# Tracer Testing at Los Azufres

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## 1. Summary

Up until February 1987, nearly 8 million tonnes of water had been reinjected at Los Azufres, mainly at wells Az-40, Az-15, and Az-7. Six tracer tests had been performed up to the most recent one in July 1987. No tracer was recovered in any of the tests. We reviewed the format used in the tracer tests, and the implications of the null responses. Based on the results, it appears as if reinjection into wells Az-7 and Az-8 is unlikely to affect reservoir performance detrimentally. Since tracer return times seem to be long at Los Azufres, further tracer testing is probably not warranted--as an alternative, long time monitoring of liquid and gas chemistry (such as chloride and nitrogen) may identify the longer term transport of injected fluid through the reservoir.

## 2. Reinjection History at Los Azufres

Reinjection has taken place at Los Azufres since 1982, and there has been no difficulty accepting the entire waste water flow from the five wellhead units. Table 1 summarizes the total quantities of water injection up to February 1987. Altogether about 8 million tonnes of water had been injected by that time. The principal injection sites have been wells Az-40 and Az-15 in the Northern Sector, and wells Az-7 and Az-8 in the Southern Sector. Recently, well Az-31 has been added as an injector in the Southern Sector. Well Az-1 has been proposed as a potential reinjection site, based on its proximity to the central power station site. At the present time, well Az-40 accepts most of the fluid from the Northern Sector, and well Az-7 accepts most of the fluid from the Southern Sector.

The total fluid injection requirement for the field will be about 700 tonnes/hour. Well Az-7 can, by itself, accept at least 425 tonnes/hour without raising the water level in the casing by more than 10 meters (from a static level about 450 meters below the casing head). It has not been demonstrated that well Az-7 can accept more than this (as only 425 tonnes/hour is available for testing), but it seems highly probable that well Az-7 could accept even the entire 700 tonnes/hour required. Well Az-8 has been demonstrated to be able to accept at least 225 tonnes/hour, so between these two wells, there is already sufficient proven reinjection capacity for the 50 Mw development.

There does not seem to have been any problems with deposition in the reinjection wells, but well Az-40 has shown evidence of casing corrosion due to the dissolution of acidic alteration products into the water from Laguna Verde.

## 3. Tracer Tests at Los Azufres

A total of six tracer tests have been performed at Los Azufres (see Table 2). The first of these used 1000 kg of potassium iodide, the other five all used radioactive $Ir^{192}$. All of the tests were of the well-to-well type. In two of the tests, the wells were flowed only briefly after the injection; thus, the probability of a return of the tracer being detected was low--and in fact none was seen. Even in the other four tests, in which injection was continuous, no tracer was ever detected, even after 2 or 3 months of monitoring.

The following paragraphs describe each of the six tracer tests in detail.

The first test was conducted in 1983 by the personell of the Instituto de Investigaciones Electricas (IIE) in collaboration with Stanford University. In this study, 1000 kg of Potassium Iodide (KI) was injected into well Az-8, which was receiving the total water production from well Az-2. Wells Az-2 and Az-16 were monitored for the return of the Iodide, as well as for changes in sodium, potassium and lithium. The monitoring continued for three months.

No tracer was detected in either Az-2 or Az-16.

Following the lack of success with KI, it was decided to use radioactive materials as tracers in subsequent studies. Iridium-192 ($Ir^{192}$), with a half-life of 74 days, was selected since it was possible to acquire it within Mexico, and since it was easy to handle and detect. In the second tracer test, 4 GBq of $Ir^{192}$ were injected into well Az-43 on March 14, 1984, using separated water from well Az-13. Monitoring for the return of the tracer was continued for five months at wells Az-5, Az-13, Az-19 and Az-32, as well as at the springs at Laguna Verde and Laguna Maritaro.

The third tracer test was conducted in the South-East zone, where 7.4 GBq of $Ir^{192}$ were injected into well Az-26 with the separated water from well Az-18. This injection was completed on August 31, 1984, and water samples from wells Az-18 and Az-31 as well as from the Los Azufres springs were monitored for a period of four months.

In the same year, 1984, one more study in the Southern zone was performed. The well selected was Az-7, into which was injected 14.8 GBq of $Ir^{192}$. The observation wells were Az-2, Az-16 and Az-16D. Injection started on September 20, and monitoring continued for four months.

Next, in 1985 it was decided that more tests would be done in the central part of the Southern zone, known as Tejamaniles. Well Az-33 was selected to receive 14.8 GBq of $Ir^{192}$. Injection took place on March 28, 1985, and wells Az-6, Az-17, Az-24, Az-36, Az-38 and Az-46 were monitored. It is important to note that, except for Az-46, all the monitored wells produced dry steam. Monitoring was continued for seven months after the injection.

Finally, the sixth and last study was again done in the South-Eastern zone. In this case 12 GBq of $Ir^{192}$ were injected into well Az-31, on July 30, 1987, using the separated water from wells Az-18 and Az-26, and from the Laguna de Los Azufres. This last test lasted four months.

## 4. Discussion of the Tracer Tests

As can be appreciated from the preceding descriptions, there was intensive study of the fluid movement in the Southern zone through the use of tracers. In spite of all these studies, there still remains an uncertainty about the chemical stability of the tracers once the reservoir pressure and temperature was reached. Nor is the tracer/rock interaction fully understood, and adsorption of the tracer may have been a factor that reduced the effectiveness of the investigations.

In hindsight, it is possible to pinpoint some errors and omissions in the tests so that they will serve as a precedent for the reformulation of this type of study. In particular, the first test made use of natural chemicals present in the fluids (such as $Cl^-$ and $Na^+$) in addition to the artificial tracers. This is shown in Figure 1 (from Iglesias, 1983).

In the second test, in the Northern zone, the radioactive tracer injected into well Az-43 was displaced by 40 t/hr of separated water from well Az-13. The injection continued at constant rate for 11 days. An important detail here is that once the injection was concluded, well Az-43 was shut for two months before being reopened again for another test. The water produced at that time was analyzed in attempt to detect any indications of the tracer initially introduced. None was found, suggesting that the tracer was either retained or migrated so far into the reservoir that it could no longer be detected.

The next three tests in the Southern zone were all similar, in that each of them monitored the chemistry of the springs in the area, which was found to behave similarly to that of the observation wells. Figures 2 and 3 show the observations during the 1984 tests, while Figure 4 shows the activity at the springs.

The final test at Los Azufres, which used Az-31 as the injection well, can be considered in general as the least reliable of the group. This is due to the fact that there was no adequate control of the samples nor of the measurements made on them. There were also periods of time in which no measurements were taken due to problems with the detectors. Thus the information from this test is practically impossible to interpret.

Based on this synthesis of the work done on tracer testing at Los Azufres, there are four major points that can be summarized:

(a) It would be important to perform a laboratory study to determine the effects of adsorption of the tracer onto the rock. Otherwise there would be continuing uncertainty over this phenomenon.

(b) It is necessary to describe a dispersion model for the tracer in order to define the frequency of sampling needed in each case. For example, in the first study the sampling rate was proportional to the square root of the elapsed time since injection.

(c) It is necessary to understand the effect of change of phase of the fluid containing the tracer. This is important in places like Los Azufres, where wells in the Southern zone produce mainly dry steam. Perhaps the tracer that is contained will eventually be condensed at the side of this zone.

(d) It is necessary to revise the methodology for the detection of the radioactivity present in the fluid produced from the wells. The importance of this can be appreciated by examining the measured response when the detector is placed in the water vessel without much attention to its position. This can be quite different to the response of the same detector when it is centralized in the vessel, as shown in Figure 5. Much smaller dispersion of the values can be seen once the detector is centralized.

## 5. Interpretation

Some of the tests are of particular importance; namely, those in which tracer was injected into well Az-7, well Az-8, and well Az-31. These wells are to be used for reinjection during plant operation; therefore, it is important to know where the reinjected water went. As discussed in the previous section, the test at well Az-31 encountered some problems, and the observation well Az-26 could not be produced (for mechanical reasons) until some time after the injection commenced. Thus, the (null) result of this test is rather inconclusive. On the other hand, tracer injection into wells Az-7 and Az-8 was effectively achieved, yet no return was detected at the two closest production wells (Az-2 and Az-16). We must conclude either (a) the tracer was retained within the field by some mechanism or (b) the return occurred after the monitoring was terminated, or was at such a low concentration as to escape detection.

To examine these possibilities, we looked for changes in chemical composition at well Az-16. Since well Az-7 has been injecting for some time, it is to be expected that chloride concentrations in the reservoir may increase (since chloride is concentrated in the reinjection water due to the separation of the steam). In fact, an increase in chloride concentration at well Az-16 has been observed. Other explanations for this increase are possible--for example, the well could be drawing fluid of higher chloride concentration from greater depth. On the other hand, a much more definite piece of evidence was discovered in the nitrogen content of the production from well Az-16. Nitrogen concentration at well Az-16 is higher than the nitrogen solubility of the geothermal fluid--indicating that nitrogen (which is injected into the reservoir through the open wellhead at well Az-7) is mobile through the reservoir in both dissolved and gaseous forms. Well Az-6 also shows an increasing nitrogen content.

There is an obvious source for this abnormally high Nitrogen. It is observed that well Az-7 sucks large quantities of air into its wellhead, which is open to the atmosphere. The exact quantity entrained is not known, however the suction at the well head is sufficiently vigorous to warrant caution for the personell working in its vicinity. It is reasonable to assume therefore that the intake of air is substantial. More than that, the intake is known to have been occuring periodically (time period of order of minutes) throughout the time that reinjection has taken place there.

Thus, it appears evident from this "natural tracer" that water reinjected into well Az-7 does return to well Az-16, and perhaps to well Az-6 as well. In order to estimate the rate of movement of the reinjected water, we examined historical data of chloride and nitrogen production at well Az-16, as well as nitrogen production at well Az-6, and we recommended that an attempt be made to estimate the rate of nitrogen intake into well Az-7. Figures 6 and 7 show the nitrogen production as a function of time in wells Az-6 and Az-16. Other contributing evidence was obtained by plotting the argon and argon/nitrogen ratios in wells Az-6 and Az-16 (Figures 6 and 7) which demonstrate that the gases are atmospheric in origin.

It is evident from these plots that the transit time from well Az-7 towards wells Az-6 and Az-16 is of the order of months, which suggests why the radioactive tracers were never detected. This is an encouraging conclusion from the point of view of reinjection, as it suggests that thermal breakthrough of the reinjected water will be slow between these particular wells.

## References

Iglesias, E.R.: "Reporte de avance del primer intento de utilizacion de trazadores en el Campo Geotermico de Los Azufres", Memorias de la Primera Reunion Interdisciplinaria CFE-IIE, Los Azufres, Mich., Mexico, Nov. 22-24, 1983, pp 161-170.

Aragon, A.A.: "Uso de trazadores radioactivos en la Zona Norte del Campo Geotermico de Los Azufres", Informe Interno 1385-004, Dep. Yaciemientos, CFE, (1985).

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Table 1: Summary of injection in to Los Azufres (up to Feb, 1987)

| Well | Volume Injected ($m^3$) | Until |
|---|---|---|
| Az-1 | 49,342 | Oct. 1984 |
| Az-3 | 39,021 | Dec. 1984 |
| Az-7 | 1,506,013 | Feb 1987 |
| Az-8 | 73,569 | Aug. 1986 |
| Az-15 | 2,181,618 | Aug. 1986 |
| Az-40 | 3,899,338 | Feb. 1987 |

Table 2: Tracer tests performed at Los Azufres

| Date | Injection | Method | Tracer | Monitored | Response |
|---|---|---|---|---|---|
| 5/8/83 | Az-8 | continuous | 1000 kg *KI* | Az-2, 26 | none |
| 3/14/84 | Az-43 | 11 days inj. | 4.1 GBq $Ir^{192}$ | Az-5, 13, 32 | none |
| 8/31/84 | Az-26 | continuous | 7.4 GBq $Ir^{192}$ | Az-18, 31 | none |
| 9/20/84 | Az-7 | continuous | 14.8 GBq $Ir^{192}$ | Az-2, 16, 16D | none |
| 3/28/85 | Az-33 | no injection | 14.8 GBq $Ir^{192}$ | Az-6, 46, 17, 36, 38, 24 | none |
| 7/30/87 | Az-8 | continuous | 12.0 GBq $Ir^{192}$ | Az-26 | none |

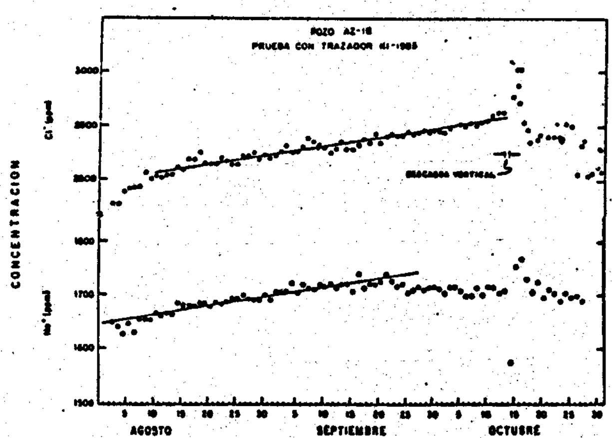


**Figure 1: Observations of Cl and Na in the water separated from well Az-16.**

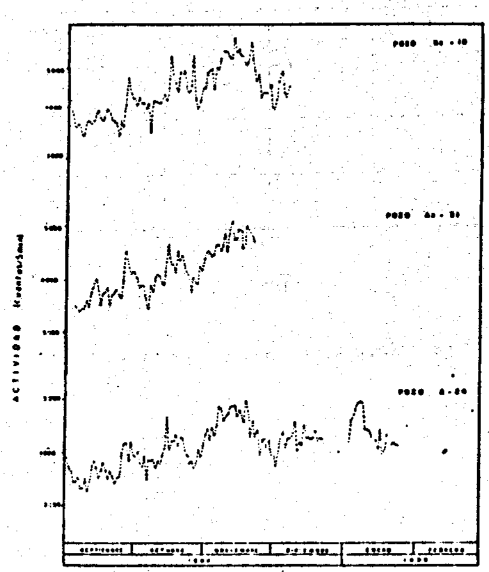


**Figure 2: Tracer test results from the SE zone.**

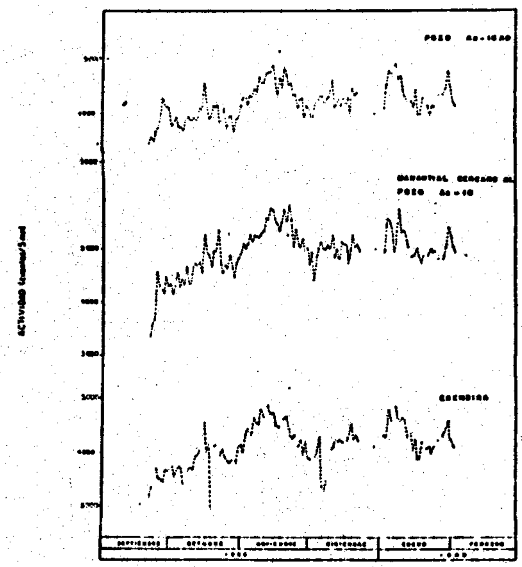

**Figure 3: Tracer test results from the southern zone.**

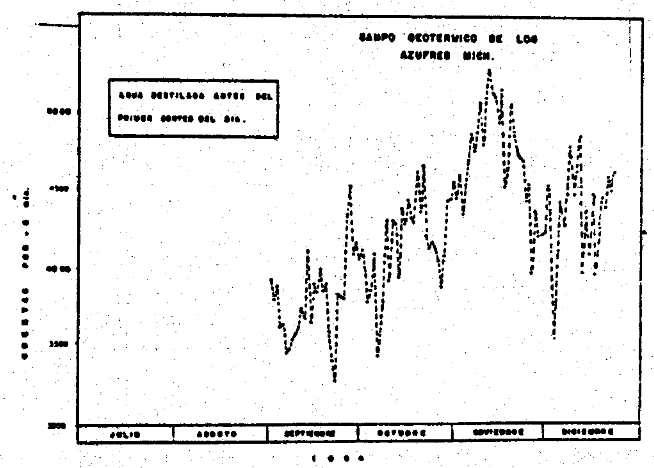

**Figure 4: Activity in the springs during the tracer tests.**

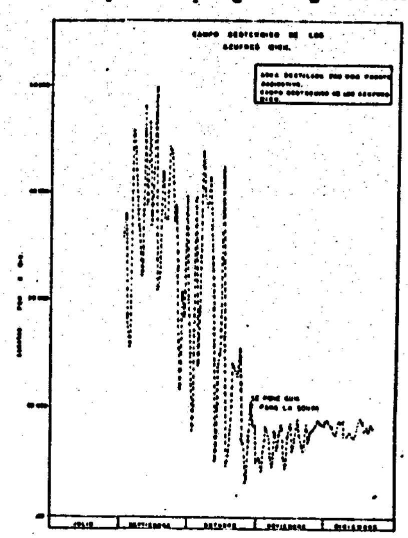

**Figure 5: Measurement sensitivity of $Cs^{137}$.**

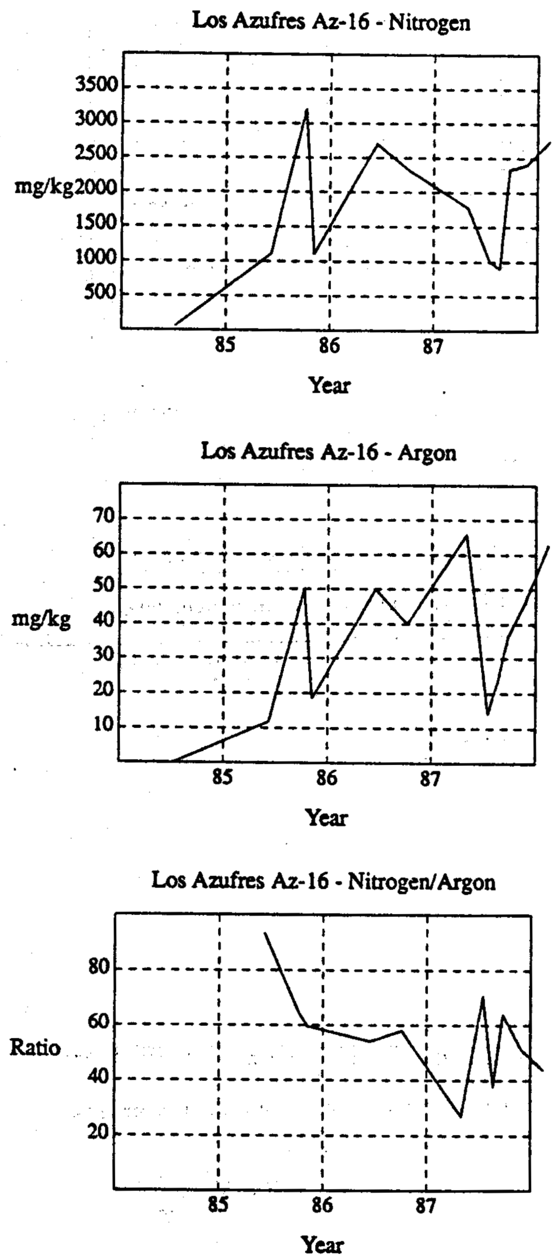


**Figure 6: Gas production values for Az-16**

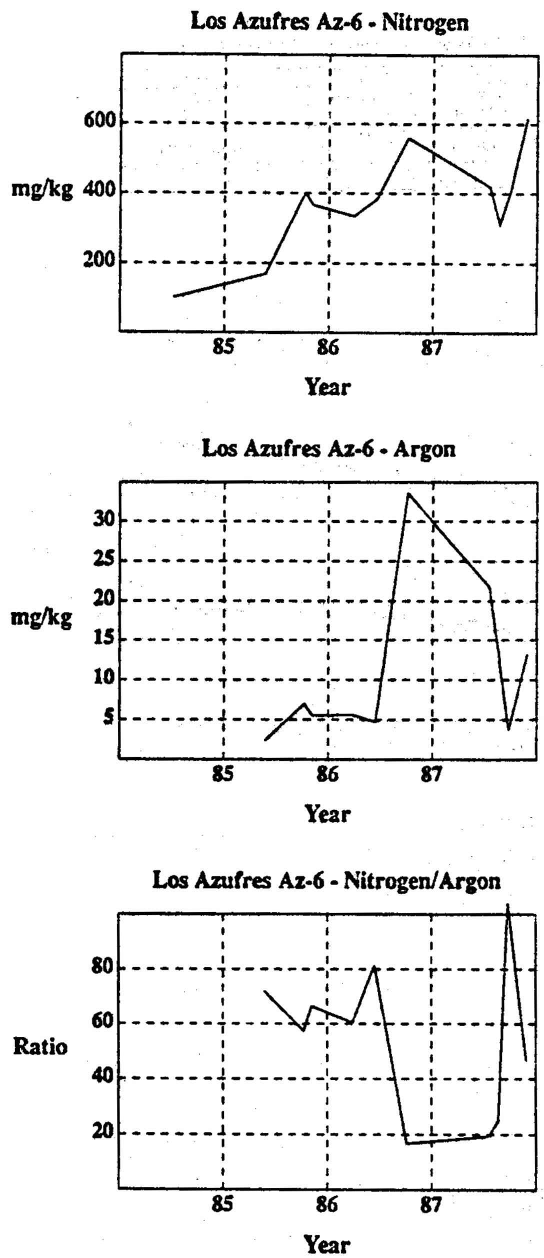


**Figure 7: Gas production values for Az-6**