Tracer Use during the EGS Demonstration at Newberry Crater

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Tracers are chemicals that can be detected in very low concentration that let researchers find out how water injected for the EGS Demonstration project moves through the subsurface. Tracers will be injected at Newberry in very small amounts into the well, and then will return to the surface in minute quantities when the well is "flowed back" after the stimulation. The tracers selected for the project have been extensively tested and are environmentally benign. The tracer concentrations will be approximately 10 to 100 parts per thousand in the injected pulse, and approximately 0.1 to 100 parts per billion when produced at the wellhead. These tracers are typically detectable at the parts-per-trillion level.

The Newberry Volcano EGS Demonstration Project Environmental Assessment (EA) lists 18 tracers that have been selected for potential use during the Newberry EGS Demonstration project. None of these are toxic, especially in the tiny quantities planned for use in the project. We will use two tracers for each stimulation phase. One tracer will react either with the rock itself or with heat. The other tracer selected for each zone of the stimulation will be stable and will not react with the rock or heat. This way, the stable tracer can be compared to the reactive tracer when the well is flowed back to see how much surface area has been developed during the stimulation. The stable tracer will also not deteriorate over long time periods even at high temperatures so that if any of the injected water were to get into a ground or surface water supply it could be detected.

Further characteristics and history of their use for the specific tracer families listed in the EA are provided below.

Naphthalene Sulfonates

Naphthalene is a known carcinogen; however *naphthalene sulfonate* is neither toxic nor carcinogenic, since the addition of the sulfonate groups renders the naphthalene molecule environmentally benign (Greim et al., 1994). Consider a similar pair of compounds: benzene and benzoic acid. The latter is also known as carboxybenzene or benzene carboxylic acid. Benzene is a known carcinogen, but the addition of the carboxylic acid group renders it benign, so much so that it is used as a preservative in acidic beverages like fruit juice and soft drinks, and other acidified foods like pickles.

In the late 1980's, the U.S. Department of Energy requested that EGI initiate a program to develop thermally stable tracers for use in geothermal-reservoir tracing. At the time, several groundwater tracers were available, but no tracers had been characterized for high-temperature geothermal applications. Within a few years, EGI had developed a family of fluorescent tracers—the naphthalene sulfonates—that were shown in the laboratory to be both thermally stable and very detectable (Rose et al, 2001). In biological studies, these tracers were shown to

be neither carcinogenic nor mutagenic (Greim et al., 1994). EGI has confirmed the laboratory studies on the thermal stability of the naphthalene sulfonates through numerous tracer tests at geothermal fields in the Western U.S. (Rose et al., 1997; Rose et al., 1999; Rose et al, 2001; Rose et al., 2002; Rose et al., 2003), including California, Nevada, and Utah. Settings where the naphthalene sulfonates have been used in geothermal fields internationally include Ohaaki, New Zealand; Awibengkok, Indonesia (Rose et al., 2000); Soultz, France (Sanjuan et al., 2006); Bulalo, Philippines (Rose et al., 2002), Mexico, Japan, Iceland, Germany, and Portugal. They were used as ground-water tracers at the Idaho National Laboratory, Idaho; and in petroleum steam-floods in California. In all instances, use of the naphthalene sulfonates as tracers was subject to strict constraints from responsible government agencies.

Although the naphthalene sulfonates are environmentally friendly, we do not intend to use them in high concentration within the waters deep within Newberry Crater. Among their useful properties is their fluorescence, which renders them very detectable. Their detection limits are approximately 100 parts per trillion through conventional liquid chromatographic methods using fluorescence detection. Among all of the studies cited above, their concentration at the production wells never exceeded a few hundred parts per billion. We propose the use of these compounds at the minimum required concentrations. Our experience in their use assures that we will not exceed these very low concentrations.

Rhodamine WT

Rhodamine WT is a very commonly used tracer that was designed for groundwater applications. Like the naphthalene sulfonates, it is fluorescent and therefore extremely detectable with detection limits in the tens of parts per trillion through conventional liquid chromatographic techniques. We intend to use it at only the lowest concentrations necessary.

Lithium

Lithium is a common groundwater tracer with low human and biological toxicity. For our tests, it will be injected in the form of lithium iodide, which has an LD50 of 1,800 mg/kg in mice (oral ingestion). The detection limit for lithium is in the low microgram/kg range. We will inject at a level of about 100 mg/kg and produce in the range of about 100 microgram/kg. Therefore, both the injection concentration and production concentration are well below the LD50. In fact, our working concentration of 100 microgram/kg (parts per billion) is well below the capability of most commercial laboratories.

Cesium

Cesium is also a common groundwater tracer possessing low human and biological toxicity. It will be used in the form of cesium iodide, which has an LD50 of 2,386 mg/kg in rats. It is non-mutagenic and non-carcinogenetic. Like lithium, the detection limit for cesium is in the low microgram/kg range. We will inject at a level of about 100 mg/kg and produce in the range of about 100 microgram/kg. Therefore, both the injection concentration and production concentration are well below the LD50. In fact, our working concentration of 100 microgram/kg (parts per billion) is well below the capability of most commercial laboratories.

Rubidium

Rubidium is another conventional groundwater tracer possessing low human and biological toxicity and will be used in the form of rubidium iodide. Its LD50 is 4708 mg/kg and like the two previous tracers has a detection limit for in the low microgram/kg range. Also, as with the two previous tracers, we will inject at a level of about 100 mg/kg and produce in the range of about 100 microgram/kg. Therefore, both the injection concentration and production concentration are well below the LD50. In fact, our working concentration of 100 microgram/kg (parts per billion) is well below the capability of most commercial laboratories.

Fluorescein

Likewise, fluorescein is a fluorescent tracer that is so nontoxic that it is used in human medicine to trace the flow of tears through tear ducts. It is the compound that is used at St. Patrick's Day celebrations to dye the Charles River green in Boston, Massachusetts. Given its excellent fluorescence cross section, we will use it in concentrations not exceeding 100 parts per billion.

Safranin T

Safranin T is a fluorescent tracer that possesses low human and biological toxicity and that is primarily used as a textile dye. Since the EA was completed Safranin T has been further tested in the field and determined that it will not survive at the temperatures present at Newberry. Therefore, we will not use Safanin T at Newberry. The other tracers listed above will be sufficient for the Demonstration's needs.

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