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THE USE OF RADIOISOTOPIC TECHNIQUES IN THE CERRO PRIETO GEOTHERMAL FIELD.

OBJECTIVES

The original basic objective was to explore the usefulness of radioactive isotopes as tracers for hydrogeological purposes.

The final objective is to establish a technique for using radioactive tracers to follow the movements of underground fluids in geothermal fields in general and to be able to estimate the average relative predominating speeds and directions in the geothermal aquifer of Cerro Prieto in particular.

An immediate goal was to determine the transit time of the tracer between the injection well M-9 and producer well M-29, the producer wells M-19, M-25, M-30, M-34, M-5, M-26, M-31 and M-35 were taken to witness (Fig. A).

BACKGROUND

Hydrogeology

The Cerro Prieto geothermal aquifer is currently being exploited through an average of 30 wells from 1,500 to 2,300 m deep, which provide an average flow rate of 1 ton/s of a mixture of water and steam and the steam is used to operate five turbo-generators with a total capacity of 180 MW.

The direction of underground hydraulic flow in Cerro Prieto I, the zone on which the present study focuses, had previously been defined on the basis of interpretation of pressure logs and the piezometric levels of observation wells as being radial and moving toward the center of the exploitation area, the direction obviously being the result of extracting geothermal water (Fig. B).

Furthermore, on the basis of drawdowns and the extraction to which the aquifer was subjected from 1973 to 1979, the transmissibility coefficient of the aquifer was inferred with conventional hydrogeological techniques to be on the order of 0.0034 m^2/s.

With the above information, the transit time for a particle of water in the geothermal aquifer of well M-9 to M-29 was estimated to be approximately 90 days, which is essential information for designing a test with radioactive tracers.

It should be pointed out that the above deductions were made with data from years prior to the injection of the radioactive isotope, so the hydraulic flow conditions do not coincide exactly with the conditions that existed during the radioactive tracer test, owing to an increase in the rate of extraction and the location of new exploitation wells.

Reinjection

For some time, the need to reinject geothermal water in Cerro Prieto has been planned in order to meet two basic objectives: the first is to recharge the aquifer hydraulically and the second is to assist in solving the waste problem of geothermal water.

In order to gain knowlege of the problems and to develop technology for the reinjection process, the Coordinadora Ejecutiva of Cerro Prieto began reinjecting well M-9 with water separated from well M-29 on an experimental basis in August 1979. It should be noted that there have been no major problems in the reinjection process from the time it was initiated to date, but doubts have arisen regarding whether the reinjected water actually circulates toward the exploitation zone and is integrated into the geothermal process or if it spreads in other directions.

TECHNIQUE USED

Theoretical considerations

Knowledge of underground hydraulic flow speeds is of almost importance in assessing the potential of a geothermal system and establishing a suitable policy for exploitation.

Conventional methods of determining flow speed and direction are all indirect and are based on interpreting variations in parameters such as drawndown, piezometric levels, hydraulic gradients, etc., which requires observation wells and adjustment in the readings obtained to certain mathematical models that may be adjusted in each specific case with greater or less precision, depending on the quantity of information available and its proper interpretation.(1)

Another interpretation method is the use of tracers, the characteristics of which present certain advantages that sometimes offset the difficult techniques involved.

In fact, the tracer method is based on the so-called "Tracer Paradox," which stems from its definition in which tracer is the name given to the agent used to observe the behavior of part of a system and this agent must fulfull two functions or roles simultaneously: 1) it must have identically to the component it is tracing (be equal to it) and 2) it must have "something" that makes it distinguishable (be different from it). In general, tracer analysis methods need for the tracer's behavior to be as similar as possible in the characteristics to be measured, but to have some other characteristic that makes it possible to distinguish it without interfering.(2) With chemical stain tracers, for example, similar chemical behavior is sought, but with a different color.

From this standpoint, radioactive tracers appear to be the solution that comes closest to the ideal, since the same element or chemical compound to be traced may be used as long as it contains a radioactive isotope, which will behave exactly as the element or compound chemically, but will have a characteristic that is distinguishable. Tritiated water (HTO), for example, is the ideal means of following the movement of water, since it behaves as water (because it is water), but has a radioactive characteristic that makes it easily distinguishable.

In the case of reinjecting fluids in geothermal fields, the knowledge sought through tracers is the flow speed and direction of underground water, so that important parameters may be measured for the proper exploitation of the aquifer, such as porosity and permeability. Tracers are also used to determine whether the underground flow pattern is consistent with the estimate made prior to beginning reinjection.

The principle of the radioisotopic tracer technique is simple and is based on adding the radioisotope to the reinjection water in order to evaluate its presence and, if possible, its concentration in the water and steam of nearby production wells as a function of time that has elapsed since reinjection.

In all work with radioactive tracers, the starting point is choosing the radioisotope to be used, which is selected according to the type and energy of its radiation, its half-life, its radiotoxicity, availability and price. Once the radioisotope has been chosen, the tracer compound needs to be defined on the basis of the type of work to be performed, that is, affinity between the radiotracer and the compound to be traced is sought. Once the radiotracer has been defined, it is necessary to evaluate its activity, particularly its specific activity in relation to the system to be traced and the detection equipment available. During the final phase of this stage of the study, a careful examination of radiological safety should be made in order to obtain related permits from the pertinent safety groups involved.

Interpretation of results

According to theoretical considerations,(3) if an instant injection is made in a porous environment with channeling to determine the flow rate, the irruption curve of the tracer may be of the type in Fig. C. In our case, a type-1 curve may be expected. In every case, instant injection is assumed to be at the moment when t=0.

From the response curves, moments may be defined as:

$$Mn = \int_0^\infty t^n \quad c\ (t)\ dt$$

The moment zero (MO) is the lower part of curve C (t) or a measurement of the radioactive material recuperated if C(t) is expressed as absolute radioactivity.

The transit time of the tracer is given by:

$$Tt = Min = \frac{M_1}{M_0} = \frac{\int_0^\infty t\ c(t)dt}{\int_0^\infty c\ (t)\ dt}$$

Where both integrals may be solved with numerical methods.

DEVELOPMENT

Choosing the Tracer

Half-time. The half-time indicates the time at which the original radioactivity is reduced by half. For practical reasons, this period of time should be on the same order as the duration of the experiment. In our case, the expected time of irruption was on the order of 90 to 100 days and therefore an isotope with a half-life from 50 to 200 days was sought.

Radioactivity. An effort should be made to reduce radioactivity to the minumum without sacrificing results. In our case, the limit for detection was on the order of 1 Ci/m^3, with expected dilution of approximately 10^5 (data obtained from prior experience in oil fields, which, though limited, are the only base available), the estimated minimum would be 100 mCi.

Type and Energy of Radiation. Since laboratory counts are not included in plans, a medium energy gamma emitter is sought in order to minimize risks during injection.

Bearing in mind the considerations mentioned, handbooks on the use of radioisotopes were consulted (4,1) and Ir-192 was selected as the most recommendable, as a γ emitter of 0.32 MeV and β emmitter of 0.66 MeV (T1/2=74 days).

Among the possible compounds based on Ir-192, $Na_2Ir^*Cl_6$, sold commercially as an industrial "universal water tracer" called RAWT-192, was the one selected.

Injection

Once the tracer is selected, its injection and detection are planned. There was a device for injection such as that indicated in Fig. D, which, because of its simplicity, ensures a minimum of risk during the operation.

After the main tank is filled to two thirds of its capacity with water, the tracer is immediately added, which is the operation with the greatest risk from a radiological safety standpoint. Immediately thereafter, the tank is filled to its calculated maximum volume (20 l.) with water and the water and tracer inlets are hermetically sealed. With the upper valve open, nitrogen is then "bubbled" from below in order to obtain a perfect mixture of the tracer in the total volume to be injected.

Since this was the first attempt at an experience of this type, two injections were made in order to ensure the proper functioning of all the phases and to demonstrate the measurement of hydraulic flow in the casings; the first injection involved transferring 500 ml of the original solution (approximately 2.5 mCi) to a second injection tank, which was instantly injected into the system, making it possible to observe the proper functioning of the injection and detection system along the injection pipeline from M-29 to M-9.

The injection of total radioactivity (approximately 97.5 mCi) was conducted in a continous and uniform manner during 3 hours with the injection pressure controlled by the nitrogen tank regulator. The purpose of such continous injection was to ensure "in situ" detection and sampling, which, at the beginning, took place every three hours to avoid failure of the experiment in case there was extensive channeling.

The injection pressure for the first injection was on the order of 12 kg/cm^2 and during the continous injection 10.4 kg/cm^2. The injection pressure of reinjected geothermal fluids is 8.6 kg/cm^2.

The instant injection was made at 8:59 p.m. on August 29, 1981, in order to minimize problems of temperature and unauthorized personnel in the area.

The continous injection took place from 12:30 a.m. to 3:30 a.m. on August 30, 1981.

In Situ Detection

An effort was made to detect the passage of the first injection at different points along the injection pipeline from M-29 to M-9.

Using a rate meter with a plotter, the passage of the tracer at the injection point (8:59 p.m.) and the entry point of injection well M-9 (9:57 p.m.) were both recorded.

Once the volume between the injection point of the tracer and the entry point into well M-9 is known, the injection flow rate can be calculated; if the flow rate is known, the volume between the points may be estimated; and if the length of the pipeline is known, its effective diameter can be determined (to evaluate scaling).

To prevent the unobserved passage of the tracer into well M-29, a bypass of separated water was connected to its outlet in order to reduce the temperature and be able to place a detector in the controlled flow. The detector (NaI) was joined to a rate meter and plotter, which operated continually during the entire experiment (4 months).

Sampling

Apart from the "in situ" detection in well M-29, all the wells near M-9 were sampled in order to detect the passage of the tracer into one or several of them and be able to determine the flow pattern.

Since both theoretical considerations and experience demonstrated that the time duration of the irruption curve of the tracer in instant injection is related to the time it takes for the tracer to appear, while, in the case of continuous injection, the duration of the injection itself should be added as a plateau, the program was planned so as to avoid, insofar as possible, having sampling points on both sides of the irruption curve.

Thus, at the end of the continuous injection, sampling was initiated at intervals of three hours, which even in the case of extensive channeling could cover the possible passage of the tracer during a three-hour plateau period. Gradually, the frequency of sampling was reduced to one sample per day and continued at this rate until the passage of the tracer into well M-29 was observed.

RESULTS

Instant Injection

As mentioned above, the purpose of this injection was to verify the proper functioning of the systems and to demonstrate the use of radiotracers in measuring hydraulic flow in pressurized pipelines.

From the measurements taken, however, it was also possible to determine the transit time of the tracer as 58 minutes.

a.- Assuming a flow rate of 12.5 ton/h (determined from 28 to 31 August) and 490 meters of pipelines, the effective diameter was calculated at 6.90 inches.

b.- Considering the nominal diameter and length of the pipelines, as well as the density of the reinjection fluid, a flow rate of 15.2 ton/h was observed instead of 12.5 nominal ton/h.

Continuous Injection

In this case, the goal is to estimate the transit time and average speed of the water in the underground reservoir.

a.- "In Situ" Detection. The results were not conclusive, since there was insufficient separated water around the detector, which, in addition, should have been thermically insulated from the water. Such conditions made it extremely difficult to detect the tracer. The observations of the continous detection plotter, however, seemed to indicate the presence of the tracer when it was confirmed by the continuous sampling.

b.- Sampling. The irruption curve of the tracer in well M-29 (Fig. E) makes it possible to evaluate the transit time through the moment method as being t=80 days.

Since the distance between well M-9 and well M-29 is 217 meters, the average speed of the water is 2.17 m/day.

CONCLUSIONS AND RECOMMENDATIONS

The basic objective of the work was achieved to a great extent, since the conclusive results obtained make it possible to recommend using the technique established, both in the same area or in other areas of the same field where knowing the preferential flow directions and average transit times could be of interest.

The immediate goal was fully achieved, since the previous estimate of transit time as being on the order of 90 days was confirmed and adjusted to 80 days.

On the basis of recommendations stemming from the results obtained, a program is under way to apply radiotracer techniques to study 3 zones in the Cerro Prieto field itself, including a repetition of the M-9/M-29 system with a double tracer to evaluate the possible use of other radioisotopes.

In addition to extending the use to other areas within the field itself, the possibility of applying the technique to other geothermal fields under the control of the CFE, such as Los Azufres and La Primavera, is being studied.

Information on the results obtained will be presented in the future.

RADIOLOGICAL SAFETY

As indicated in the theoretical considerations, an extremely important factor in the use of radiotracers is radiological safety.

From the time the radiotracer was being selected, an effort was made to keep radiotoxicity to the minimum and always within acceptable limits.

A tracer was sought that would not permanently contaminate the field or interfere with any other studies that were to be carried out or might be carried out.

Thus, tritium was not used because it

would interfere with other studies and carbon 14 was avoided because it would contaminate the area permanently.

The radioactivity used was as low as possible, even at the expense of somewhat affecting the project's possibilities for success. In future applications, a bit more radioactivity is expected to be used and the detection systems are expected to be improved in order to obtain more reliable quantitative results.

The radioactive material was obtained through the ININ and was approved and supervised by the Comisión Nacional de Seguridad Nuclear y Salvaguardias at all times.

All possible precautions were taken for the injection and it was even carried out at midnight on a weekend in order to reduce the staff present to the minimum.

The injection was performed by experienced staff that had previously carried out a simulated injection to verify the proper functioning of all the systems. The quantity injected (100 mCi), when diluted in 20 liters, produced a concentration of 5 mCi/l or 5 Ci/ml, which is high but not dangerous if ingestion is avoided. When mixed with the volume of reinjected fluids (37.5 tons in 3 hours) a concentration of less than 3×10^{-3} Ci/ml was obtained, which is only one order of magnitud above that allowable for drinking water.

According to the samples taken, the production water showed no appreciable concentration, even at the time of the maximum irruption curve of the tracer, since the concentration was 3 orders of magnitude below that permitted for drinking water and it should be noted that the salt content of the water (particularly silica) makes this water unfit even for irrigation.

FIGURES

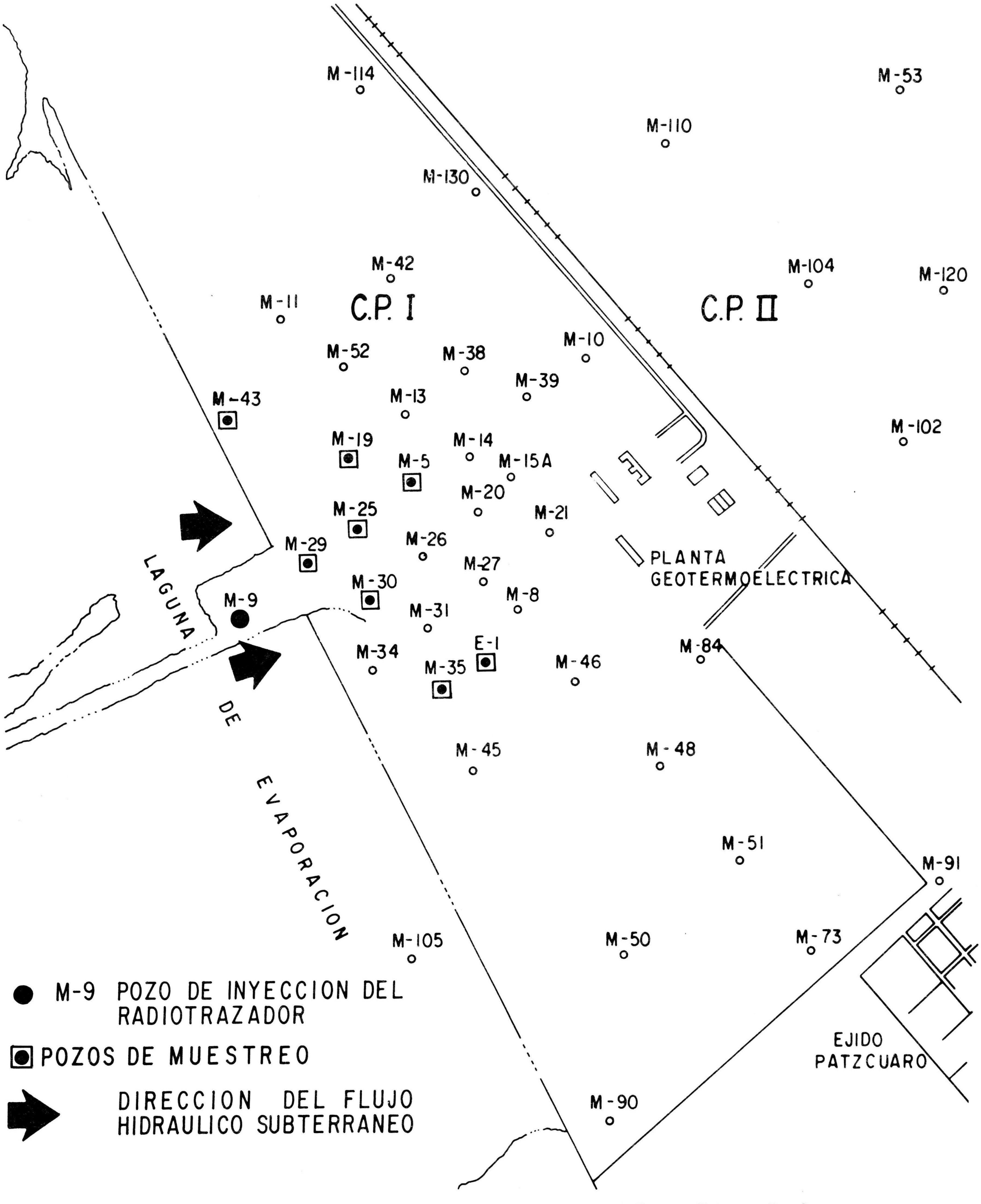
Fig.A. Location of the Wells in the Rediotracer Study.

Fig.B. Curves of Equal Depth at the Piezometric Level.

Fig.C. Tracer Irruption Curves.

Fig.D. Diagram of Facilities for the Injection of Iridium 192.

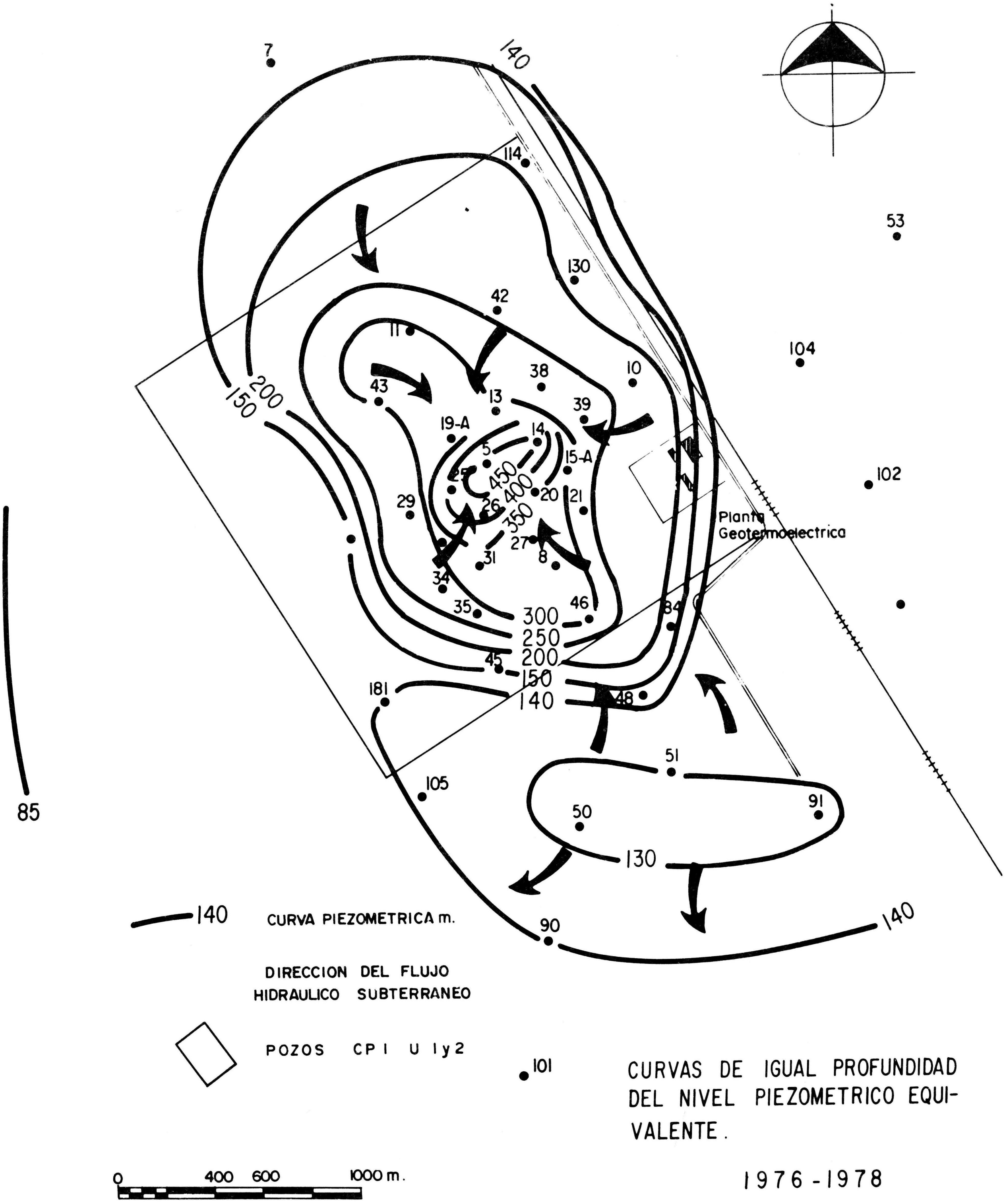
Fig.E. Plot of Relative Radioactive Variation in Well M-29.



LOCALIZACION DE LOS POZOS DEL ESTUDIO DE RADIOTRAZADO

fig. A

HIDROLOGIA



CURVAS DE IGUAL PROFUNDIDAD DEL NIVEL PIEZOMETRICO EQUIVALENTE.

1976 - 1978

fig. B

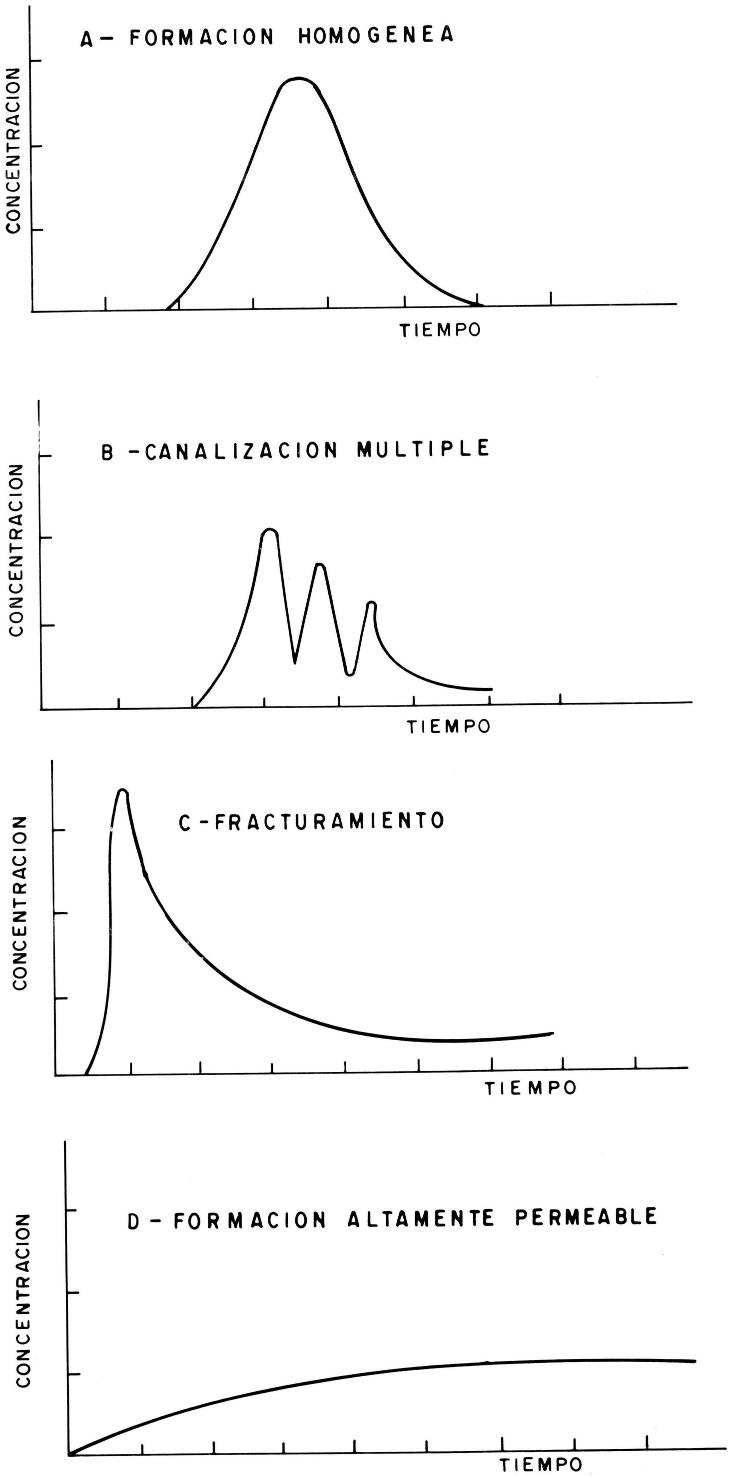


FIG. C CURVAS DE IRUPCION DEL TRAZADOR

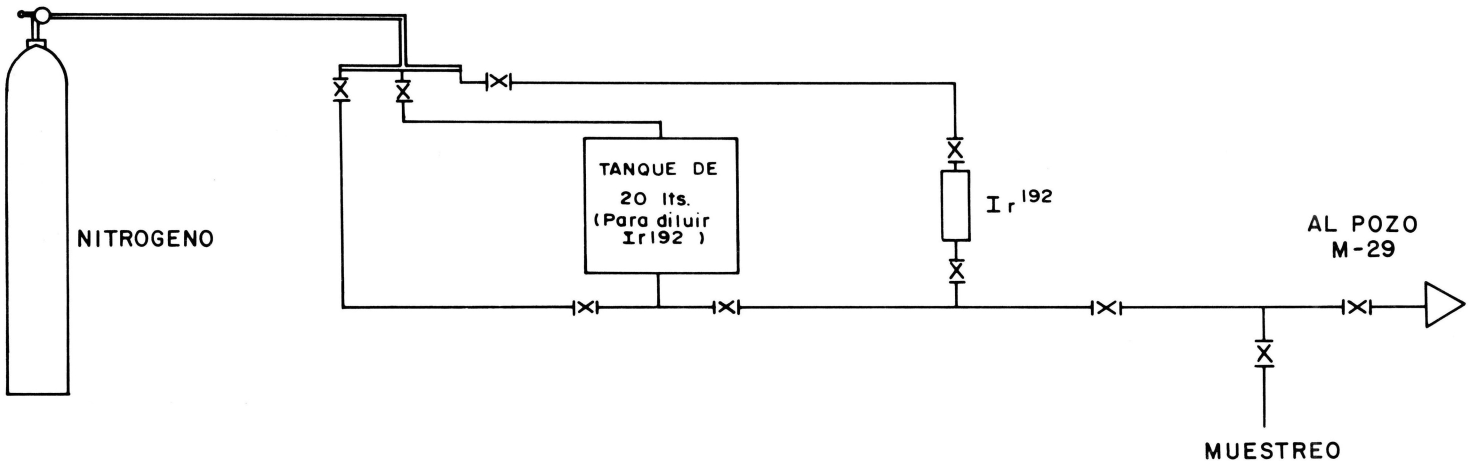


DIAGRAMA DE INSTALACIONES PARA LA INYECCION DEL IRIDIO 192 fig. D

GRAFICA DE VARIACION DE LA ACTIVIDAD RELATIVA EN EL POZO M-29

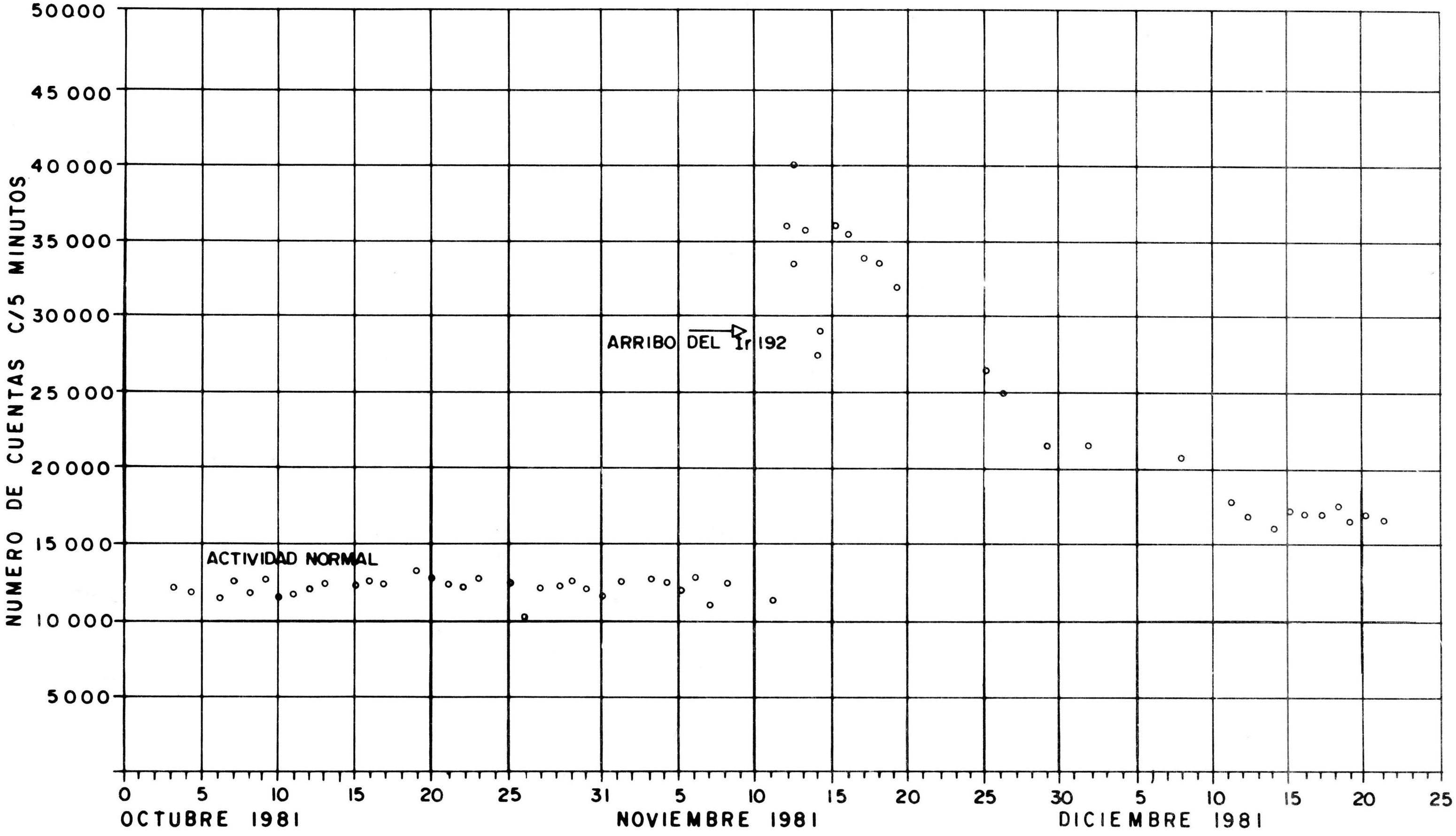


fig. E