TRITIUM TRACER AS A MEANS FOR RESERVOIR VERIFICATION IN GEOTHERMAL RESERVOIRS

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ABSTRACT

Naturally occurring or man-made tritium can be used to obtain information on reservoir characteristics not available any other way.

Determination of naturally occurring tritium may allow conclusions about a) age of fluid in reservoir, b) flow patterns within the reservoir, and c) natural recharge of reservoir. The shortcomings of utilizing natural tritium for these purposes are explained.

Man-made tritium as a tracer for geothermal reservoir studies is an extremely powerful tool. Tritiated water as a tracer added to the reinjected brine will indicate a number of reservoir heterogeneities such as fractures (number of fractures, fracture directions, fracture conductivities, etc.), other high permeability zones (streaks with higher permeability than the majority of the reservoir) and communications across "impermeable layers" (shale breaks, flow channels behind pipe, etc.).

Tritium tracers will not replace common reservoir engineering methods such as pressure test work. However, it must be seen as a verification method and as a supplement to the common reservoir engineering methods. Its greatest value during actual field operations lies in the extreme sensitivity and accuracy of the tracer determinations. This will allow constant reservoir monitoring at a very low cost. If cold brine (from reinjection) should break through the reservoir, a financial disaster can occur. Tritium tracers will indicate this damage long before the actual cold front arrives at a producer. This would allow remedial measures to be taken before larger financial losses have occurred.

NATURALLY OCCURRING VS. MAN-MADE TRITIUM TRACERS

Tritium (T) is a naturally occurring radioactive hydrogen isotope. Its half-lifetime is comparatively short (12.26 years), and, therefore, the concentration of T in most reservoir fluids is so low that it cannot be detected even with the most sensitive instrumentation. If the reservoir is being charged by waters that have been "recently" in contact with surface waters or the atmosphere (rain), the reservoir water may contain T at various concentrations. Theoretically, and--in a few instances--practically, the precise analytical measurement of these T concentrations can be used to determine a few important reservoir parameters:

1. Age of the reservoir water

2. Natural recharge of the reservoir

3. Flow patterns within the reservoir

## Age Determination

An age determination of the reservoir fluid could be made provided all of the four following conditions are met:

a) When recent water (containing T) has entered the reservoir, no mixing between recent (entering) and the old (previous) water is allowed, i.e., a 100% displacement must have occurred.

b) No subsequent mixing of water containing different T contents has occurred.

c) The T content of the recent water at the time of entering the reservoir must be known.

d) The age of the recent water cannot be older than approximately 60 years.

The first two conditions are unlikely to be found in any reservoir.

The original T content of the recent water cannot be known for sure because of the varying T concentrations in the biosphere during the recent history (30 years). Due to atmospheric testing of nuclear devices after World War II and a subsequent stop in the 1960s, the T content in the biosphere went through a steep maximum and is presently leveling off. Pre-bomb T concentrations in the biosphere are not known, due to the lack of sensitive instrumentation during that time. The upper limit of an age determination is approximately 60 years at the very most. Even extremely accurate measurements will leave large uncertainties at older ages, as indicated in Figure 1.

For these reasons, age determinations of reservoir fluids seem to be questionable at the very most.

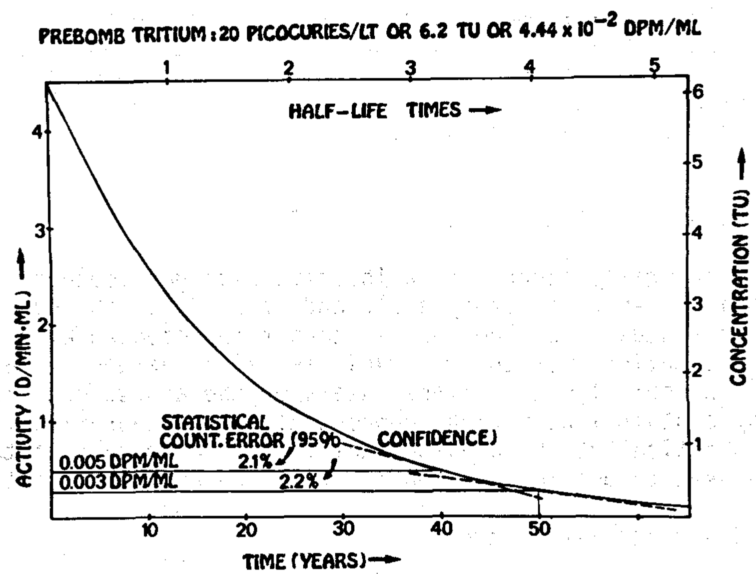


Figure 1. Age Determination by Tritium Measurements

## Natural Recharge of the Reservoir

Because of the problems outlined above (mixing of formation fluids, age of brine, and pre-bomb T contents), a recharge of the reservoir could be determined by low-level T measurements only in a very qualitative way. Conclusions as to the precise degree of the recharge cannot be drawn.

## Flow Patterns Within the Reservoir

Determination of the flow patterns within a reservoir can also be made only in a very qualitative manner. This data may, however, be sufficient for certain geological or reservoir evaluations.

## MAN-MADE TRITIUM TRACERS

The basic objective in the use of tritium as a reservoir tracer in reinjection systems (as opposed to a "huff and puff" type of tracer method) (1) is to find heterogeneities in a reservoir. Many publications have been written on the use of these tracers in water, oil and gas reservoirs (2-6). Only a very few studies have been performed in geothermal reservoirs (none is published). To our knowledge, there has been no tritium tracer study in a liquid-dominated field even though this tracer is perfectly suited for the situations found in these reservoirs. If we assume that the tritiated water will follow the injected water and behave like regular water in the reservoir, a number of reservoir characteristics could be determined in a very elegant way. Heterogeneities such as fractures and high permeability streaks can be found, and many of their parameters can be quantitatively determined. Fracture conductivity, fracture directions, number and size of fractures, or other high permeability streaks are just a few examples.

However, the great value of using tritium tracers lies elsewhere. In order to recover most of the reservoir heat and also to satisfy regulations regarding environmental preservation, we must reinject the brine into the reservoir. Even if this reinjection is planned "properly" using advanced reservoir engineering methods, an early breakthrough of injection fluid can occur, due to unknown high permeability zones in the reservoir or to changes of a number of reservoir characteristics caused by the injection of relatively cold fluid. If the cold fluid advances toward the producer at an "unreasonably" high rate, it will leave behind a "cold front" in the most valuable and critical portions of the reservoir. The problems are recognized when this lagging cold front arrives in the producer. At this time, the major reservoir damage has already been done and the value of the reservoir (recoverable heat) has decreased considerably. Theoretically, all the high permeability zones, that is, the most critical and vital flow channels in the reservoir between injectors and producers, can be cooled down and may render the power plant unoperable. Observation wells between injector and producer will somewhat decrease this risk, but will not eliminate it.

If tritium tracers are injected, they will provide an almost perfect means for reservoir monitoring in this regard. These tracers are not affected by heat or pressure. As soon as they are detected in the produced fluid (observation well or producer), the entire field operations can be evaluated before a major damage has occurred. Rearranging of the injectors and producers must then be considered to prolong the life and yield of the field. Due to an extremely high accuracy of the quantitative T determinations, very little guesswork is involved. The present damage and the future operations could quantitatively and very exactly be determined by using this tracer method. This method may save large investments by prolonging the life of the reservoir and by optimizing the recovery of the reserves within the reservoirs.

## SAMPLING AND ANALYTICAL METHODS

Depending on the objectives of the T tracer test, a sampling schedule must be provided. The samples can be collected by any field person according to the sampling schedule. No radiation hazard is involved in the sampling procedure.

To decrease the considerable cost of the analytical work, the samples will normally be stored for a longer time and then mailed to the laboratory where they are analyzed in larger labs. First, a "spot check" is performed, that is, every fifth or tenth sample is analyzed for its T content. The decision as to which samples to analyze for the final reservoir analysis will be made after this "spot check" is completed.

The analytical procedures to determine the inherently low levels of T in the samples call for extremely sensitive instrumentation. Most samples are analyzed with a "Low Level Beta Scintillation Spectrometer." Only a recent and advanced model should be used because of the problems caused by rather complicated chemiluminescence and quench reactions during the actual measurement. Geothermal fluids can be especially bothersome in this respect. In addition, to keep the analytical cost low and the precision of the analyses as high as possible, the instrument itself and the applied procedures must be extremely efficient. A good overall measuring efficiency should be on the order of 65%. The instrumentation should have provisions for the automatic correction (or at least indication) of chemiluminescence or quench problems.

The accuracy of the data is another problem. It will mainly depend on the counting time in the spectrometer which in turn may boost the cost for the analytical work. No data should be accepted unless the "counting error" is stated in the analytical report. Low level T counts can be off by order of magnitudes if the analytical laboratory measures the samples for too short a counting period in order to save on the actual expenses for the analytical work. In most instances, an error limit of $\pm 5\%$ of the total T concentration can easily be achieved with the more sophisticated scintillation counters and if the tracer test is designed properly.

## PROBLEMS OF AND INCONVENIENCES WITH TRITIUM TRACERS

Even though the actual injection of tritiated water into a reservoir is a simple and straightforward procedure, certain legal and technical requirements must be met for each tracer job.

### Legal Requirements

Only a qualified and licensed person can perform the handling of the T tracer before and during the actual injection. A good knowledge of the legal and technical aspects and extensive practical experience in applying the tracers in the field is absolutely required to avoid the inherent risks in handling the radioactive materials.

The Nuclear Regulatory Commission (NRC) and/or state rules require that handling of liquids (water) containing more than $3 \times 10^{-3}$ u Curie/ml T demands a special license. Only a general license is required if the T concentration in the water drops below $3 \times 10^{-3}$ u Curie/ml. This means that every T tracer injection job will be designed so that the "high level" injection fluid will be handled by a licensed person who is fully and personally responsible to the proper governmental authorities for the actual injection and meeting of all legal regulations, including safety measures. The legal authorities (e.g., State Health Department and Division for Industrial Safety) must be notified by the licensed person before any test is performed.

The jobs are normally designed so that the required dilution is achieved immediately after discharge (injection of the "high level" tracer fluid). The "discharged" fluid or the fluids to be sampled can then be absolutely safely and legally handled by any unqualified person. The salt content of the produced brine will pose a much larger health hazard than the T content.

Unfortunately, this procedure requires a thorough knowledge of the tracer injection equipment itself and the operating conditions of the fluid handling in the field (injection rates, pump equipment, wellbore geometry, etc.).

Technical Procedures

The technical procedures for applying the T tracer will vary from test to test, depending upon the field conditions and the objectives of each individual test. The only general rule is the duration of the actual T tracer injection period: it will seldom last longer than 36 hours. However, in a few instances, the field conditions and test objectives may require a deviation from this rule. Some objectives may require a long duration tracer injection (at low T concentrations) as opposed to the more common slug method (using a tracer fluid with high T content for a short time). Sometimes it may be difficult to decide which method (short or long duration) to use. This decision will depend on the type of reservoir, field conditions, and objectives of the study. The slug method is preferable in most cases.

Interpretation

The interpretation of the rough test data can be rather tricky. The job is not done by just injecting the tracer and supplying the reservoir engineer with a plot of data.

Figure 2 indicates a very simple tracer behavior not normally expected in reservoirs, particularly not in a sandstone reservoir such as most reservoirs in the Imperial Valley. Three fractures are indicated in Figure 2. The interpretation of Figure 2 must take into account a) shape of the curve, b) area underneath the curve, c) tracer behavior as a function of surface area contacted by the tracer, and d) contact time. Proper interpretation of Figure 2 will allow conclusions regarding fracture conductivity and fracture dimensions.

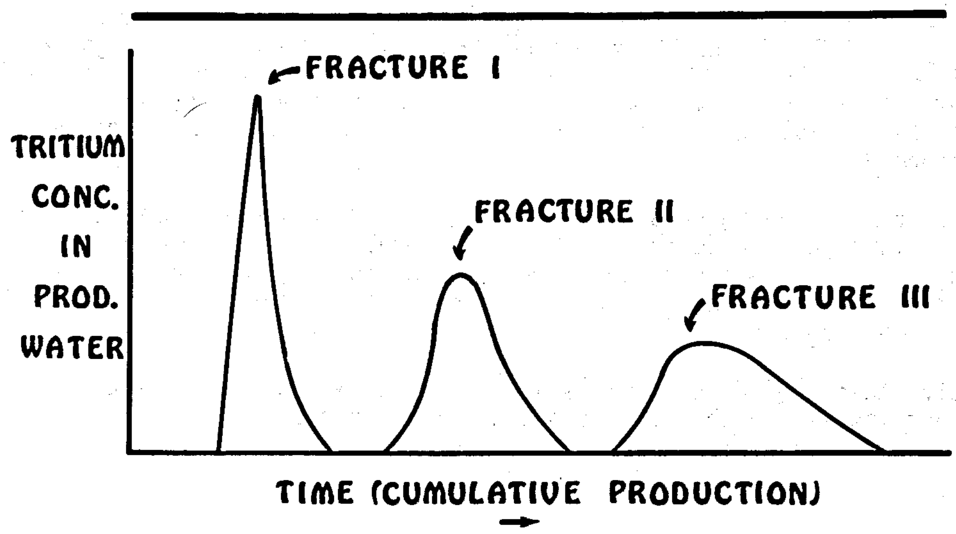


Figure 2. Return Profile of Tritium Tracer from Different Fractures (Same Conductivity, Different Path Length)

The interpretation of Figure 3 is much more difficult and reflects not only certain reservoir characteristics such as high permeability streaks, but also the very special reactions of the tracer itself (7,8). The adsorption-desorption sand isotopic reactions of the tracer (tritiated water) itself must be recognized and properly evaluated. Unfortunately, no precise data of these high temperature reactions of this tracer are published. Fairly simple lab studies could easily resolve some of these problems. For example, the adsorption isotherms could easily be measured (1) and some isotopic effects could be calculated from simple lab tests. The data from these lab studies could be included in the interpretation of actual field data. Thus, additional information will be retrieved from the actual tracer test in the field.

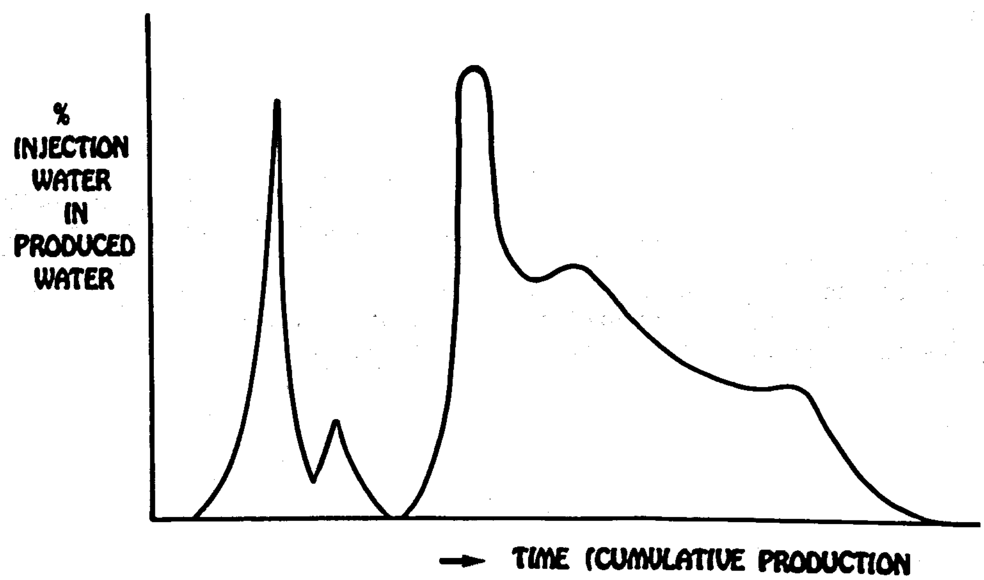


Figure 3. Tritium Tracer Profile in "Stable" Reservoir

CONCLUSIONS

1. Determination of naturally occurring tritium in reservoirs gives only limited information as to a) age of fluid in reservoir, b) natural recharge, and c) flow patterns within reservoir.

2. Tritium injection into the reservoir is an extremely powerful tool to determine certain reservoir characteristics: fractures and high permeability streaks (conductivity, dimensions, direction, etc.).

3. Tritium tracers can give early warning of a cold front breaking through from the injectors. This early indication can be used to prevent major damage to the reservoir by restimulating the injectors in the early periods of reinjection.

4. The high-temperature behavior of any tracer in water-saturated porous media is not well known. Fairly simple lab studies are required to shed some light on the surface reactions at the solid phase.

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