Report of the Independent Review Panel San Bruno Explosion

Prepared For California Public Utilities Commission

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that has grown from around 55 to 60% through wall to 80% through wall in a local portion of the incomplete PUP 1 weld.

Four different defect lengths were evaluated – 2.4 inches long, 4.8 inches long, 9.6 inches long, and 19.2 inches long. In all cases the driving pressure was assumed to be 400 psi. The evaluations showed that, for the 2.4 inch long defect, the applied stress intensity was only about 25 ksi√in, implying that such a short defect –although very deep – would not be unstable. For the 4.8 inch long defect, the applied stress intensity factor was about 36 ksi√in, which implies marginal but likely defect stability. Both the 9.6 inch long and 19.2 inch long defects were unstable.

Therefore, it would appear that localized acceleration of growth from the original manufacturing welding defect is an alternative and more likely failure scenario. At present, such localized growth must be considered anomalous absent some evidence of localized soil movement, or some phenomenon that locally increased soil pressure, or a third-party action that could have led to localized bending or ovalization of the pipe in the region near PUP 1. Localized bending or ovalization would be of particular concern if the stresses on the interior of the pipe caused by denting or ovalization were locally tensile at the azimuthal position of the longitudinal weld, adding to the circumferential pressure tensile stresses.)

NTSB Findings to Date

The NTSB investigation has not yet determined the root cause and any underlying contributing factors that led to the San Bruno pipeline failure, and will not issue its report on the incident for several months. However, the NTSB has recognized the failed San Bruno pipe section contained a longitudinal seam weld with a defect that extended the full length of PUP 1 and about 50 to 55% across the pipe wall. Because of this recognition, the NTSB recommended PG&E and other natural gas transmission pipeline operators should review their records to assure: (1) the mischaracterization by PG&E of the San Bruno pipe segment as seamless is not a systemic error, (2) any longitudinal seam-welded piping is properly characterized and appropriately classified in terms of risk, and (3) the risk associated with similar defects in other piping segments is appropriately mitigated.

The NTSB interim findings to date are both reasonable and useful, especially with respect to:

- Discovery that the failed piping was of longitudinal-seam-welded construction, rather than seamless.
- Discovery that the failed piping was composed of several short, girth-weld-connected segments.
- Identification of record keeping deficiencies by PG&E related to pipe characterization and MAOP determination.

- Production of useful metallurgical information on the failed piping, including relatively low Charpy V-notch energies for the base metal and some relatively low yield and ultimate strength values for some of the PUP segments.

All four of these interim findings raised significant issues with respect to legacy gas transmission piping in general and with respect to PG&E's legacy gas transmission piping, in particular. For PG&E, the unavailability of at least some legacy piping records and potential mischaracterization of other legacy piping records raised the issue of whether threats similar to the Line 132 San Bruno segment are currently unidentified.

Those legacy piping segments for which PG&E was unable to retrieve adequate documentation to confirm the piping characteristics are expected to undergo hydrostatic pressure testing over the next several months, with the test pressure planned to be 150% of the Maximum Allowable Operating Pressure (MAOP). The purpose of the relatively high test pressure is not only to expose any defects that threaten future operation at MAOP, but also to drive even smaller defects to instability (leakage or rupture), potentially generating a greater degree of integrity demonstration. The defects that threaten future operation are those that have been and are currently *stable*, but which have margins of safety that have been reduced to the point that uncertainties in material behavior, loadings, or environments could cause *instability*.

Hydrostatic pressure testing of uncharacterized legacy piping with potentially low fracture toughness may not be the optimum approach, depending upon whether the San Bruno Incident is viewed as an anomaly that is not likely to exist elsewhere in the PG&E transmission system, or whether the San Bruno Incident is viewed as evidence of potentially more systemic behavior. If systemic issues are suspected, another option is available that would either be a precursor to hydrostatic pressure testing, or which would replace some or even most of the hydrostatic pressure testing. That option would involve excavating and exposing any longitudinal seam welds along segments of uncharacterized legacy piping, probably at a frequency of every mile or every other mile, while using a tool such as the automated ball indenter to characterize the piping material. Such testing would include indenter determination of yield strength and "indentation energy to fracture," but could also entail a circumferential hardness traverse to locate the longitudinal seam weld and its heat-affected zones, with the potential for a volumetric non-destructive examination (e.g., ultrasonic testing) to determine any significant defect structure on the interior of the pipe. Destructive examination to remove an occasional section of the pipe (which would involve shutting down an occasional transmission line segment) to measure Charpy impact energy for confirmation of automated ball indenter results could be considered.