electrical contacts may be provided by pins or other electrically conducting elements. Preferably the electrical contacts are resiliently forced into contact with the sample, for instance by springs. The electrical contacts may be provided in pairs, preferably with the voltage between predefined pairs being measured during the investigation. The electrical contacts and/or pairs of electrical contacts may be evenly spaced along the direction of current flow and/or unevenly spaced along the direction of current flow. Electrical contacts may be provided throughout the sample, in the direction of current flow and/or perpendicular to the direction of current flow. The electrical contacts may be provided all around the cross-section of the bore or other internal surface form provided by the sample. The method may involve measuring the voltage for one or more pairs of electrical contacts simultaneously. Four or more and preferably eight or more pairs may be considered simultaneously. The number of pins provided may be between 8 and 256 pins, more preferably between 16 and 128 pins and ideally between 24 and 64 pins.

The electrical contacts may be provided by a mounting unit. The mounting unit is preferably provided with one or more surfaces configured to match one or more surfaces of the sample to be investigated, ideally to match at least one internal surface of the sample. Preferably the electrical contacts are provided on or associated with the one or more matching surfaces. Preferably the electrical contacts project outward from the mounting unit.

The mounting unit may be in a form which is fully receivable within the space defined by the internal surfaces of the sample. The mounting unit may be received within a bore provided by the sample. The mounting unit may have the general profile of a cylinder. Ideally the mounting unit has one or more external ring like and/or collar like and/or annular surfaces which oppose, and ideally match, the internal surface of the sample.

The mounting unit may be introduced to the sample by inserting it into the sample. The mounting unit is preferably slid into the sample. Preferably the electrical contacts are withdrawn from contacting the sample during insertion of the mounting unit.

The mounting unit may be clamped or otherwise releasably fixed in position once introduced to the sample.

The external surface may be contacted with the environment by placing the sample in the environment, for instance prior to the environment setting or solidifying. The external surface may be contacted with the environment by introducing the environment around the sample. The contact between the sample and the environment may involve a solid interface by the sample. The contact between the sample and the environment may involve a solid and/or liquid and/or gaseous interface by the environment.

The voltage measured may increase in voltage as corrosion progresses. The variation in voltage with time may occur evenly for all the respective electrical contacts considered. The variation in voltage with time may occur unevenly for all the respective electrical contacts considered. The variation may occur at an even rate over time. The variation may occur at an uneven rate over time.

The voltage measurements may be made after the current has started. Preferably the voltage measurements are made at least $200ms^{-1}$ after the current has been applied. Preferably the voltage measurement is made within $800ms^{-1}$ of the current being applied.

Preferably the voltage measurements are made after the current stops preferentially flowing in the surface part of the sample. Preferably the voltage is steady when the voltage measurements are made.

Preferably the temperature of the two or more electrical contacts is measured at one or more of the first time and one or more other times. Preferably the temperature is measured each time a voltage is measured. The temperature of the two or more electrical contacts may be measured by measuring the temperature of the electrical contacts. The temperature of the two or more electrical contacts may be measured by measuring the temperature of the location. The temperature of the two or more electrical contacts may be measured by measuring the temperature of the environment surrounding the two or more electrical contacts.

Preferably the voltage measurements are compensated for temperature variations at the electrical contacts and / or location and / or reference location and / or the environments thereof.

The first time may be prior to the sample contact the given environment. The first time may be shortly after the sample has contact the environment, for instance within 1 hour or less and more preferably within 5 minutes or less.

The one or more other times may be provided at regular intervals, for instance every few hours, once a day or even once a month.

Preferably the method includes providing a power source external of the sample to provide an applied current.

The power source may be a mains power source or portable power source, such as a battery. The power source may provide the same or a different current level for respective measurements.

The current is preferably a DC current and particularly a square wave DC current. The DC current may be provided in a single direction but is more preferably applied in both directions, ideally alternately. The current may be applied for between 200 and 2000ms^{-1} per time and more preferably between 500 and 1000ms^{-1}.

The current may be introduced to the sample towards one end thereof and leave towards the other end thereof. The current may be introduced and/or exit by a current contact unit. Preferably the current contact unit and / or current electrical contact are configured to match or engage one or more surfaces of the sample, preferably an internal surface and ideally an end internal. The current contact unit and / or current electrical contacts may be configured to match an external surface of the sample and / or a surface in contact with the environment by a seal or coating, and / or the current electrical contacts may be isolated from the environment by individual seals or covers. The current contact unit or units may be in the form of one or more terminals in contact with, preferably attached to, the surface of the sample. One or more pins may possibly provide the current contact unit. One or more welded contacts and / or bolted contacts are preferred.

The voltage measurement at the first time may define a baseline voltage or voltages against which corrosion is considered and/or a thickness of material forming the sample or one or more parts thereof and/or the shape of the electric field against which variations can be considered.

The voltage measurements for the sample may indicate a general level of corrosion for the sample, preferable through consistent variation between the various electrical contact voltages measured for the sample and the baseline obtained. The voltage measurements for the sample may indicate location specific corrosion for the sample, preferably through inconsistent variation between the electrical contact voltages at one or more parts of the sample and the baseline and the variation between electrical contact voltages at one or more other parts of the sample and the baseline. The corrosion may be expressed as a thickness loss, proportion of material lost or other value, such as a rate of loss. The corrosion may be expressed in terms of the change between the as new state represented by the first time measurements and the corroded state of one or more of the other time measurements and/or in terms of the progress of corrosion from the first time onwards.

Preferably the internal surface is physically isolated such that no solid and/or no liquid and/or no gas from the environment can reach the internal surface.

The seal may be provided by a sealing element attached to the sample. Preferably the sealing element closes the bore inside the sample. The electrical connections for the current supply and/or voltage measurements preferably pass through the sealing element. The sealing element may be removable. The seal is preferably moisture impermeable. The seal is preferably gas impermeable.

The method may provide for passing the applied current through a reference location and measuring the variation in the voltage between two or more reference electrical contacts at the first time and at one or more of the one or more other times, the two or more reference electrical contacts being in contact with the reference location.

Preferably the temperature of the reference location is measured each time a voltage is measured for the location. The temperature of the reference location may be measured by measuring the temperature of the reference location. The temperature of the reference location may be measured by measuring the temperature of the environment surrounding the reference location.

Preferably the method provides for using the respective voltage values from the two or more electrical contacts and two or more reference electrical contacts in the investigation of the corrosion.

The reference location is preferably between the power source and the location in an electrical sense. The reference location is preferably formed of a material which does not corrode in its environment. The environment may be different from the environment effecting the location under investigation. The reference location may be provided with only two electrical contacts. The reference location may be physically distant from the location under investigation.

The voltage for the reference location at a measurement time may be used to compensate one or more voltages measured for the location or a part thereof for variations in the applied current at one measurement time and one or more other measurement times. Preferably the compensation is made according to the equation :-

$$Fc_{Ai} = \frac{B_s}{A_s} \times \frac{A_i}{B_i} - 1 \quad \times 1000 \text{ (parts per thousand)}$$

where

Fc_{Ai} = fingerprint coefficient for a pair of electrical contacts A under investigation at time I

A_s = voltage across pair A at a reference time, preferably the start

B_s = voltage across reference pair of electrical contacts B at a reference time, preferably the start

A_i = voltage across pair A at time I

B_i = voltage across reference pair B at time I.

According to a third aspect of the invention we provide apparatus for investigating corrosion of a material in a given environment, the apparatus including

a sample of the material,

two or more electrical contacts in contact with the sample during measurements thereof,

means for measuring the voltage between the two or more electrical contacts in contact with the sample at a first time and one or more other times,

a power source for passing a current through the sample at the times of the voltage measurements,

means for considering the voltage measurements from the sample to provide information about the effect of the environment on the sample with time,

the electrical contacts being provided within a sealed location relative to the environment.

According to a fourth aspect of the invention we provide apparatus for investigating corrosion of a material in a given environment, the apparatus including

a manufactured sample of the material having an internal and an external surface,

two or more electrical contacts in contact with an internal surface of the sample during measurements thereof,

means for measuring the voltage between the two or more electrical contacts in contact with the internal surface of the sample at a first time and one or more other times,

a power source for passing a current through the sample at the times of the voltage measurements,

means for considering the voltage measurements from the sample to provide information about the effect of the environment on the sample with time,

the internal surface of the sample on which the electrical contacts are provided being provided within a location which is isolated relative to the environment by a seal.

Preferably the sample of material has one or more machined surfaces. Preferably the sample has an internal surface, ideally provided within a bore. Preferably the bore is open at one end and is closed or open at the other end. Preferably the sample of material is provided with a machined external surface. Ideally the separation between an external surface and an internal surface is known.

Preferably the internal surface is provided with two or more electrical contacts.

Alternatively an external surface of the sample may be provided with two or more electrical contacts.

Preferably all the electrical contacts are provided on a mounting unit. Preferably the separation of two or more, ideally all, of the electrical contacts is fixed in one or more directions.

The electrical contacts may be provided by pins or other electrically conducting elements. Preferably the electrical contacts are resiliently biased towards the sample in use. Springs may be used to bias the electrical contacts.

The electrical contacts may be provided by a mounting unit. The mounting unit is preferably provided with one or more surfaces to configure to match one or more surfaces of the sample to be investigated, ideally at least one internal surface of the sample. Preferably the electrical contacts are provided on or in association with the one or more matching surfaces of the mounting unit. Preferably the electrical contacts project outwards from the mounting unit.

The electrical contacts may be physically isolated from the environment by seals or covers. Individual seals or covers may be provided for one or more, even all, the electrical contacts.

The electrical contacts may be provided on an internal surface of the sample, with the internal surface physically isolated from the environment. A seal may be used to provide the isolation, for instance by means of a sealing element attached to the sample. Preferably the sealing element closes a bore inside the sample.

Preferably the apparatus includes a power source external of the sample. The power source may be a mains power source or portable power source, such as a battery.

The apparatus may include means for introducing current to the sample towards one end thereof and / or means for removing a current from the other end thereof. A current contact unit may be provided to provide one or more of the current introducing /

removing means. Preferably the current contact unit and / or current electrical contacts are configured to match one or more surfaces of the sample.

The apparatus may include the provision of a reference location between the power source and a current contact unit and / or the location. The reference location is preferably provided with two or more electrical contacts.

The apparatus may particularly provide a container within which an environment is provided with a sample of the material to be investigated in contact with the environment. The container may be a drum. The environment may be a grouting material, vitrification material or concrete. Other components may contribute to the environment. Preferably the sample of material is surrounded by the environment in all directions in such a case. The apparatus may include electrical contacts leading from the sample to a remote location. Electrical contacts may be used to effect the voltage measurement and / or to provide the current. The remote location may be a processing location for the voltage measurement information and / or current information and / or corrosion determination. The remote location may be permanently connected to the sample in the environment and / or releasably connected thereto.

As well as addressing these issues, the present invention may also be directed towards other problems. For instance the field signature method in the past has generally been applied to measuring pipelines by placing the necessary electrical contacts to measure the voltage on the outside of the pipeline prior to its being installed. The electrical contacts are permanently positioned, for instance through welding.

The present invention aims to render field signature based techniques possible for a wider variety of situations, including harder to access situations.

According to a fifth aspect of the invention we provide a apparatus for investigating corrosion at a location, the apparatus comprising

two or more electrical contacts, the electrical contacts being in contact with the location during measurements thereof,

means for measuring the voltage between the two or more electrical contacts in contact with the location at a first time and one or more subsequent time,

a power source for passing a current through the location at the respective times of the voltage measurements, processing means for considering the voltage measurements to provide information about the corrosion which has occurred at the location,

the apparatus having a first state and a second state, the electrical contacts being retracted in the first state and advanced in the second state.

The electrical contacts may be provided by a mounting unit. The electrical contacts may be provided on an external surface of the mounting unit.

The apparatus may be changed form the first to the second state or vice versa by expansion of an expandable portion of the mounting unit.

According to a sixth aspect of the invention we provide apparatus for investigating corrosion at a location, the apparatus including

two or more electrical contacts provided on an external surface, the electrical contacts being in contact with the location during measurement thereof,

a mounting unit for the two of more electrical contacts,

means for measuring the voltage between the two or more electrical contacts at a first time and at one or more subsequent times,

a power source for passing a current through the location at the respective times of the voltage measurements,

processing means for indicating the extent of corrosion which has occurred for the location based on the voltage measurements,

the apparatus having a first state and a second state, the electrical contacts being retracted in the first state and advanced in the second state by expansion of an expandable portion of the mounting unit.

The fifth and/or sixth aspects of the invention may involve one or more of the following features, options or possibilities.

The corrosion investigated may occur throughout the location and/or at one or more specific parts of the location. The corrosion may occur due to contact between the location and its environment. The environment in question may be the external environment for the location and/or the internal environment for the location. The corrosion may arise as a result of chemical attack on the location and/or mechanical wear on the location.

Corrosion may or may not have actually occurred at the time of the first voltage measurement for the location.

The location may particularly be the inside of an article or an inside surface of an article. The mounting unit is preferably introduced into the location through an opening in the location. Th opening may be an end of the location or an access way provided in the location and/or a communication with the location.

The location may be an entire article or a part thereof. The location may particularly be a part of a chemical plant. The location may be a part or the whole of a pipeline, passageway, conduit, vessel, container, wall or barrier. The location may have one or more surfaces isolated from one or more other surfaces. The corrosion may effect one or more of the sets of isolated surfaces, for instance the internal surfaces in the case of a pipeline. The location may have been in use for sometime prior to the first voltage measurement. The location may be part of an existing plant when the first voltage measurements are made.

The electrical contacts may be provided by pins or other electrically conducting elements. Preferably the electrical contacts are resiliently forced into contact with the location, for instance by springs. The electrical contacts may be provided in pairs, preferably with the voltage between predefined pairs being measured during the investigation. The electrical contacts and/or pairs of electrical contacts may be evenly spaced in one or more directions on the apparatus and/or along the direction of current flow and/or perpendicular to the direction of current flow. Electrical contacts may be provided throughout the location, in the direction of current flow and/or perpendicular to the direction of current flow. The electrical contacts may be provided all around the cross-section of the apparatus and/or location being investigated. The method may involve measuring the voltage for one or more pairs of electrical contacts simultaneously. Four or more and preferably eight or more pairs may be considered simultaneously. The number of pins provided may be between 8 and 256 pins, more preferably between 16 and 128 pins and ideally between 24 and 64 pins.

Preferably all the electrical contacts are provided on a single mounting unit. Preferably the separation of two or more, ideally all, of the electrical contacts is fixed in one or more directions. The separation may be fixed in the first direction extending between one end of the mounting unit and the opposing, for instance in the direction generally taken by the current flow in use. The separation may be fixed in a second direction the direction being perpendicular to the first and preferably following surface matching the location and/or following the location's surface. The electrical contacts may be moveably, for instance being spring loaded, perpendicular to the surface matching the location and/or perpendicular to the location's surface and/or perpendicular to both the first and second direction defined above.

It is preferred that the electrical contacts project outward from an external surface of the apparatus and/or project inwardly from an internal surface of the apparatus. The electrical contacts may extend away from one another and/or towards one another.

The electrical contacts may be provided by a mounting unit. The mounting unit is preferably provided with one or more surfaces configured to match one or more surfaces of the location to be investigated. The mounting unit may be provided with one or more surfaces configured to match the location in the sense that the surface or surfaces has a generally equivalent cross-sectional shape, but is preferably either smaller or larger in size. The one or more surfaces may be outer surfaces. The one or more surfaces may be inner surfaces of the apparatus. Preferably the electrical contacts are provided on or associated with the one or more matching surfaces. The electrical contacts may project from apertures provided in the apparatus, for instance in the matching surfaces.

One or more sections of the matching surface may be moveable relative to one or more of the other sections. Preferably at least three sections, potentially at least four, which are moveable relative to one another are provided. The movement of the sections may cause the electrical contacts to advance and/or retract.

The assembled mounting unit may be in the form of a ring and/or collar and/or provide an annular surface matching the surface of the location to be investigated, particularly where the location is a pipeline, conduit or other locations of circular or partially circular cross-section. The ring, collar or annular surface may be formed of a plurality of separate sections to allow the electrical contacts to be advanced and/or retracted and/or to allow the apparatus to be introduced to the location.

The variation in voltage may be an increase in voltage as corrosion progresses. The variation may occur evenly for all the respective electrical contacts considered. The variation may occur unevenly for all the respective electrical contacts considered. The variation may occur at an even rate over time. The variation may occur at an uneven rate over time. The variation may occur at an even rate around the cross-section of a pipeline or other conduit. The variation may occur at an uneven rate around the cross-section of a pipeline or other conduit.

The voltage measurements may be made after the current has started. Preferably the voltage measurements are made at least 200ms^{-1} after the current has been applied. Preferably the voltage measurement is made within 800ms^{-1} of the current being applied. Preferably the voltage measurements are made after the current stops preferentially flowing in the surface part of the location. Preferably the voltage is steady when the voltage measurements are made.

Preferably the temperature of the two or more electrical contacts is measured at one or more of the first time and / or one or more other times. Preferably the temperature is measured each time a voltage is measured. The temperature of the two or more electrical contacts may be measured by measuring the temperature of the electrical contacts. The temperature of the two or more electrical contacts may be measured by measuring the temperature of the location. The temperature of the two or more electrical contacts may be measured by measuring the temperature of the environment surrounding the two or more electrical contacts.

Preferably the voltage measurements are compensated for temperature variations at the electrical contacts and / or location and / or reference location and / or the environments thereof.

Preferably the apparatus provides a power source external of the location to provide an applied current.

The current is preferably a DC current and particularly a square wave DC current. The DC current may be provided in a single direction but is more preferably applied in both directions, ideally alternately. The current may be applied for between 200 and 2000ms^{-1} per time and more preferably between 500 and 1000ms^{-1}.

The current may be introduced to the location at one end of the apparatus and/or location and leave at the other end of the apparatus and/or location. The current may be introduced and/or exit by a current contact unit, preferably configured to match one or more surfaces of the location to be investigated or be an element in electrical contact with the location such as a pin or terminal. The current contact unit or units and/or the element may be advanced and/or retracted, preferably due to the first to second or second to first state transition. Preferably the current contact unit and/or element moves in the same direction as the electrical contacts. In some situations permanent current electrical contacts and / or current contract units may be provided, for instance by means of bolting or welding to the location.

The power source may be a mains power source or portable power source, such as a battery. The power source may provide the same or a different current level for respective measurements.

The voltage measurements for the location may indicate a general level of corrosion for the location, preferable through consistent variation between the various electrical contact voltages measured for the location. The voltage measurements for the location may indicate location specific corrosion for the location, preferably through inconsistent variation between the electrical contact voltages at one or more parts of the location and the electrical contact voltages at one or more other parts of the location. The corrosion may be expressed as a thickness loss, proportion of material lost or other value, such as a rate of loss. The corrosion may be expressed in terms of the change between the as new state represented by the measurement at the first time and a corroded state at one or more of the other measurement times and/or in terms of the progress of corrosion from the first time onwards.

In one preferred embodiment, in the first state the electrical contacts are preferably closer together than in the second state. Preferably the electrical contacts are provided on an external surface of the apparatus. Preferably the electrical contacts and/or mounting unit and/or sections thereof is moved apart in the change from first to second state. Preferably the movement is caused by the expansion of a portion of the mounting unit, preferably a portion between the electrical contacts and/or sections of the mounting unit. The portion may be expanded by insertion of an element into it. The portion may be a bore or other opening. The element may be a rod, preferably with an outwardly tapering end. The element may be inserted along the ais of the mounting unit. The portion may be expanded by rotation of an element within, for instance a cammed surface. The element and/or the surface of the mounting unit it contacts may be provided with an inclined surface to provide the camming action. The rotation is preferably about the axis of the mounting unit. The portion may be expanded by increasing the pressure within it, for instance by introducing a fluid. An inflatable component, such as a catheter may be provided. The portion may be contracted by a reversal of the expanding process. The mounting unit, particularly the sections from which it may be formed, is preferably forced together to move the apparatus from the second state to the first state. The mounting unit may be forced together by one or more resilient components which are deformed in the change from first state to second state, for instance one or more elastic elements. The elastic elements may be rings or bands which encircle the cross-section of the mounting unit. Preferably such elements are provided at a plurality of positions along the mounting unit's length.

In a second alternative embodiment, particularly suited to situations in which the apparatus surrounds the location to some extent, in the first state the electrical contacts are preferably further apart than in the second state. Preferably the electrical contacts are provided on an internal surface of the apparatus. Preferably the electrical contacts and/or mounting unit and/or sections thereof are moved together in the change from first to second state. Preferably the movement is caused by the expansion of a portion of the mounting unit, preferably a portion outside of the electrical contacts and/or sections of the mounting unit. The portion may be expanded by insertion of an element into it. The portion may be a passage, bore or other opening. The element may be a hollow cylinder, preferably with an outwardly tapering end. The element may be inserted along the ais of the mounting unit. The portion may be expanded by rotation of an element within, for instance a cammed surface. The element an/or the surface of the mounting unit it contacts may be provided with an inclined surface to provide the camming action. The rotation is preferably about the axis of the mounting unit. The portion may be expanded by increasing the pressure within it, for instance by introducing a fluid. The portion may be contracted by a reversal of the expanding process. The mounting unit, particularly the sections from which it may be formed, is preferably forced apart to move the apparatus from the second state to the first state. The mounting unit may be forced apart by one or more resilient components which are deformed in the change from first state to second state, for instance one or more elastic elements. Preferably such elements are provided at a plurality of positions along the mounting unit's length.

The mounting unit may be introduced to the location by causing the parts of the mounting unit which are brought into opposition with the location to approach the location.

Preferably one or more, and ideally all, of the location opposing parts of the mounting unit are brought into opposition with the part of the location they oppose in use along an axis substantially perpendicular to the part of the location and/or such that the part of the mounting unit and part of the location are substantially parallel to one another. Substantially perpendicular and/or parallel preferably means at an angle thereto which does not result in scrapping or other movement of the electrical contacts across the location between first contact therewith and reaching the position of use. The angle may be within 10° of the stated angle, or more preferably within 5^0 of the stated angle.

The mounting unit may be clamped or otherwise releasably fixed in position once introduced. In one embodiment the potential variation in current between measurements may account for using the technique set out in applicant's co-filed patent application bearing reference P17639, GB 0005945.1, also continued as a PCT application.

The method may provide for passing the applied current through a reference location and measuring the variation in the voltage between two or more reference electrical contacts at the first time and at one or more of the one or more other times, the two or more reference electrical contacts being in contact with the reference location.

Preferably the temperature of the reference location is measured each time a voltage is measured for the location. The temperature of the reference location may be measured by measuring the temperature of the reference location. The temperature of the reference location may be measured by measuring the temperature of the environment surrounding the reference location.

Preferably the method provides for using the respective voltage values from the two or more electrical contacts and two or more reference electrical contacts in the investigation of the corrosion.

The reference location is preferably between the power source and the location in an electrical sense. The reference location is preferably formed of a material which does not corrode in its environment. The environment may be different from the environment effecting the location under investigation. The reference location may be provided with only two electrical contacts. The reference location may be physically distant from the location under investigation.

The voltage for the reference location at a measurement time may be used to compensate one or more voltages measured for the location or a part thereof for variations in the applied current at one measurement time and one or more other measurement times. Preferably the compensation is made according to the equation :-

$$Fc_{Ai} = \frac{B_s}{A_s} \times \frac{A_i}{B_i} - 1 \quad \times 1000 \text{ (parts per thousand)}$$

where

Fc_{Ai} = fingerprint coefficient for a pair of electrical contacts A under investigation at time i

A_s = voltage across pair A at a reference time, preferably the start

B_s = voltage across reference pair of electrical contacts B at a reference time, preferably the start

A_i = voltage across pair A at time i

B_i = voltage across reference pair B at time i.

According to a seventh aspect of the invention we provide a method for investigating corrosion at a location, the method comprising

providing two or more electrical contacts and introducing the electrical contacts being in contact with the location during measurements thereof,

measuring the voltage between the two or more electrical contacts in contact with the location at a first time and one or more subsequent times,

passing a current through the location at the respective times of the voltage measurements,

considering the voltage measurements to provide information about the corrosion *which has occurred at the location,*

introducing the apparatus to the location in one or a first or second state and performing the measurements in the other of the states, the electrical contacts being retracted in the first state and advanced in the second state.

According to a eighth aspect of the invention we provide a method for investigating corrosion at a location, the method including providing two or more electrical contacts on a mounting unit and provided the electrical contacts on an external surface of the location during measurement thereof,

measuring the voltage between the two or more electrical contacts at a first time and at one or more subsequent times,

passing a current through the location at the respective times of the voltage measurements,

indicating the extent of corrosion which has occurred for the location based on the voltage measurements,

introducing the apparatus to a location in one of a first or second state and performing the measurements in the other of the states, the electrical contacts being retracted in the first state and advanced in the second state by expansion of an expandable portion of the mounting unit.

The seventh and eighth aspects of the invention may include any of the features, options or possibilities set out elsewhere in this document including the first and second aspects of the invention.

The method may include bringing the electrical contacts closer together in the transition from the second to the first state. Preferably the movement from first to second state is caused by the expansion of a portion of the apparatus, preferably a portion of the mounting unit. Preferably a portion of the mounting unit between the electrical contacts and / or between the sections of the mounting unit is expanded. The method may include inserting an element into the portion to expand it. The method may include rotating an element within the portion to expand it. The method may include increasing the pressure within a portion to expand it, for instance by means of an inflatable catheter. Preferably the transition from second to first state is effected by a reversal of the process used to cause the transition from first to second state.

In an alternative embodiment of the method the transition from first to second state may move the electrical contacts together. The electrical contacts and / or mounting unit and / or sections thereof may be moved together during the transition from first to second state. The movement may be caused by an expansion of a portion of the mounting unit, preferably a portion outside of the electrical contacts and / or sections of the mounting unit. The portion may be expanded by inserting an element into it and / or rotating an element within it and / or by increasing the pressure within it. Preferably the transition is reversed by reversing the expanding process.

Various embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which :-

Figure 1 illustrates a longitudinal cross-sectional view of a field signature sensing unit according to the present invention in a sample of the component whose behaviour is to be investigated;

Figure 2 illustrates a plan cross-section of the embodiment of Figure 1;

Figure 3 illustrates an embodiment of the present invention deployed in a body of material whose effect is being investigated;

Figure 4 illustrates results for measured corrosion against predicted corrosion for one set of test results;

Figure 5 illustrates measured cumulative metal loss against predicted cumulative metal loss for a second set of experimental results;

Figure 6 illustrates a side cross-sectional view of an embodiment of the present invention;

Figure 7 illustrates a plan cross-sectional view of the embodiment of Figure 1; and

Figure 8 illustrates the embodiment of the present invention illustrated in Figure 2 deployed inside a pipeline.

The evaluation of the likely behaviour of a component in a body of material, be it reinforcement in concrete or a radioactive material in an encapsulating grout, is an important feature of the correct design, maintenance and prediction of a system. The need to take into account variations in the environmental conditions encountered with time complicates the evaluation.

The present invention aims to simplify evaluation and/or monitoring of such systems by an extensive development of the field signature method.

When ever an electric current is passed through a location an electric field is generated. The material, thickness of material, shape and configuration of the location effect the size and shape of the electric field that results. Changes in one or more of these potential variables effects the electric field. In particular, corrosion of a location generally reduces the thickness of material, increases the resistance and hence the voltage drop between different positions along the location in the direction of current flow.

The field effect method makes use of this basic principal to provide information on corrosion, particularly to date on sub-sea pipelines.

The method applies an excitation current to the location under consideration for a short time period, fractions of a second, and measures the voltage drops between a large number of different pairs of electrical contacts touching the location. By considering the results the progress of corrosion can be evaluated. In general the results are considered in terms of a fingerprint coefficient for a given pair of electrical contacts with time, particularly according to the formula :-

$$Fc_{Ai} = \frac{B_s}{A_s} \times \frac{A_i}{B_i} - 1 \quad \times 1000 \text{ (parts per thousand)}$$

where

Fc_{Ai} = fingerprint coefficient for electrode pair A at time I

A_s = voltage across pair A at start

B_s = voltage across reference pair B at start

A_i = voltage across pair A at time I

B_i = voltage across reference pair B at time I.

The reference pair of electrodes being provided on a non-corroding material through which the excitation current passes on its way to the location. This feature is generally employed so that variations between measurement in the current provided by the power supply do not effect the measurements.

Information on general corrosion due to a general variation in the field over time can be investigated and monitored and/or localised corrosion can be investigated and monitored where variations occur for only some of the pairs of electrical contacts.

The present invention takes this external monitoring technique into a new form and uses it for a completely different type of monitoring and different subsequent use of the information obtained.

As illustrated in Figure 1 and Figure 2 the present invention involves the formation of a sample 2 of the component whose behaviour is to be investigated into a form. In this example a cylindrical body 4 is formed with an internal bore 6 which is open at one end 8 and closed at the other end 10. The body 4 is formed of the component that will actually be present in the body of material, in this particular example uranium.

The precise dimensions of the body 4 are determined in the initial manufacturing process so that the starting point for the investigations, particularly with respect to corrosion, is known. For uranium a body of around 50mm external diameter, 35mm internal diameter and 130mm deep bore were employed.

Once the mounting unit 12 has been introduced the cylindrical body 4 is sealed by a lid 13.

To effect the field signature method measurements a mounting unit 12 is provided which carries at known positions on its external surface 14 a number of electrical contacts 16 (removed for clarity in Figure 1). The electrical contacts 16 are in the form of pins and can be retracted and presented as desired, but are generally maintained in the same position in contact with the sample 2 once current measurements have been started so as to ensure that the only variation measured is due to corrosion / erosion. The pins are sufficiently sharp to make good electrical contact with the body 4.

The necessary connections to monitor the voltages arising during the measurements between the various predetermined pairs of electrical contacts 16 are provided within the mounting unit 12 and convey their signals to a remote data processing location via cable bundle 18 which pass through the lid 13.

The excitation current needed for the method is introduced from a remote power source, not shown, along power lines 22 which pass through the lid 13, ideally along the same route as cable bundle 18. The current is fed to the body 4 through a terminal 26 which are inserted in hole 28 drilled in the lid 13. Once the terminal 26 has been successfully tapped into the lid and connected to the mounting unit 12 the hole 28 is plugged, ideally with the same material as used to form the lid 13 and body 4. In this way a reliable technique for introducing current to the test body is provided. The current is removed from the body by a single terminal 30 provided in a closed hole 32 in the closed end 10 of the body 4. The terminals 26, 30 are preferably formed by spraying of an electrically conducting material into the relevant positions. Preferably, electrical leads are bolted in place to ensure reliable contact. An excitation current of between 1 and 50 amps is preferred.

Once introduced the current initially flows preferentially through the skin of the body 4. After a period of time, however, the current settles down and a constant voltage between any pair of pins being considered is reached. One, two or more pairs of pins may be measured at a given time.

If the measurements are repeated over time then the values will change as corrosion progresses. All over corrosion will result in a generally consistent voltage increase for all of the electrical contact 16 pairs considered. More location specific corrosion, for instance around a crack or scratch, will result in different variations occurring for different pairs of pins.

Measurements over time thus allow levels, rates and locations of corrosion to be evaluated.

To achieve effect monitoring of the body of materials effect on the component the system is used as shown in the example of Figure 3. Here a body 4 of the component is placed in an encapsulating material 30 within a storage drum 32. Thus the real life make up of the body of material forming the storage system is provided. The bore 10 which receives the mounting unit 12 is fully sealed by a cap 34 to prevent any ingress of material from the body of material 30 and/or any ingress from the surrounding environment 36, such as water. Providing the electrical contacts internally and sealed in this way is important for the electrical contacts to be maintained during the encapsulating process, during the subsequent life where corrosion of the external surface is anticipated and materials which are hostile to the maintenance of good contact are likely to be encountered.

Periodic monitoring of the component represented by the body 4 can be performed using connections 38 to see how the component and body of material interact. The rate of corrosion and location of corrosion could be considered.

Furthermore, if the body of material is likely to encounter differing environmental conditions, due to location or the time which has elapsed for instance, then the simulating storage system can be contacted with these different environments. This may take the form of investigations with the system in a body of water, with water penetrating the storage system or in some other form. A wide variety of conditions can be simulated.

The type of investigations described could be provided on a full or scaled down form in laboratory conditions. For instance a full scale storage system could be considered under artificially controlled conditions or the body could be surrounded by a small but representative amount of the body of material.

The technique is also applicable to real-time monitoring of real storage systems. In such a case one or more storage systems according to the present invention which possess a monitorable component in the body of material could be introduced to the storage location alongside any number of real storage systems formed of the same container, with the same body of material and the same type of component, but without the manufactured and wired up monitoring system. The monitoring storage system would generally contain other pieces of the component to be stored in the body of material too. Ideally such monitoring storage systems would be mingled with the real storage systems in the various storage positions and environmental conditions experienced at the storage site. Periodic monitoring of the monitoring storage systems would give information on the extent of corrosion and rate of corrosion incurring in that system and also provide a strong indication as to the events in the real storage systems as they would have encountered equivalent conditions and be of equivalent make up.

Monitoring for corrosion of the body itself and/or hence the formation of corrosion products can thus readily be monitored accurately and in a representative manner. Corrosion products, such as gases, may cause mechanical damage to the body of material and/or to the container for the system, hence such monitoring is important.

By way of experimental confirmation of the success of the technique, we refer to the following experimental results..

Specimen Fabrication

The uranium specimen was manufactured from un-heat treated natural uranium cast bar (alpha phase). It was machined into the form of a cup with an internal diameter of 34mm, a wall thickness of 5mm and a total length of 13.5cm and a surface finish of 6.3μm. The sensing head was inserted inside the uranium specimen and a mandrel inserted to force the sprung loaded pins into electrical contact with the specimen. The current leads were connected to the top and bottom of the specimen and test measurements were performed. An excitation current of 15A was found to give a signal level of ~200μV, a level which historically has given a good signal to noise ratio. The end caps were fixed to the specimen and sealed using RTV silicone resin. The specimen was then thermally cycled to 40°C in case thermal expansion of the specimen altered the positions of the sprung loaded pins.

After 24 hours to allow the silicone resin to cure, the signature, an average of five readings taken at 5 minute intervals, was taken with the specimen at ambient temperature (~23°C).

Temperature Compensation Measurements

Because the resistance of the specimen not only changed due to metal loss but also due to changed in temperature, the standard experimental procedure for our FSM experiments is to perform measurements as the specimen temperature changes in order to derive temperature compensation coefficients. The instrument was set to take readings at five minute intervals, five readings were taken with the specimen at ambient temperature (~23°C), the specimen was then transferred to the waterbath at 40°C and a further five readings taken, finally the specimen was removed from waterbath and a final five readings were taken as the specimen cooled.

Although a consistent set of temperature compensation coefficients were derived from these measurements (average value ~2.6ppt/°C), when applied to the experimental results inaccurate temperature compensation resulted. All the experimental results presented have been compensated for the effects of temperature using alternative and more appropriate temperature compensation coefficients derived from a portion of the experimental data.

Uranium Corrosion Measurements

The FSM instrument was set to automatically perform a measurement had been taken, and approximately 30 minutes after the grout had been mixed, the uranium specimen, inside a 5 litre drum, was encapsulated to give an average depth of cover of ~5cm.

Approximately 24 hours later the encapsulated specimen was transferred to a waterbath at 40°C. All but the top 3cm of the grout was immersed in the waterbath. The upper surface of the grout was left exposed to the atmosphere to allow the evaporation of seepage water.

The signal obtained from all pin pairs was analysed.

Experimental Results

Reference is made to Figure 4 which presents the measured cumulative metal loss results from one test and to Figure 5 which represents the measured cumulative metal loss from a further test, line 200 in each case, when compared with predicted losses from other experimental analysis. As can be seen close correspondence was found and the best fit is generally observed for Figure 5. The decrease in the rate of uranium corrosion with time is entirely consistent with the build up of corrosion products on the external surface of the uranium and / or decreasing availability of water within the grout. Around 80 days after encapsulation the uranium corrosion effectively decreases to zero.

To date systems employing field signature based investigates have involved mounting a series of electrical contacts on the outside of a location to be investigated. The mounting is generally permanent and is provided before the location is introduced to its position of use. For instance, when laying a pipeline a short section with the field signature method apparatus mounted on it is introduced ever once in a while to the pipeline as it is laid. This type of system can only be used in limited situations.

The apparatus of the present invention and its accompanying method are intended to be more versatile in its potential positioning and particularly to be suited to internal mounting in a bore of the like. In particular the invention allows the electrical contacts to be brought into contact with and removed from a location easily, and without risk of damaging or changing the position of the electrical contacts. Damage obviously reduces the amount of information which can be obtained. Any movement of the electrical contacts generally or relative to one another can swamp the effects on the voltages caused by the corrosion process.

In the embodiment illustrated Figure 6 apparatus for use on internal surfaces is illustrated. The apparatus comprises a mounting unit 302 which carries a large number of electrical contacts 304 in the form of spring loaded gold pins. The spring loading allows the pins to move in and out in the apertures in which they are provided. Spring loading is useful in ensuring a good electrical contact in use. The electrical contacts 304 are actually provided on four separate collars 306. Each of the four collars 306 is divided up into four sectors a,b,c,d, by cut away portions 308. One of the sectors of each of the four collars 306 is mounted on a core member 310, the core being formed of four such members 310. As shown in Figure 6 and Figure 7 the apparatus is in the state ready for insertion. In this state the collar sectors 306a, 306b, 306c and 306d are held in position with the cut away portions 308 closed by elastic O-rings 312 which encircle the apparatus.

At each end of the apparatus a current contact portion 318 is provided. The current contact portion 318 is also divided into quarters and mounted on the core members 310. The electrical contacts 320, however, are used to introduce the current to the location being investigated and the electrical contacts 322 are used to remove the current from the location being investigated. Bolts, welds or screw threaded elements could be used to introduce the current where permanent contacts are possible. Drilled and tapped holes may be used to clamp leads to the location being investigated.

As can be seen in Figure 7 the apparatus is provided with a bore 314 extending down its centre. The bore 314 is open at least one end 316 and is shown at a first diameter. At this first diameter the sides of the collar sectors 306a, 306b etc abut the adjacent collar sectors. In this state the apparatus is designed to have a maximum cross-section less than the location in to which it is to be introduced. As shown this maximum cross–section is in effect the maximum diameter between the tip of one electrical contact 304 and the tip of the electrical contact 304 on the opposing side of the apparatus. The maximum cross-section could be considered relative to a maximum radius, from the central axis to an electrical contact tip for instance, where the apparatus is not necessarily symmetrical.

When inserted in this state the electrical contacts can be kept clear of the location during insertion and any damage is thus avoided. To assist in this process the apparatus may be provided with a spacing element 324, shown only in Figure 6, which is provided at each end and is intended to abut the location in a sliding contact during insertion so as to maintain the gap between the location and the electrical contacts 304.

Once at the desired position of use a core element 330, shown in Figure 8 can be inserted. As the core element 330 is inserted the collars 306 and core members 310 are forced apart. In effect the core element enlarges of the bore 314 size. This change in position of the collars 306 results in the electrical contacts 304 being brought into contact with the inner surface 332 of the location 334 in which the apparatus is provided.

The gradual and even expansion of the apparatus results in the electrical contacts 304 being brought into contact with the inner surface 332 of the location 334 without any laterally or other scraping movement.

The effect can be reversed by removing the core element 330 so allowing the elastic O-rings 312 to pull the collars 306 and core members 310 back together again.

In the expanded state the voltages at the location can be measured. In the contracted state the apparatus can be moved relative to the location without damaging or changing the position of the electrical contacts with respect to one another.

The type of location illustrated in Figure 8 is consistent with the inside of a pipeline, but a wide variety of other situations could be investigated. For instance such apparatus could investigate any manner of circular cross-sectioned conduit and other curved or square or rectilinear cross-sections could be accommodated by providing suitable collar configurations. The apparatus could also be reconfigured to expand in response to the rotation of a cammed core element and/or in response to hydraulic or other pressure introduced into the bore. It would also be possible to provide the apparatus as a ring like structure which encloses a location to be measured, with the inner surface of the apparatus being pushed closer together to bring it into contact with the location and then expanded to remove it.

CLAIMS:

1. A method of investigating corrosion of a material in a given environment, the method including

manufacturing a test sample from a sample of the material,

providing two or more electrical contacts in contact with an internal surface of the test sample,

providing an external surface of the sample in contact with the environment,

measuring the voltage between two or more electrical contacts at a first time and at one or more other times, an external surface of the sample being in contact with the environment during one or more of the times,

a current being passed through the sample at the time of the voltage measurement,

the voltage measurements providing information about the effect of the environment on the sample with time,

and wherein the internal surface of the sample on which the electrical contacts are provided is physically isolated from the environment during the voltage measurements by a seal.

2. A method of investigating corrosion of a material in a given environment, the method including

providing a sample of the material,

providing two or more electrical contacts in contact with the sample,

providing the sample in contact with the environment,

measuring the voltage between two or more electrical contacts at a first time and at one or more other times, the sample being in contact with the environment during one or more of the times,

a current being passed through the sample at the time of the voltage measurement,

the voltage measurements providing information about the effect of the environment on the sample with time,

and wherein the electrical contacts are physically isolated from the environment during the voltage measurements.

3. A method according to claim 2 in which the sample of the material is manufactured to provide a test sample.

4. A method according to claim 2 or claim 3 in which the two or more electrical contacts are provided on an internal surface of the sample, an external surface of the sample is provided in contact with the environment and the internal surface of the sample on which the two or more electrical contacts are provided is physically isolated from the environment during the voltage measurements.

5. A method according to any preceding claim in which the environment includes an encapsulating material and/or concrete and/or vitreous material.

6. A method according to any preceding claim in which the environment is that environment occurring within a container in which the sample is also present.

7. A method according to any preceding claim in which the method includes machining or otherwise forming at least a part of the shape and/or one or more surfaces of the sample.

8. A method according to any preceding claim in which the internal surface is physically isolated such that no solid and no liquid and no gas from the environment can reach the internal surface.

9. A method according to any preceding claim in which the seal is provided by a sealing element attached to the sample, the sealing element closing a bore inside the sample.

10. Aparatus for investigating corrosion of a material in a given environment, the apparatus including

a manufactured sample of the material having an internal and an external surface,

two or more electrical contacts in contact with an internal surface of the sample during measurements thereof, means for measuring the voltage between the two or more electrical contacts in contact with the internal surface of the sample at a first time and one or more other times,

a power source for passing a current through the sample at the times of the voltage measurements,

means for considering the voltage measurements from the sample to provide information about the effect of the environment on the sample with time,

the internal surface of the sample on which the electrical contacts are provided being provided within a location which is isolated relative to the environment by a seal.

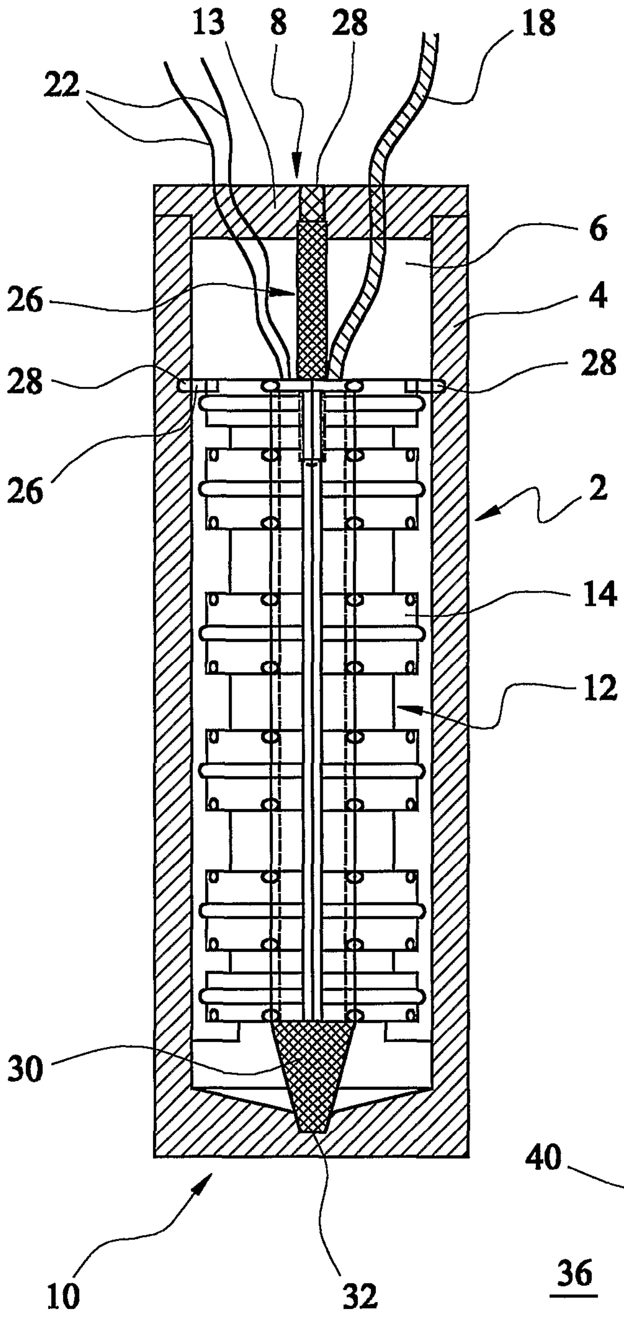


FIG. 1

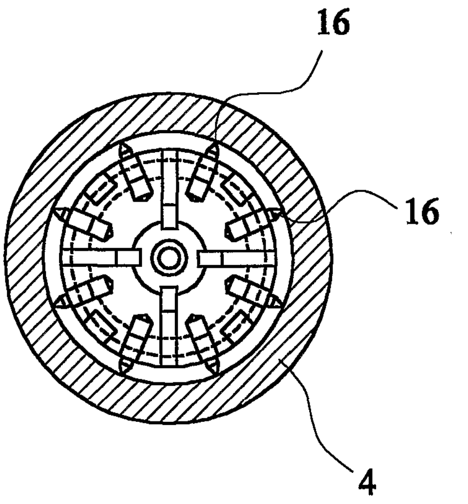


FIG. 2

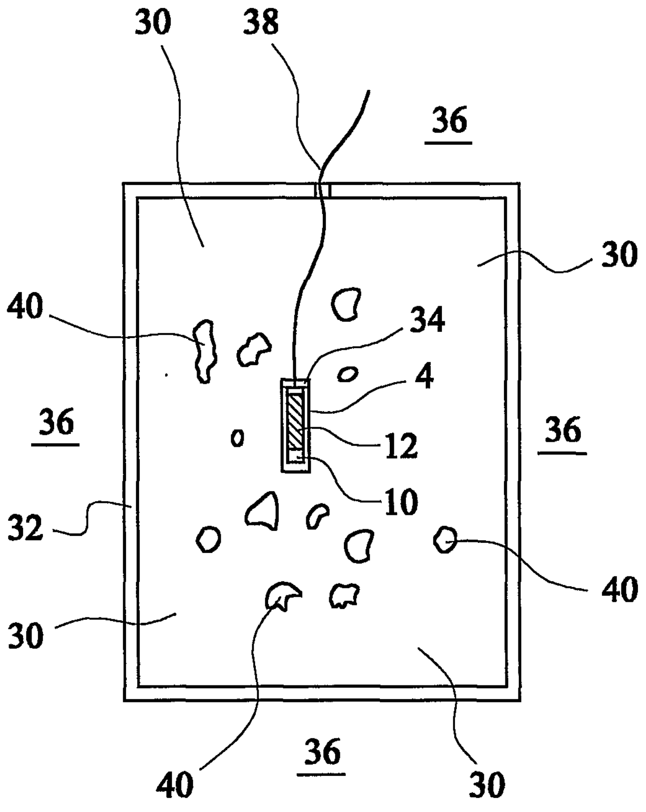
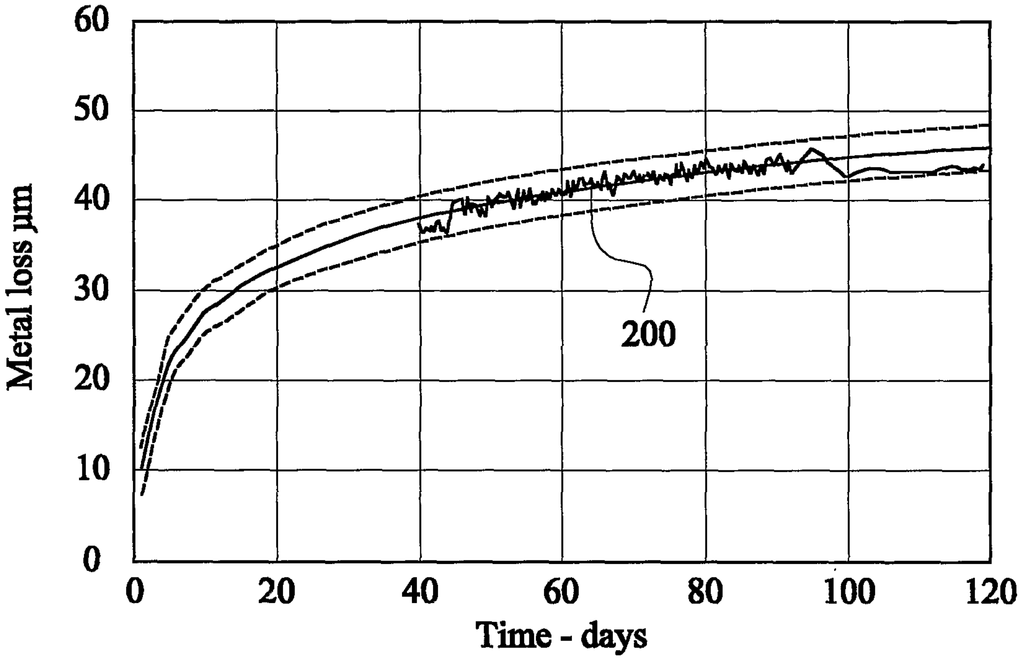
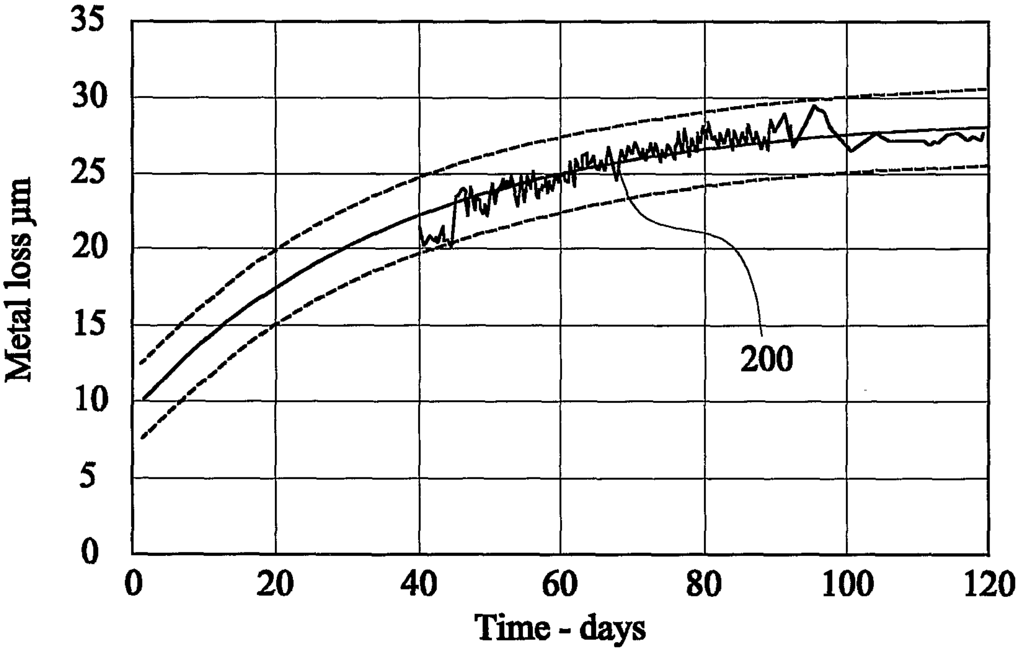


FIG. 3



Predicted and measured cumulative metal loss - inversely decaying corrosion rate.

FIG. 4



Predicted and measured cumulative metal loss - exponentially decaying corrosion rate.

FIG. 5

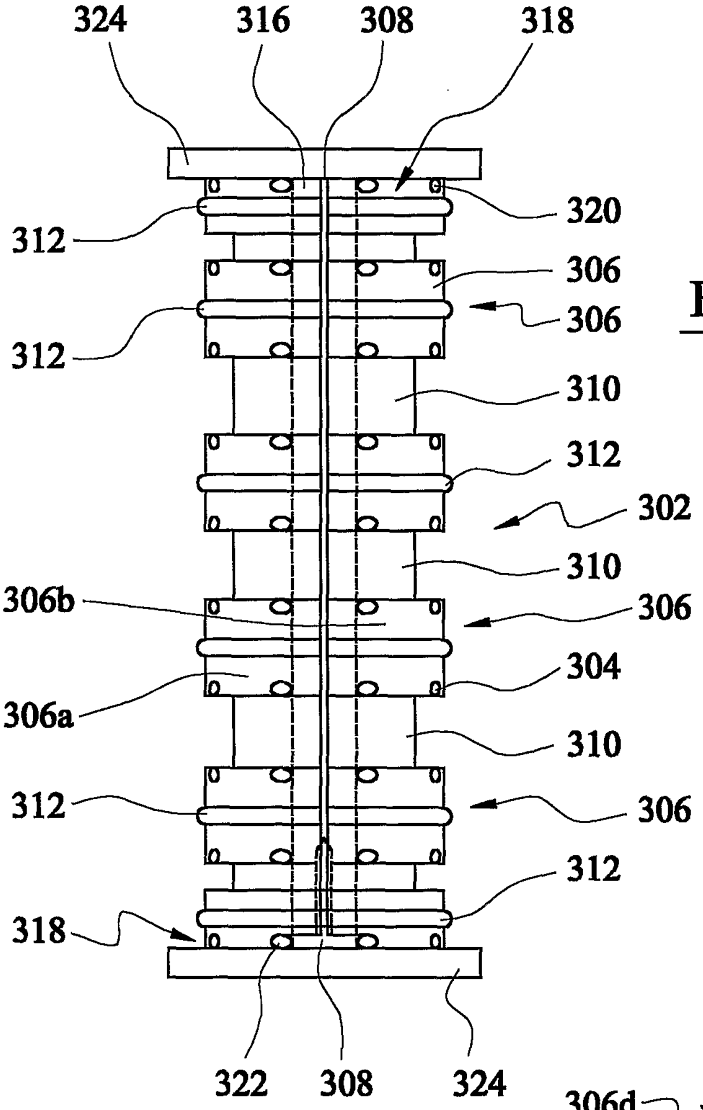


FIG. 6

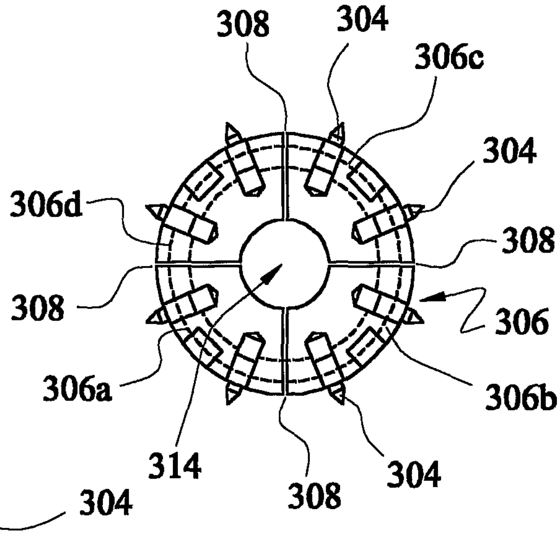


FIG. 7

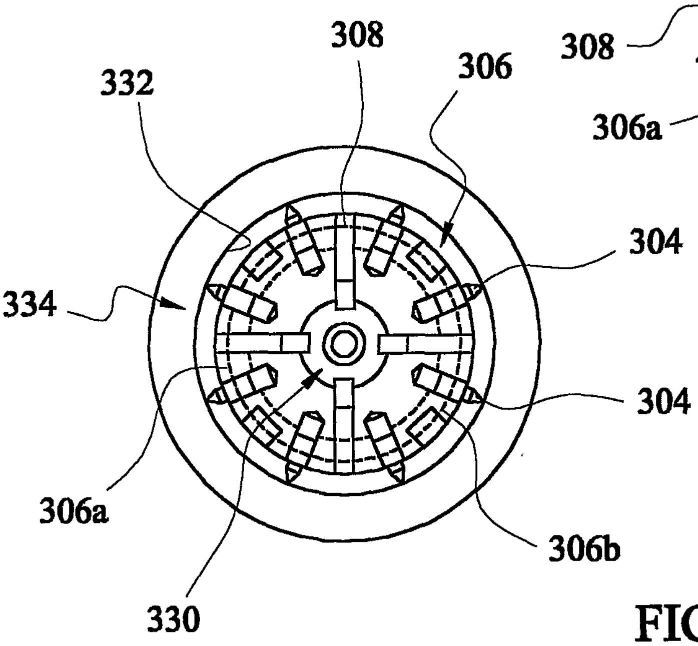


FIG. 8