APPENDIX C

LABORATORY MEASUREMENT OF BULKING FACTOR

C.1 INTRODUCTION

Rubble obtained from the field investigation at Fran Ridge, described in Appendix B, was shipped to the Center for Nuclear Waste Regulatory Analyses (CNWRA) for further analyses. At that time, CNWRA staff decided to augment the planned literature review and limited field study with a brief laboratory investigation. This would provide further information on estimating possible loose rubble mass densities that may occur in drifts constructed in the Topopah Spring welded Lower Lithophysal zone (Tptpll). Rubble from Plot 2 was used in the laboratory tests to establish a better link between *in-situ* rock mass densities and loose rubble mass densities. The rubble from Plot 2 was extracted directly from an outcrop with minimal force. The resulting rubble and the small percentage of fines were placed in two 0.2 m^3 [55-gallon] drums at the field site. Approximately 0.3 m^3 [10.6 ft^3] of rubble from Plot 2 subareas A and B, which included the void volume between rubble fragments in the drums, was shipped to CNWRA. The laboratory tests would estimate a range of loose mass densities of rubble that may initially form in drifts constructed in welded tuff. The mass of rubble needed to fill wooden boxes with known dimensions was measured using a calibrated balance. The laboratory test was based on the procedure of Peele (1961) described in Section 2.4, Measurement of Bulking Factor.

C.2 BULK DENSITY OF RUBBLE

Two boxes were constructed to determine the mass density of loose rubble (Figure C–1). The volume of each box was approximately 0.23 m^3 [8.1 ft^3] and each could hold approximately 75 percent of the Plot 2 rubble sample sent to CNWRA. The box volume was chosen to minimize boundary effects associated with the box walls and so that different rubble fragments could be used in replicate packing of the boxes to investigate variability of the measurements. One box (Container 1) was 61.0 cm [2.0 ft] high by 61.0 cm [2.0 ft] wide by 61.0 cm [2.0 ft] long and was cubic in shape. The other box (Container 2) was 61.0 cm [2.0 ft] high by 40.5 cm [1.325 ft] wide by 91.5 cm [3.0 ft] long and was rectangular in shape. The different shaped boxes have slightly different surface area to volume ratios, which could potentially affect measured loose rubble mass density. Much larger boxes, which would further minimize box boundary effects, could not be constructed, because of the limited available rubble volume. Given the rubble size distribution for Plot 2, subareas A and B (see Appendix B), approximately 10 rubble fragments could fit in each direction within the boxes, except for possibly the shorter dimension of the rectangular box. Figure C–1B shows one packing of the cubic box; the box dimensions are such that approximately 10 rubble fragments can fit into the box dimensions in each direction, which is a generally accepted approach for measuring mass per volume relationships of particles.

Before packing the boxes, all rubble from Plot 2 was removed from the drums and placed on a tarp according to size. When packing the boxes, staff tried to reproduce the size distribution of rubble observed on the tarp in the packed boxes using visual determination. Two box-packing approaches were used to obtain a range of loose rubble mass densities. In some packings, the open spaces between large rubble fragments were not filled with smaller rubble fragments. In other packings, smaller rubble fragments were placed in the larger openings to obtain a denser packing. In all packings, staff adjusted the orientation of the rubble fragments along the box walls to minimize boundary effects.

(A) **(B)**

(C)

Figure C–1. Experimental Setup to Determine Mass Density of Packed Rubble (A) Container 1–Cubic Shape, (B) Top View of Container 1, and (C) Container 2–Rectangular Shape

In packings 1–4, there was no attempt to fill all larger openings between the rubble fragments with smaller–sized rubble fragments. However, the packings were conducted such that no extraordinarily large openings or void spaces existed in the packed rubble. There was no attempt to pack the boxes as tightly or densely as possible. In packings 5–7, smaller sized rubble fragments were placed in larger openings/voids between the rubble fragments to produce a denser packing than in packings 1–4. A greater percentage of smaller fragments were used in packings 5–7 than what was observed on the tarp initially and was contained in packings 1–4. Openings/voids remained between the rubble fragments, however, but their size was not as large as may have existed in packings 1–4. The shape of the boxes did not appear to affect the measured, packed rubble mass density.

The loose rubble bulk densities measured in packings 1–7 are shown in Table C–1. Also shown are estimated bulking factors based on an *in-situ* rock density of 1,979 kg/m^3 [123.5 lb/ft^3] (Bechtel SAIC Company, LLC, 2003) for the Lower Lithophysal welded tuff unit at Yucca Mountain, Nevada. A dry *in-situ* bulk density was used to estimate the bulking factor because the rubble fragments used in determining the rubble bulk densities were dry. Table C–1 shows that the packing procedure yielded dissimilar loose rubble densities. Packings 1–4 were less dense than packings 5–7. The bulking factors calculated in Table C–1 are only estimates and are dependent on the *in-situ* bulk density Bechtel SAIC Company, LLC (2003) reported the mass proportion of smaller particle sizes that were not included in the rubble samples, and experimental conditions in the laboratory. They reflect the bulking factor before any settlement due to load or seismic events. The resulting bulking factor values are similar to some values in Tables 2-1, 2-2, A–1, and A–2 for hard rock types.

C.3 REFERENCES

Bechtel SAIC Company, LLC. “Subsurface Geotechnical Parameters.” Report 800–K0C–WIS0–00400–000–00A. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2003.

Peele, R. *Mining Engineers’ Handbook*. 3rd Edition. New York City, New York: John Wiley & Sons. 1961.

Table C–1. Bulk Density of Rubble From Laboratory Measurements

Packing Number	Container*	Total Mass (kg)†	Rubble Density (kg/m^3)‡	Bulking Factor (%) Assuming *In-Situ* Rock Density of 1,979 kg/m^3
1	1	244.05	1,080	83.2
2	2	256.29	1,130	75.1
3	1	257.12	1,130	75.1
4	2	260.74	1,150	72.1
5	1	284.34	1,250	58.3
6	2	273.17	1,210	63.6
7	1	276.32	1,220	62.2

*Volume of Container 1 = 0.23 m^3 [8.1 ft^3]; Volume of Container 2 = 0.226 m^3 [7.98 ft^3]
†1kg = 2.2 lb
‡1kg/m^3 = 0.062 lb/ft^3