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ENEL GEOTHERMAL DATABASE

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ABSTRACT

The different activities related to the exploration, development and utilization of geothermal resources generate a huge amount of data that must be verified, managed and elaborated. The need for an efficient information retrieval system has been recognized as a vital tool for our organization. After an initial period of managing an enormous amount of data collected as paper-files (containing all the historical archives since 1930), an integrated information system was developed aimed at achieving maximum data integrity: Uniqueness, safety, accessibility and security. Our strategic goal was to achieve the completeness and dissemination of data among ENEL units for a variety of purposes.
This type of system has the advantage of integrating information from different sources for analysis, elaboration and interpretation. The transfer of all the paper-based data into a structured body of information has required considerable effort, involving both internal personnel and external resources for data-entry.
The focus has been on the Logical Information flow among ENEL units with the aim of storing data in the system as soon as they are obtained and measured, i.e., in their infancy. Because ENEL has a split structure, the system adopted is designed on a dual-server architecture - one in Pisa and another in Larderello - with the continuous on-line exchange of data along a designated line and an automatic alignment from the two machines each night.
The Man-Machine Interface is based on client-server strategy using windows based products on a PC (Visual Basic, Power Builder).

1. INTRODUCTION

The efficient and effective management of a geothermal field implies a huge quantity of data. The exploitation of this resource can be achieved with good «Data Management». At present, a variety of methods are used, from paper-collection to advanced computerized systems. ENEL has developed a Data Base System, called ARTURO, based on Oracle RDBMS in a network client-server architecture (Bertani, 1995). It is a centralized data organization with distributed access designed to achieve optimum «Data Integrity»:

- UNIQUENESS
- SAFETY
- ACCESSIBILITY
- SECURITY

Immediately after on-site measurement, the collected technical data are stored only once on the centralized system where the system manager is responsible for back up, thus minimizing the risk of deletion or corruption (Date, 1981). Since data must be easy to read and use, everyone within the ENEL internal network can be connected to the system and access data for simple consultation or for more sophisticated analysis. Security is guaranteed by the implementation of a password and different levels of access permission. The internal coherence of data, i.e. their uniqueness and the relationships existing between them, is maintained by the so-called Referential Integrity (Maier, 1983; Tsichritzis and Lochovsky, 1977). For instance, it is impossible to assign a measurement to a given well if it has not already been defined in the well-dictionary. At a logical level, a database is made up of several integrated elements:

- ENTITY (the main concepts)
- ATTRIBUTES (the property of the entity)
- RELATIONSHIP (the logical links between the entities)

At a physical level these elements become:

- TABLE (the structure for data storage)
- RELATIONSHIP (the physical link between the tables)

The integrated system is devoted to the follow-up of the entire life cycle of wells and power plants.

1.1 History

The ENEL database has evolved with the development of computer technology. The first implementation dates back to 1987 with several different stand-alone applications in DBIII in a DOS PC with Intel 286 processor. In 1991 ENEL chose Oracle 5.0 as a centralized database system and in that year the first Ethernet based network system was implemented. The ARTURO 1.0 was a terminal based application using PC 286/386 as the passive terminal of a centralized VAX VMS system. In 1993 a number of different data management systems were integrated in ARTURO 2.0, revolutionizing the data structure, and Oracle was upgraded to 6.0. In 1997 the current 3.0 version was released. This was designed for the new PC 486/Pentium using the client/server concept and was aimed at maximizing the power of the new generation PC. Oracle 7, with its advanced replication capacity, was used for the centralized RDBMS. The upgrade to Oracle 8 is still underway.

1.2 Present situation

The central offices of the ENEL geothermal branch are situated in Pisa while the operative sections, on the geothermal field, are located in Larderello, 100 km away. ARTURO is fully distributed between two central servers. The two-server architecture is based on the replication option of Oracle 8. The two databases are aligned every night with a «snapshot refresh» of the modified data in both machines. Users gain access to the database for data retrieval in each server; the only restriction in editing data is on the local server.

2. ARCHITECTURE

The project is structured on different levels and consists of hardware (computer and network); the operating system and network protocol; the database system and tools used to design and develop client software.

2.1 Hardware & Software

The database is sited on two different Unix servers: At Larderello an HP9000 with operating system HP-Unix (v 6.0), in Pisa a SUN ENTERPRISE 3000 with operating system Sun Solaris 2.6. The servers are connected to a LAN, with Pentium PCs operating in Windows95 environment. A geographical network links the two LANs. The total number of operating stations is around 60 at both sites.

The standard net protocol is TCP/IP; the database is Oracle (ver 8.0.4). The Oracle server is connected to the LAN using the Sqlnet 8 software (see Figure 1).

2.1 Developing tools

Oracle was chosen as RDBMS mainly because it is independent of the hardware platform. Changing our application from VAX VMS to Unix SUN and HP did not cause any major problems in porting the whole database. The constantly evolving hardware and operating environment is a critical issue for ENEL. Oracle is also independent of a given supplier and possesses built-in standard language for data retrieval and manipulation (SQL) and the replication maintenance between the two servers (snapshots) are built in. It has also the capacity to implement the Referential Integrity directly on the database without the need to write *ad-hoc* procedures. Another important feature includes the capability of writing functions, procedures and triggers on the servers, leaving the interface only on the client machines. Finally, it is a standard ENEL database system, used by our company in a variety of applications.
Power Builder, which is a graphical Windows-based product, is used for client applications. It is a general purpose commercial package, leading in database developing, and is used to design the forms, reports and the general menu.
Erwin is another important application. It is used to design and generate logical and physical Entity-Relationship (E-R) and can also be used for reverse engineering and for producing documentation on the database automatically.

2.2 Data base Features

The entire database is built with exclusive ownership, and is split between two servers (Pisa and Larderello). The database administrator grants permission to a number of selected users for different portions of the data (see Figure 2).
We have defined a group of ARTURO users and different levels of permission. The philosophy is to provide data access within the ENEL environment while restricting access for data manipulation to a carefully selected groups responsible for predefined types of data. For example, the chemical laboratory has fifteen operators who are allowed to update, insert and delete chemical data only. There are, however, a few exceptions to this rule. Some chemical or physical data are not accessible to personnel outside the laboratory staff prior to their validation.
The ARTURO structure has been designed according to the following guidelines:

- Uniformity of rules for all applications
- Compatibility with previous versions
- Possibility of upgrading the system
- Graphical Interface for man-machine interaction
- Automation of documentation
- Entity relationship model

As regards the database, we adopted a number of strategies directed at improving data reliability and performance. The table data and structure are stored in different table spaces, one for each database category: Tables, indexes, temporary table, snapshots, and new structures (currently being developed). In order to improve performance in disk access, data are stored in table spaces and kept separate from indexes and other items. Another important implementation at the database level on servers regards the procedures, functions and triggers. These procedural programs use server CPU-time. Portability has also been enhanced because upgrades in the client interface do not involve any modifications on server database software.

3. DATA TYPES

The overall structure of ARTURO is based on tables and relationships. A block diagram of the main elements of the whole project is shown in Figure 3.
Table 1 shows how the database has grown over the last two years. The users listed in the table refer to the people who have been granted data modification permission on some of the tables in the system. The increase in the number of tables is the result of improvements in the ARTURO structure, allowing for the addition of extra items. The number of records and the dimension greatly increased in 1998, as historical chemical data were included in ARTURO.

3.1 Well Construction

Well construction data are analyzed in our database, including definition, name, project, location, target scope, and other general information.
A well is described in the system with a well name, the definition of the operation performed (if it is the first drilling, or the deepening of a previous one, or other type of work) and of its branching structure. The first hole is marked with the number 0 and the number increases as offspring branches are created. Each branch, except the first one, is the offspring of its parent branch. Thus a logical branching structure can be retrieved from the database.
During the construction phase, drilling staff using stand-alone software called WIRS - Well Information Retrieval System, collects relevant data. This is interconnected with the main drilling unit computer and many field data are automatically transferred from the on-line process computer to the WIRS PC. Other information, such as daily drilling notes and relevant events, hole diameter, casing, deviation measurements, lithological profile, etc., is directly recorded in the WIRS by the on-shift staff.
Data are transmitted from the WIRS system by modem and LAN connection to the ARTURO Larderello Server, where they are stored inside the database. The detailed analysis of the lithological data, performed by geological staff in Pisa, and the comparison with different wells in the same area and, if available, core data, all produce a stratigraphic geological profile, which is then written in the system.
All the measured geophysical data are stored in the database, providing a general description that includes all relevant information, suitable for finding the archived data (on compact disks, or tapes, or paper report) kept in our Geological Library.
Our Laboratory at Larderello is responsible for a number of physical well measurements, like pressure and temperature logging. These data are collected using an *ad-hoc* system, called SALP (Sistema Acquisizione Log in Pozzo→Well Log Acquisition System). Again, the data collected by the SALP on-line computer are modem-transmitted to the ARTURO Server in Pisa, where they are stored in the database. The raw data are also transferred to a special file server. The total amount of space available for these raw data is 35 Mbytes. All the thermal profiles of each well, recorded as a function of depth or at a fixed depth as a function of time, are analyzed and extrapolated by Reservoir Engineers. A «reference thermal data» is also defined.
An important feature of our system is the storage of both acquired and interpreted data, which are labeled so as to avoid any misunderstandings. ARTURO has been designed to allow for the immediate recording of raw data, as well as the subsequent interpretation analysis performed by our engineering staff.
At well completion, production, injection, build-up and fall-off tests are carried out at the laboratory. The data and the

results of the data interpretation (well parameter permeability, skin, and injectivity) are inferred by the well testing analysis for the various detected fractures and written directly into the system.

3.2 Steam Production

ARTURO controls the entire production system, comprising the wellhead, and the whole steam gathering pipeline network as well as power plant production or generic consumer (greenhouses, chemical factory, fish-farming, etc.,).
Routine chemical data sampling and physical measurements are taken on a monthly basis.
The gathering system is the heart of the data structure. In simple terms, a «gathering system» is a closed system of producers and users. Each well is a dynamic member of one (or more) gathering system(s) as a steam-producer; the power plant or other steam clients are steam-users. The reverse definition applies to a re-injection gathering system.
The steam from one well must be diverted (totally or partially) from one gathering system to another system. The history of the connection and the maneuvering is kept in the database in order to perform the mass balance for producers and users at any time.
All the collected data can be easily analyzed and information for a single well or for several wells can be retrieved in an excel-style table. By using a standard reporting function of the database, the laboratory produces an official monthly report of steam production and re-injected water.
The most important parameters are pressure, temperature, steam and water flow, CO_2 percentage in different positions on the steam-line gathering system - on the well-head, at the power plant inlet, and in important crossing points on the net. The relevant measurement system data are kept in the database and are used to calculate steam flow from the measured pressure difference.

3.3 Re-injection Well

All measurements of injected water are stored in ARTURO. The water flow is followed from the power plant to the re-injection well.
Measured data include flow, temperature, and pressure. In some cases, the monthly re-injected water is recorded as well as the hours of effective re-injection, thus allowing for an estimation of the flow rate.

3.4 Power Plant Electrical Data

The electrical production data (power and produced energy) are stored in the central ENEL computer system in Milan, in a general electrical data base called ET01, which is used for geothermal, thermal and hydroelectric production. The relevant information for the geothermal power plant is retrieved from this system by means of an application called ENELWATT and is stored in our database for comparison with steam data so that plant efficiency can be checked on a daily basis.

3.5 Chemical analysis and other measurement

The last extended application of the database concerns chemical analysis and other parameters such as physical core characteristics.
Chemical data are stored in a data structure focused on the «sample». Each sample is defined with the relevant information concerning the sampling date and conditions. Several quantitative and qualitative determinations are linked to it.

A sophisticated security system has been developed. Each determination has its own security level. Permission to read a determination is granted to a select number of users, therefore, with respect to critical determinations, low level users cannot access information on the measurement of a given sample.

4. APPLICATIONS

The information flow forms a key part of the entire project. It is in a sort of biunivocal-relationship with the ENEL structure. The offices responsible for the equipment used for their measurement enter data into the system. The final user can access data for a variety of purposes, such as reporting, reservoir engineering analysis, comparison and so on.

4.1 Menu ARTURO

This is the most important client application used for data management, manual input, incorporating files collected from other external applications into the database and for modifications, queries, standard reporting, database administration functions and more.
The menu ARTURO is a window to all the technical-scientific data stored in the database and is an invaluable tool for data manipulation and extraction. It was designed using a standard window-based product: Power Builder.
The Menu is structured in two main parts: Dictionaries and data tables/reporting. It is possible to be connected to both servers, irrespective of the client PC location. After menu navigation, the ultimate objective is a window-form with the functions of query and update/insert/delete on specific data, provided access permission has been granted. The forms have four standard formats: Single/multi row, single row master plus detail form, and reports. The query results can be printed or exported to excel/ASCII files.
A help function is on-line on the entire menu. An example of a sample form is shown in figure 4.

4.2 S.A.L.P.

SALP was developed by one of the ENEL subsidiary companies with the aim of achieving an on-line data acquisition system of the temperature and pressure LOG instrumentation. Files are transferred to the ARTURO system and are displayed with a proper window application.

4.3 W.I.R.S.

WIRIS is one of the ENEL service companies pioneering data acquisition systems. It is used to manage the data for the drilling staff and has both automatic and manual data management for relevant drilling information. Files are put on the ARTURO system in the relational environment.

4.4 Enelwatt

Electrical data for all the ENEL power plants are stored in a special database, called ET01, in the ENEL mainframe. Geothermal data are extracted daily from the general system and inserted into ARTURO for a direct comparison with steam production data. A function for controlling the cross-correlation of dictionaries between the two systems has been developed ad-hoc.

4.5 ArcInfo

This is a cartographic package on an ALPHA station used by ENEL for all cartographic requirements and for preparing scientific data, such as geological sections and profiles, isothermal representation at a given depth in specific

geothermal areas, and for the production of maps containing technical items (wells, pipelines, power plants). The package has the capacity to extract information and coordinates from ARTURO, plotting them on a cartographic background.

4.6 MasterLog

This program is the last user application left on the server part. It is a FORTRAN program designed for the generation of an AUTOCAD file with a graphical representation of the main well data: lithological, stratigraphical, hole and casing profile, core data, thermal and physical data, and the main drilling events.

5. FUTURE DEVELOPMENTS

The geothermal database is continuously being improved and the chief goals for the near future concern the new MasterLog, the steam pipeline network representation at a topological level, the microseisimc data integration and an intranet web-based application with a geographical reference.

5.1 Enhanced Master Log

MasterLog must migrate to a client/server environment, with its modification as a window application. A large number of improvements are in the specification phase. Representations will be given of the well trajectory (vertical section and XY map) and of the description of operations performed at different times (deepening, change of casing, and so on). Data from well testing and the fracture characterization will also be shown.

5.2 Steam Pipeline topology

The steam line network topological representation will be described in ARTURO. The entire pipeline system can be represented as a net of junctions and arcs, with physical characterizations, like length, diameter, and roughness. This information can be used to analyze steam transport inside the system, and performing technical optimization of pipeline operations.

5.3 Microseismic data

Microseismic data are collected and managed by a dedicated on-line real time system, with 26 seismic data acquisition stations and radio transmission to the central computer in Larderello for recording and elaboration. It would be important to correlate the seismic information with other on-line data, like the re-injection. An integration of the seismic data in ARTURO is under investigation.

5.4 Intranet application integrated with cartography

We are currently developing an intra-news application that combines ARTURO data and cartographic information from ArcInfo. This application will use standard Internet browsers in our internal network with a geographic navigation on on-screen maps until a specific well appears. It will be possible to access particular technical data from ARTURO by selecting them from graphical icons. The approach will therefore be entirely different from the present menu based method.

6. CONCLUSIONS

ARTURO has proved to be an invaluable tool for data retrieval and maintenance. New improvements are being specified and will be the first objectives of the new millennium.

Transferring and validating data from previous systems in the database has required an enormous effort. The change of mentality and the new approaches have radically changed the working environment. Instructing and training personnel to use sophisticated computer based systems will be our next goal and an exciting challenge for the near future.

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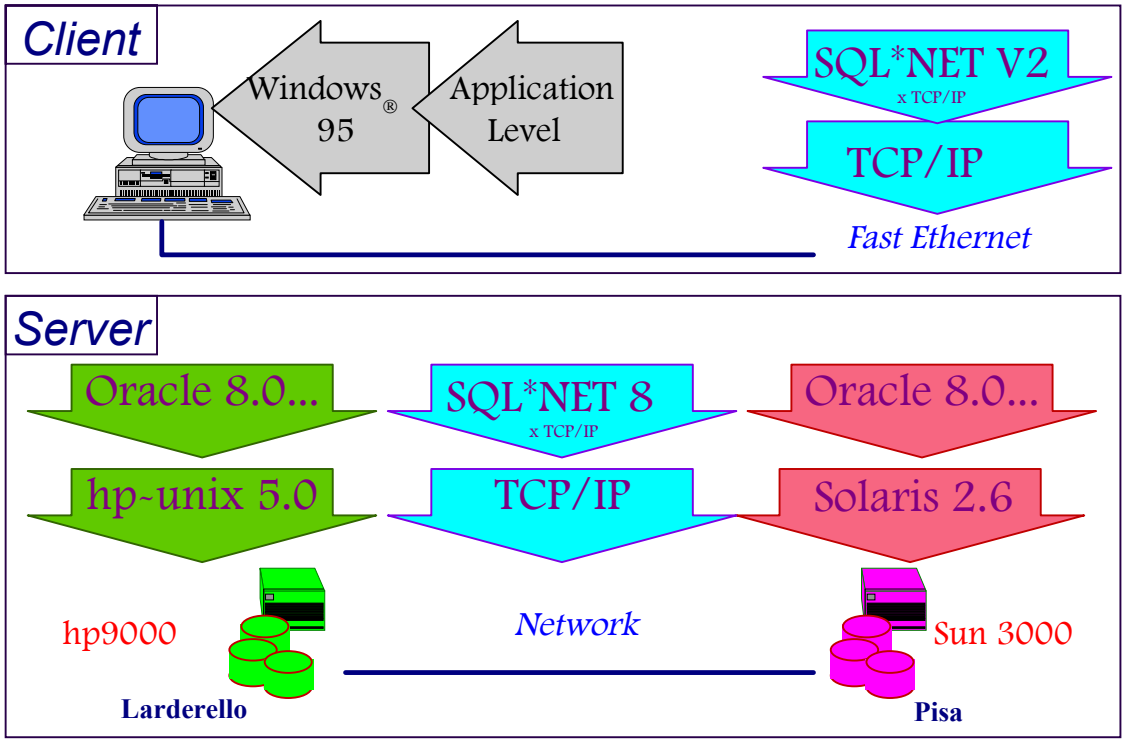

Figure 1: Hardware & software architecture.

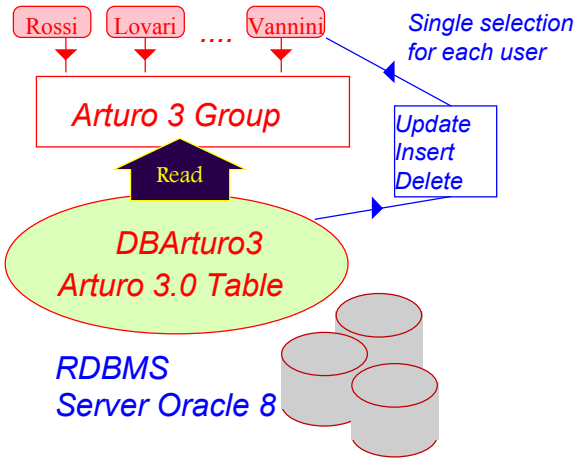

Figure 2: Database architecture

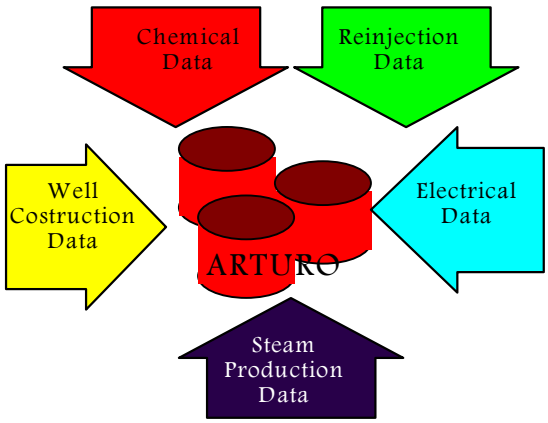

Figure 3: Main elements of geothermal database

YEAR	USERS	TABLES	LINKS	RECORDS [thousand]	SIZE [MB]
1997	31	156	172	828	111
1998	39	159	198	891	163
1999	43	167	198	1125	182

Table I: Estimated database growth

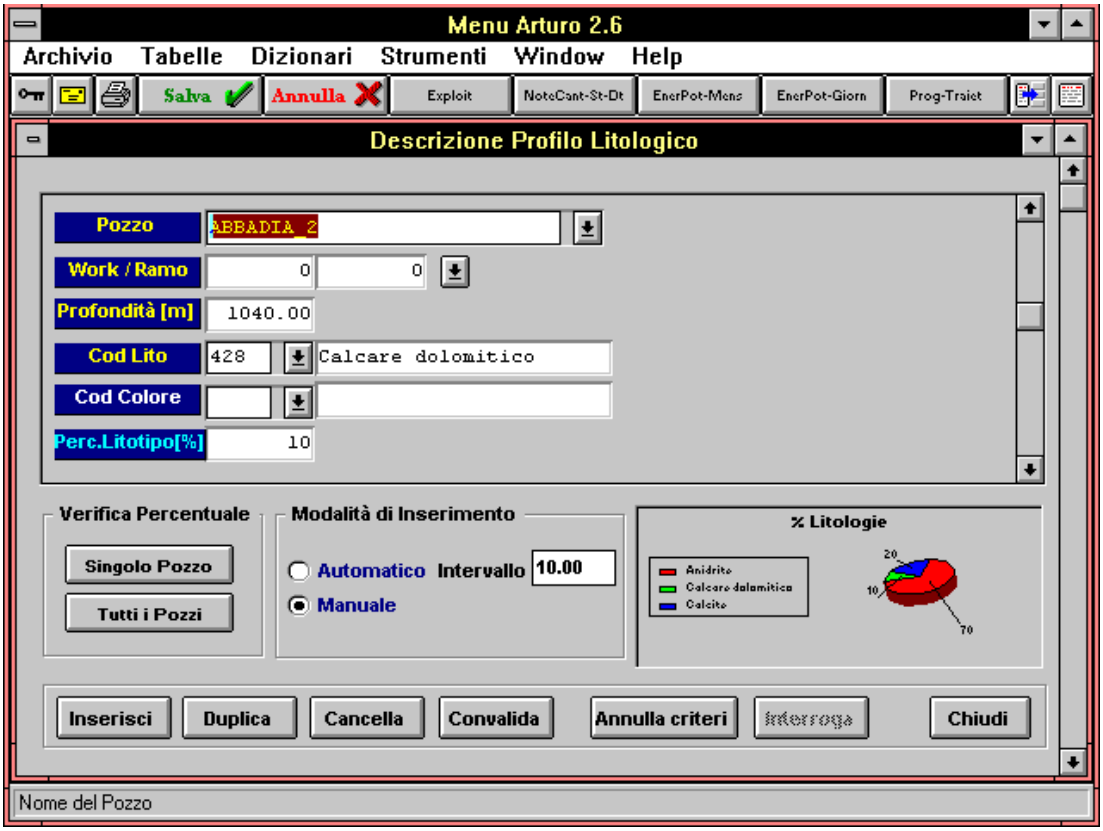

Figure 4: Interface for lithological data in Menu ARTURO.