DATABASE FOR MATERIALS PERFORMANCE IN GEOTHERMAL FLUIDS

P.G.H. McILHONE and K.A. LICHTI
DSIR Industrial Development, Wellington, NZ

SUMMARY - Surface corrosion test results for metals and alloys exposed to geothermal fluids in New Zealand are being captured in a relational database using a software development tool, Paradox3(TM). A develop and revise process has been used to produce a prototype stand alone application (called GTEST) having user-interface facilities which permit use of the system by inexperienced users. The system features search and results display options which include: browsing through data tables, viewing individual test results, viewing and printing screen reports, graphical presentation of selected results and data editing functions.

1 INTRODUCTION

The performance of metals and alloys exposed to geothermal fluids can not be predicted solely on the basis of corrosion theory. However, practical experience and materials exposure test results when combined with corrosion theory can be used to identify candidate materials and critical materials and environment properties which must be controlled to guarantee reliability.

Data and advice is being collected in an expert system (GeoMat) for provision of advice on selection and use of materials in geothermal energy applications and environments (Lichti and Wilson (1990)). This advice is based on corrosion results and experience obtained over several years of corrosion research and testing at the Wairakei and Broadlands geothermal fields (Braithwaite and Lichti (1980), Lichti and Wilson (1983)).

Experienced users of the expert system can improve the reliability and quality assurance of the advice provided if they can review the information on which the advice is based and reassess the relevance of the historical data for their particular application (Lichti and Wilson (1990)).

Provision of this background for the GeoMat expert system will be via a database programme for d a c e corrosion test results for metals and alloys exposed to simulated power station environments.

The three main objectives of this work were:
- to develop a prototype database for the geothermal corrosion test results
- to ensure that the results were suitably archived and readily available to DSIR staff working in the field of geothermal corrosion
- to gain experience in capturing alloy performance data in a computer database.

(TM) Borland International, USA.

2. DATABASE SYSTEMS

The development of materials databases has been extensively reviewed (Rumble and Hempel (1984), Glazman and Rumble (1989) and Anderson (1989)) and has been the subject of a recent standard (NACE Standard RP0690-90). Software programmes suitable for database development are also readily available (Personal Computing Journal (1988)). These programmes generally provide a range of facilities to permit development of applications without the need for extensive programming expertise. Facilities provided and terminology used by software suppliers vary. The following general discussion is presented with primary reference to Paradox3(TM) the relational database programme used for this application. Use of the Paradox(TM) package for other types of geothermal database developments has been previously reported (Barnett et al (1987)).

2.1 Relational Database Terminology

A spread-sheet can be visualised as a table for storage and manipulation of essentially numerical information, whereas a database is used to store, and then extract from storage, selected items of information, which may or may not be numeric, and to present the selected items in a convenient format for the user. A relational database system can link several *files* or *tables* in the database using *keys* constructed fiom one or more *fields* from each table. (A *field* is a single entry eg a name; a group of fields is called a *record* eg a name, address, and telephone number; a *file* or *table* is a collection of records eg a telephone directory; a *key* is a value constructed in such a manner so that it uniquely identifies one record in a *file* or table.)

In a relational database several tables can be searched at once. It is possible, for example, to search one table for the UNS number of an alloy, a second for its chemical composition, and a third for the corrosion performance in a particular environment. The results obtained from searching through these different tables can then be presented on a single screen. A less trivial search might involve finding the corrosion performance results for all alloys having similar chemical composition.

These searches can only be achieved if there exists a field common to each table to enable the alloy or alloys (in the preceding examples) to be uniquely linked between the tables.

In any table of information, whether produced manually or by a computer programme, identification fields tend to occupy the first column or columns of the table. These fields may be considered as "key fields". Key fields can be used:
- to sort tables according to the values in the key fields
- to speed searches and other operations.

2.2 Presentation Of Information

The results of a search or a query of a database may be presented to the user by several different methods.

Database developers generally provide initial results for a query in the form of an "answer" table on the screen. The results presented in an answer table may span more than one screen width, and the number of records presented in the answer table can fill more than one screen in a vertical sense.

If answer tables are large it may be more convenient to present the results one record at a time, ensuring that all the information contained in each record is available to the user on one screen display, and to allow the user to move through the individual records at will. Formats for these individual screen displays are called *forms*. A default "standard form" is often available, or forms can be "custom"-designed by the user.

A third method of presenting the results is to generate a printed report, which can be sent either to the screen, or, more usually, to a printer. Reports also differ from forms in that they usually contain information from more than one record The information from each individual record may also be spread over more than one page of the report if the answer table spans more than one screen width.

A fourth method of presenting results is by means of charts and graphs. These can be used to give a pictorial view of some of the information present in the database. Facilities for presentation of these must usually be preprogrammed for inexperienced users.

3. Paradox3(TM) RELATIONAL DATABASE

The relational database system, Paradox3(TM), and its associated programmes, Personal Programme—— and PAL(TM) (Programme Application Language), have been used to create the prototype application GTEST.

Paradox3(TM) was chosen as the database programme to be used for this development because:
- it could be used relatively quickly by an inexperienced operator
- it was possible to generate "stand alone" applications (via the Personal Programmerm) that could obviate the need for prospective users to learn how to use the database system
- reviews of relational database systems in the computing literature (Personal Computing Journal (1988)) had rated the programme satisfactorily
- DSIR staff with previous experience in developing applications with this system were available for consultation.

The development was seen as having three phases:
- developing a suitable structure for the database
- making the database easily accessible to DSIR staff
- providing direct access to the data from within the GeoMat expert system

3.1 Using Paradox3(TM), Personal Programmer(TM) and PAL(TM)

An experienced Paradox3(TM) user can use the four methods of presenting selected information descrii above when working interactively with the system, asking questions of the tables, and specifying the mode of answer presentation. To do this requires a knowledge of how to ask these questions of Paradox3(TM), and how to obtain the answers in the required format.

Paradox3(TM) also has two levels of programming available to the user to enable the most likely questions to be encapsulated in a stand alone *application*, which can then be run by someone with little knowledge of the system. These two levels of programming are Personal Programme——, and PAL(TM) the Paradox Applications Language. A developer with a knowledge of the way in which Paradox3(TM) is used interactively can use Personal Programmer(TM) to write such a stand alone application, which can then be improved by means of PAL(TM) if required. PAL(TM) is essentially a programmer's language, and requires *study* in its own right if it is to be used effectively.

4. THE DEVELOPMENT PROCESS

GTEST has been developed by utilising Personal Programmer(TM) to write the majority of the programme files required. PAL(TM) has then been used to a limited extent to make GTEST more "user-friendly".

4.1 Method Of Development

A develop and revise process was used in assembling the experimental results and designing the database structure. This process provided ample opportunity to progress in understanding Paradox3(TM) operations while simulating and testing *small* sections of the required application.

The develop and revise process, although a *successful* method of developing the application, was not used as a substitute for planning in the initial stages of the project, however, specific aims and objectives needed to be kept flexible to accommodate changes in data presented for inclusion in the database, and the limitations inherent in Personal Programme——. Unfortunately, once the basic building blocks of the application (eg tables etc.) had been decided upon, and entered into the computer, it was usually very time consuming to make what appeared to be very small changes.

4.2 Using Personal Programmer(TM)

The availability of Personal Programmer(TM) meant that writing the application was a relatively quick process; GTEST could be "written" in two days using Personal Programmer(TM). What was far more time consuming was the planning stage, where decisions had to be made concerning the design of a user-friendly application:
- what questions were to be asked and how were they to be answered
- what was the most effective way to store the information in the database
- how were these ideas best fitted into a working menu structure.

With these decisions made, preparation of the tables which contained the information, and the design of the various forms to be used for presentation of the answers was undertaken. *All* of these activities required a working knowledge of the Paradox3(TM) "system", and any attempt to use Personal Programmer(TM) without this knowledge would not have been successful. Our experience suggests that for an inexperienced developer a two to three week familiarisation time with Paradox3(TM) is required.

4.3 Graphs For GTEST

Paradox3(TM) and Personal Programme—— are both menu driven programmes. Development of applications using Personal Programme—— results in the generation of *scripts* or programme statements which execute a series of menu functions. However not all of the facilities available in Paradox3(TM) can be implemented in Personal Programmer(TM).

One shortcoming of Personal Programmerm is that it is unable to write sections of applications that require graphs or charts to present the results. The requirement to do this was thought to be an essential part of GTEST, and this meant writing the scripts necessary for this part of the application separately, using the Paradox3(TM) script writing facility, and then combining the scripts into the application using Personal Programme——. PAL(TM) was also used for improving the user-interface, results presentation screens and editing facilities.

4.4 The Benefit Of Expanded Memory

The initial version of GTEST was found to require approximately three and a half minutes to process a search. This time was reduced to approximately thirty seconds by the addition of a one megabyte memory expansion board, which reduced considerably the amount of read/write activity that was observed to be taking place during each search. A similar savings of time would be anticipated with extended RAM.

5. GTEST PROTOTYPE

Initial development of the GTEST prototype application involved results from only three materials, exposed as corrosion test coupons in seven different geothermal test environments during 1976/77 at Broadlands well BR22 (Braithwaite and Lichti (1980)). It was thought that this approach would enable the application to be developed without the need to modify repeatedly large numbers of data tables, and that after the application had been tested with these few results, it would then be a straightforward task to add the main *body* of results at a later date.

The comprehensive recommendations given in NACE Standard RP0690-90 were used as guidelines for this application.

5.1 Key Fields

The principle key field used in GTEST is A# or "alloy number". Each alloy considered is listed in a table called ALLOYS, and consecutive numbers (A#s) are consigned to each alloy in turn. Some of the other key fields in GTEST are also given "_#" titles. Examples are V# or "test vessel number", and E# or "exposure period number". A table called RESULTS uses a multi-field key consisting of three key fields, A#, V#, and E#, to identify uniquely an individual corrosion result. Each result is then a record of what happened when a particular alloy (A#) was exposed in a particular environment (V#) for a particular time (E#).

5.2 Tables

A listing of the nine tables used in GTEST is presented below, with brief comments on each of the tables.

NAME	DESCRIPTION
Alcomp	Alloy compositions
Alloys	Alloy identification codes
Codes	Codes and abbreviations
Corcodes	Corrosion form and product codes
Elcomp	Composition by elements
Refs	References
Results	Corrosion test results
Testenvs	Geothermal test environments
Times	Exposure dates and times

Alcomp and *Elcomp* both contain chemical composition information for standard and tested alloys. *Alcomp* provides a listing for each alloy of all the elements considered in GTEST and their concentrations for that particular alloy, whereas *Elcomp* simply lists the elements present for each alloy and their concentrations. *Elcomp* is used in the screen presentations.

Alloys is a listing of all the standard and tested alloys included in GTEST, along with the various identification numbers and codes for each alloy. Also included is the name of the test exposure series during which each alloy was tested, and the type of monitor used.

Codes and *Corcodes* contain the codes used in GTEST. *Codes* is a complete listing of all the codes used and a description of their meaning, whereas *Corcodes* contains only copies of the codes for the form of corrosion and corrosion product, and is essentially a display tool.

Refs is a listing of the references used in the development of GTEST. References to both internal DSIR files and published reports are given to assist in the location of individual experimental results, and conclusions that have been drawn from these results

Results is the table containing the experimental results for all the alloys tested in the geothermal test programme.

Testenvs provides a *summary* of known chemical and physical conditions for the test environments used.

Times provides information on when the tests were run, time values for each exposure, the corresponding E# values assigned to these periods, and the types of monitors used in each *case.*

5.3 Forms

There are sixty-six query pathway ends in GTEST which require the answer to the query to be displayed on the screen via a form, and a significant portion of the time taken for the development of **GTEST was** taken up in the design of these forms. In GTEST forms are used not **only** to display the answers to queries, but are also used to edit information in the database if required. Figure 1 illustrates a form for viewing data in the master Results table.

5.4 Menu Tree and Structure

A portion of the system menu tree is presented in Figure 2. **This tree** structure is generated using the "Summary" function available in Personal Programme ——. A tabulated menu structure and a tabulation of programme actions can also be obtained. These are especially useful if individual scripts are to be edited

5.5 Scripts and PAL(TM)

The programmes which Paradox3(TM) *uses* are called "scripts". Scripts were automatically generated by Personal Programme —— for **GTEST.** These are in the form of programme lines or instructions which execute desired actions as they would be carried out by an experienced Paradox3(TM) user. Changes can be made to these scripts using PAL(TM), however re-running of Personal Programme —— will automatically recreate a script and delete any changes made using PAL(TM). The desired changes must be saved separately and re-entered into the new script.

5.7 Running GTEST

Loading time for GTEST and Paradox3(TM) is approximately one minute on an 8 MHz AT equivalent personal computer. When the programme has finished loading, the screen clears and the main menu options are displayed on the top line of the screen, with a descriptive line, which relates to the highlighted choice, on the second line. The highlighted choice can be altered by means of the cursor control arrows, or by a standard letter selection technique. The system appearance and operation is similar to that of common spreadsheet programmes.

The main menu choices and their descriptive lines are listed and briefly discussed below:

MENU CHOICES	ASSOCIATED DESCRIPTIVE LINE
CORROSION	Examine corrosion results for selected alloy/environment
COMPOSITION	View composition of selected alloy or environment
GRAPH	Plot results for selected alloy as a chart
BROWSE	Inspect individual results or complete tables
EDIT	Edit database values
LEAVE	Leave the application

CORROSION is designed to be the most common choice for most users of the application, and its selection leads to the display on the screen of a set of results for a selected combination of alloy, environment, and exposure time. Sub-menus allow the selection of alloys and/or environments to be made. The user *can* scroll through the results of these selections using the cursor control pad. Results are presented under the sub-headings General Corrosion and Scaling, and Pitting Corrosion on the Face and under a Crevice, and descriptive codes and explanations are presented describing the Form of Corrosion and the physical nature of the Corrosion Products. Figure 1 gives a screen view of to a typical CORROSION **display.**

COMPOSITION enables the user to view chemical composition results for the alloys tested, the chemical requirements of standard alloys matching those alloys tested, and also the composition of the test environments utilised. Sub-menus allow the selection of alloys or environments.

```
Press [F2] when finished viewing the information
Total records: 21 - Use PgDn/PgUp/Ctrl-Z to move to other records

            CORROSION RESULTS - SELECTED RECORD NUMBER   15

UNS#: S30400   St St Austenitic             Alloy Number (A#):  4
AV82#:  39     MAT-ID: 18-304               Vessel Number (V#): 5   52 weeks

General Corrosion and Scaling     Pitting Corrosion              Face    Crevice
-----------------------------     ------------------------    -------- --------
Material Loss/µm:        18.5     Pit Density (ASTM G46):        AS       AS
Corrosion Rate/µm/yr:    18.5     Maximum Pit Depth/µm:          850      765
Note:                             Mean of X (5) Deepest/µm:      670      625
                                  Note:
Material Gain/µm:
Scaling Rate/µm/yr:
Scale Thickness/µm:
Note:
                              Codes - via F3, PgDn/PgUp/Ctrl-Z, F4       Detail
                              ------------------------------------      --------
Form of Corrosion: GPCOx      (Ox  Oxygen ingress during test     )     E-S:  MP
Corrosion Products: ABIf      (N   Non-adherent, easily removed   )     T#:    7
                                                                        Mon:  C
References: 3.0  55.0  55.1                                             Cnt:  1/3
```

Figure 1: **Typical** Form For Viewing All Entered **Corrosion** Results For One Record. A Similar Screen Is **Used** For Editing Single Records.

```
Main
├─── CORROSION
│      ├─── ALLOY
│      │      ├─── A# [ View]
│      │      ├─── UNS# [ View ]
│      │      ├─── AV82# [ View]
│      │      ├─── DESCRIPTION [ View ]
│      │      ├─── IDENTITY [ View ]
│      │      ├─── ALL [ View ]
│      │      └─── CANCEL [ Cancel ]
│      ├─── ENVIRONMENT
│      │      ├─── A#&V# [ View ]
│      │      ├─── ALL [View ]
│      │      └─── CANCEL [ View ]
│      ├─── BOTH
│      │      ├─── A#&V# [ View]
│      │      ├─── UNS#&V# [ View ]
│      │  t   —
│      ├─── ALL [ View ]
│      └─── CANCEL [ View ]
├─── COMPOSITION
│      ├─── ALLOY
│      │      I ────#[View]
│      │      ├───
│      ├─── ENVIRONMENT
│      │      ├─
│   t  —
├─── GRAPH
│      ├─── ML&CR [ Script ]
│   t  —
├─── BROWSE
│      ├─
├─
```

Figure 2: Illustration of Format For Application Menu Tree Structure.

GRAPH enables the user to draw bar charts **giving a** pictorial **display** of results **obtained** in 5 of the **7** test environments. Five graph choices are offered via a sub-menu, enabling charts to be drawn representing general **corrosion, scaling, maximum** pit depths, mean pit depths, or a combination of these **four** quantities. Figure 3 illustrates a typical GRAPH **of** pitting results.

BROWSE enables the user to inspect all the results **and** other **information** stored in the database, either **via** the information presentation screens designed for the programme, or by direct **inspection** of the tables themselves. Toggling **between** these **two** views is achieved **by** a function key. The various tables are made available via the submenus.

For users unfamiliar with either this database or the geothermal test programme, the **BROWSE** selection is a good way to become familiar with the codes used in the database, and the scope of the test programme.

EDIT enables **data** to be edited, deleted, or added. In the final version **containing** all records **this** choice is likely to be password protected to prevent accidental corruption of the data. **As** in the **BROWSE** selection, the various tables are made available via submenus.

LEAVE causes the programme to exit **from** the main menu of **GTEST** to the root *directory*.

Wherever **possible, instructions** are provided **on** the screens being viewed. The exception to this is Esc, which **can usually** be used to "backtrack" through menu choices or prompts, although this possibility is not displayed as a screen instruction.

Printed copies of any screen being displayed **can** be made **using** the computer print screen facilities.

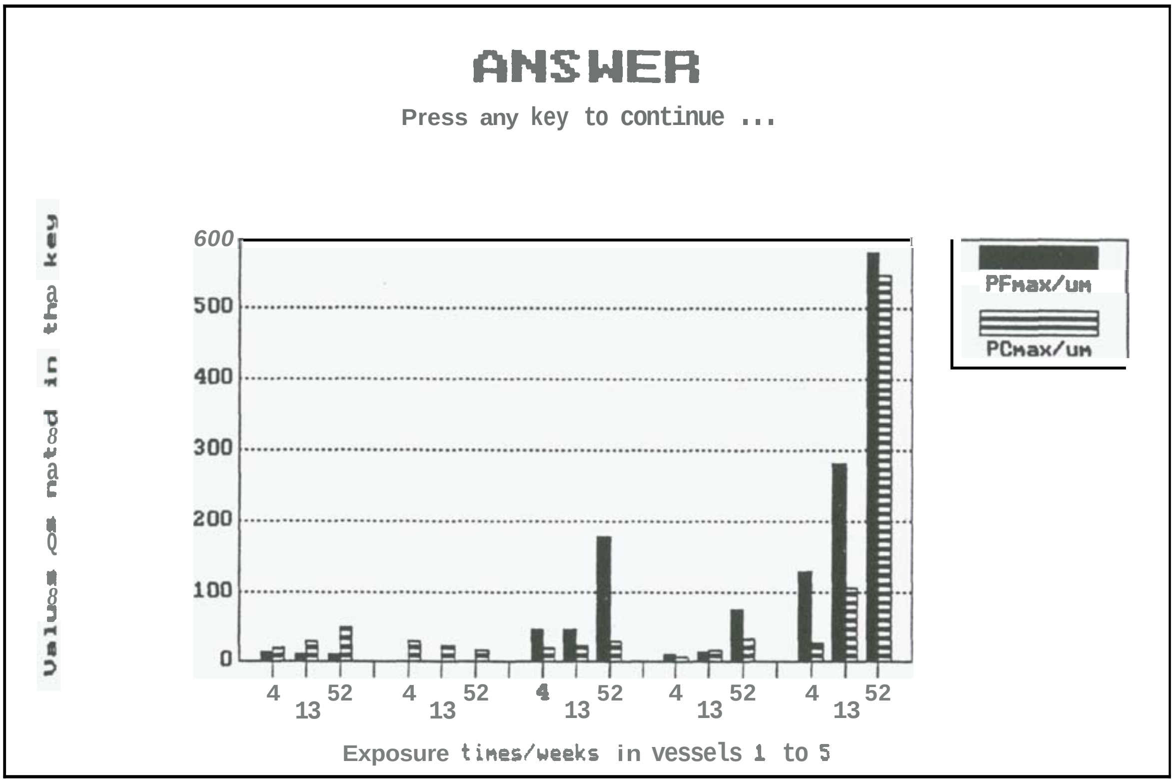

Figure 3: Typical Screen Presentation of Graphic Pitting Results

Most screen displays contain references to the original work fiom which the data has been extracted Reference details are also available for viewing in GTEST.

7. CONCLUSION

The developed GTEST application provides facilities for capturing and giving long term access to surface corrosion test results for materials exposed to geothermal fluids in New Zealand.

8. FUTURE WORK

Future work will include:
- addition of results for other alloys to the database
- addition of pass-word protection
- creation of validity checks
- addition of a help screen
- addition of an opening introduction screen
- corrosion expert testing and revision
- using PAL(TM) to improve graphics presentations
- expanding the database to include metallurgical test results for stress corrosion cracking and corrosion fatigue.
- linking GTEST into the expert system

8. REFERENCES

Anderson, D.B. (1989) Computerization of Corrosion Data, ASTM Symposium on Corrosion Testing and Evaluation, ASTM.

Barnett, P.R., Farrell, R.B., Paterson, G.N. and Ussher, G.N. (1987) GD Manager: A Development in the Management, Interpretation and Representation of Geothermal Field Data, in Proc 9th NZ Geothermal Workshop, Auckland, NZ pp 9-13.

Braithwaite, W.R. and Lichti, K.A. (1980) in ASTM STP 717, Casper L A and Pinchback T R, Eds., ASTM, pp 81 -112.

Glazman, J.S. and Rumble, J.R. eds. (1989) Computerization and Networking of Materials Databases, ASTM.

Lichti, K.A. and Wilson, P.T. (1983) Materials Testing in Geothermal Steam, in Proc. on Solving Corrosion and scaling Problems in Geothermal Systems, San Francisco, CA, USA, pp 269-284.

Lichti, K.A. and Wilson, P.T. (1990). Geothermal Materials Advisory System, 12th NZ Geothermal Workshop, Auckland, NZ, pp 17-22.

NACE Standard RP0690-90 (1990) Standard Recommended Practice for Standard Format for Collection and Compilation of Data for Computerised Material Corrosion Resistance Database Input, NACE, Houston, Texas, USA.

Personal Computing Journal. (1988) November, pp 174 - 283.

Rumble, J.R. and Hempel, V.E. eds. (1984) Database Management in Science and Technology, North-Holland.