Lawrence Livermore National Laboratory

8 September 2016

To: Alan Walker
Supervising Oil & Gas Engineer
Department of Conservation
Division of Oil, Gas, and Geothermal Resources
801 K Street, MS 18-05
Sacramento California 95814

Re: Aliso Canyon Minimum Operating Pressure

Mr. Walker:

At DOGGR's request, the National Laboratory team has reviewed the minimum and maximum operating pressures suggested by SoCalGas for the Aliso Canyon Field. Our analysis and recommendations are summarized below.

Minimum Operating Pressure:
SoCalGas has suggested that the minimum operating pressure for Aliso Canyon be set at 1080 psi bottom hole pressure. This value corresponds to ~30% of the reservoir discovery pressure (3595 psi). Given that the field has been previously cycled to this pressure with no reports of problematic subsidence, we concur that the 1080 psi recommendation is a reasonable operating threshold going forward.

Typically, reservoirs exhibit the largest subsidence during virgin consolidation, when the reservoir is first cycled to a new minimum pressure. This first drawdown typically results in significant irreversible (plastic) deformation. Subsequent pressure cycling that remains above the historic minimum pressure will induce smaller deformations that are largely reversible (elastic) in nature. Given that the proposed threshold is above the historic minimum pressure, the Aliso Canyon field has likely already experienced the maximum deformation that would be expected. We are unaware of any subsidence-related well damage issues reported by SoCalGas. We have therefore concluded that pressure cycling above the proposed threshold is unlikely to cause significant issues going forward.

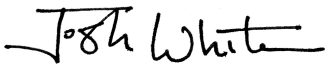
In general, we recommend that NGS operators directly monitor subsidence at their operations. There are many land-based and satellite-based survey methods available. Such monitoring would be particularly important for a field undergoing virgin consolidation to a new minimum pressure. This data can provide a direct confirmation of the suitability of the design minimum operating pressure.

Maximum Operating Pressure:
SoCalGas has suggested that the maximum operating pressure for Aliso Canyon be set at 3595 psi bottom hole pressure. This value corresponds to the discovery pressure of the reservoir. We concur that this value is a reasonable operating threshold going forward.

There are two lines of evidence to support this threshold. First, the presence of a stable gas cap in the pre-development reservoir indicates that the Aliso Canyon storage formation was able to contain gas up to at least the discovery pressure (3595 psi) over geologic time scales. Operating below the discovery pressure is therefore unlikely to create new hydraulic fractures or other leakage pathways. Second, the third-party geotechnical analysis prepared by GeoMechanics Technologies has examined available leakoff test data for the Aliso Canyon site. We agree with the report's assessment that these measurements indicate a hydraulic fracture gradient in excess of ~0.6 psi/ft in the reservoir. Applying a safety factor of 0.9 would lead to a design fracture gradient of 0.54 psi/ft, or 3888 psi at 7200'. This value is in excess of that proposed by SoCalGas.

We note that the excess pressure necessary to create and propagate hydraulic fractures varies substantially with depth, due to the depth-dependence of the in situ stress and the buoyant nature of the natural gas column. A single maximum operating pressure threshold is not the best format for conveying this depth-dependence. Instead, a fracture gradient requirement is more straightforward for guaranteeing that pressures remain below critical values everywhere in the reservoir. In particular, the critical location for hydraulic fracturing is likely to be at the shallowest point in the gas cap, immediately below the reservoir / caprock interface. SoCalGas should ensure that their pressure monitoring and subsequent analysis is sufficient to guarantee that reservoir pressure remains below critical values at all locations.

Sincerely,



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