SANDIA NATIONAL LABORATORIES
CIVILIAN RADIOACTIVE WASTE MANAGEMENT
TECHNICAL PROCEDURE (TP)

TP-229

BULK PROPERTIES DETERMINATIONS OF TUFFACEOUS ROCKS: DRY BULK DENSITY, SATURATED BULK DENSITY, AVERAGE GRAIN DENSITY AND POROSITY

Revision 02

Effective Date: Nov. 04, 2003

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(Reviewer signatures above document the review and resolution of comments.)

REVISION HISTORY

Revision	Description
0	Initial issue
1	Full revision to address QAIP 20-1 requirements and make other minor improvements.
2	TP-229 was deactivated during Audit BSC-ARC-01-010. It is now reactivated for additional work to be performed. No major technical revisions were required from the previous revision, only references to current procedures and other minor editorial revisions.

1.0 Scope and Objective

The objective of this Technical Procedure (TP) is to define the process for the determinations of the following bulk properties of tuffaceous rock: saturated bulk density, dry bulk density, average grain density, and porosity. This procedure is intended for implementation in a laboratory environment, in conjunction with work for the Yucca Mountain Project (YMP).

This procedure was developed after evaluating various techniques utilizing representative tuffs from the Yucca Mountain and Busted Butte sites in Nevada. The results of these scoping experiments are presented in Boyd el al., (1992). Nationally and internationally recognized (the American Society of Testing and Materials [ASTM] and the International Society for Rock Mechanics [ISRM]) standard methods were also used to formulate the techniques.

2.0 Prerequisites

Before performing work under this technical procedure, personnel must be trained by the author and/or the Principal Investigator (PI), and they must demonstrate their proficiency in performing the work in this procedure. The PI has the responsibility that the record of the personnel proficiency training is generated, as well as the responsibility that work is performed and documented in accordance with this procedure.

The personnel using this procedure are responsible for ensuring that a controlled copy of this procedure is available and used for performing the work in this procedure.

3.0 Description of Activity

The specimen is dried and weighed. Next it is saturated (with distilled water, if required for testing) and weighed. The bulk volume is computed from the specimen dimensions. These specimens typically have been machined for physical properties testing and will have simple geometries. Where the shape of the specimen is irregular, the buoyancy technique is used to determine bulk volume. From the dry and saturated weights, the dry and saturated bulk densities are determined by dividing them by the bulk specimen volume.

A subsample of the original raw sample (typically a core sample) is pulverized and ground to obtain a particle size of less than 1.5 mm. After drying, the grain volume of the powdered specimen is then measured by water pycnometry, and its average grain density is calculated. Finally, matrix porosity is calculated using the relationship between average grain density and dry bulk density, and/or by using the difference between the dry and saturated bulk densities.

4.0 Activity Process

The following operations are presented in the order that will normally be performed for the determination of bulk properties. Portions of these operations may be utilized in a different sequence, or individually if required.

4.1 Bulk Volume Determination

The technique to determine bulk volumes of intact specimens depends on the geometry of the specimen. For machined specimens (typically cylinders or disks) the volume is readily calculated. Where the geometry of the specimens does not lend itself to a simple calculation, a buoyancy technique will be utilized.

4.1.1 Linear Dimensions

For specimens having easily measured linear dimensions (e.g., right circular cylinders) the bulk volumes are easily calculated. The linear dimensions (length and diameter) necessary to make the calculations will be measured in accordance with the specifications of SNL TP-051, "*Preparing Cylindrical Samples, Including Inspection of Dimensional and Shape Tolerances*." Although the actual dimensions may differ, the methods and tolerances will be adhered to. For right circular cylinders (the most common geometry):

$$V_b = \pi r^2 l, \quad (1)$$

where V_b is bulk volume (cm^3), r is specimen radius (cm) and l is length (cm).

Document the results on the Bulk Volume and Density Data Sheet (BVDDS in Appendix A).

4.1.2 Buoyancy

For specimens of any geometry, the buoyancy technique can be utilized. This is a commonly practiced technique when the specimen cannot be machined because it is too fragile or is too small to obtain a representative machined specimen. The geometry of the specimen is immaterial.

Measurement Apparatus—

- Analytical or electronic balance with an accuracy of ± .01 g
- Distilled water
- Container to be used to suspend the specimen in the distilled water
- A small ($\leq$0.127 mm diameter) gauge wire with which to suspend the specimen in the distilled water
- Liquid-in-glass thermometer readable to 0.2°C
- Saturation apparatus consistent with that specified in SNL TP-064, "Vacuum Saturation of Geologic Core to Constant Weight."

Detailed Procedure—Ensure that all pertinent calibrations are up to date and acceptable (in this and all cases, per AP-12.1Q, *Control of Measuring and Test Equipment and CalibrationStandards*). The liquid-in-glass thermometer will be of adequate accuracy and precision for these purposes. Document the specimen ID, etc. on the BVDDS.

1 Saturate the specimen per TP-064. Obtain the saturated mass (M_{sat}) and resubmerge the specimen in distilled water.

2 Place a container of water of sufficient size to accept the specimen on a "bridge" over the balance sample pan. The bridge will support the container so that only the mass of the suspended specimen and wire will be measured with the balance. (Note: A bottom suspension balance can also be used.)

3 When necessary (new suite of measurements, significantly different specimen size, different water level, etc.), place the suspension wire (in an "as used" form) on the suspension hook on the balance and suspend it in the water. The water should be at the height it will be during the buoyancy measurement. Determine the mass of the wire while submerged in the water as above.

4 Attach the specimen to the suspension wire by wrapping the wire around the specimen. This should be carried out as quickly as possible to minimize evaporation from the specimen. (Alternatively, a wire basket can be used to hold the specimen.)

5 Submerge the specimen in the water by suspending it from the suspension hook on the balance with the wire. Ensure that the specimen is completely submerged in the water and that the wire extends to the depth it reached when weighed without the specimen. Mark wire at water interface or use a contact tip device to indicate the interface.

6 Determine the mass of the submerged specimen and wire.

7 Correct the submerged mass of the specimen by subtracting the mass of the suspension wire determined in Step 3 from the mass determined in Step 6. This value is M_{sub}. The mass of the suspension wire can also be subtracted using the balance tare.

8 Measure the temperature of the water with the liquid-in-glass thermometer to the nearest 0.2ºC. Use the table on the data sheet to determine the density (ρ_w) of the water at this temperature.

9 Calculate the bulk volume of the specimen using the following formula (Franklin et al., 1979):

$$V_b = (M_{sat} - M_{sub})/ \rho_w \,, \quad (2)$$

where V_b is the bulk volume (cm^3), M_{sat} is the saturated mass in air (g), M_{sub} is the submerged mass (g), and ρ_w is the water density (g/cm^3).

10 Document the results on the BVDDS.

4.2 Saturated Bulk Density

Calculate saturated bulk density by using the data acquired in Section 4.1 in the following formula:

$$\rho_{sb} = M_{sat} / V_b \,, \quad (3)$$

where ρ_{sb} is the saturated bulk density (g/cm^3), M_{sat} is the saturated mass (g), and V_b is the bulk volume (cm^3).

Document the results on the BVDDS.

4.3 Dry Bulk Density

Dry bulk density is computed with data acquired in other procedures according to:

$$\rho_{db} = M_{dry} / V_b \,, \quad (4)$$

where ρ_{db} is the dry bulk density (g/cm^3), M_{dry} is the dry mass (g), and V_b is the bulk volume (cm^3).

The dry mass of the specimen is determined by completing the drying procedure described in SNL TP-065 entitled “Drying Geological Samples to Constant Weight.” Bulk volume is determined by one of the techniques described in Section 4.1.

Document the results on the BVDDS.

4.4 Average Grain Density via Water Pycnometry

Average grain density determined by water pycnometry requires a powdered specimen in order to expose as much of the surface area of the material as possible. This will minimize the contribution of occluded porosity to the grain volume determined by the procedure. These measurements will typically be carried out on specimens that have been subdivided from original samples from which physical test specimens have also been prepared.

The method conforms to standard methods of the ASTM and the ISRM. It incorporates most of the requirements of these methods and meets the intent of their scope. There are some modifications to the established methods due to the nature of the volcanic tuff at Yucca Mountain. These modifications were developed as a result of scoping experiments carried out at New England Research (NER) on representative tuff specimens (see Boyd et al., 1992).

4.4.1 Measurement Apparatus

- Nominally 100-mL volumetric flasks
- Liquid-in-glass thermometer readable to 0.2°C (Labeled "For Indication Only")
- Saturation apparatus consistent with that specified in SNL TP-064, "Procedure for Vacuum Saturation of Geologic Core Samples"
- Analytical or electronic balance as specified in SNL TP-064
- Drying apparatus consistent with that specified in SNL TP-065, "Drying Geologic Samples to Constant Weight"
- Drying pans
- A $\geq$99% pure quartz powder, or other suitably characterized standard material
- Tool steel mortar and pestle or hammer, rock jaw crusher, rock pulverizer, or equivalent capability
- Distilled water
- Miscellaneous operating materials: e.g., transfer funnels, lint-free wipes, cotton swabs and pipettes

4.4.2 Specimen Preparation

Prior to making a measurement, the specimens must be ground to a particle size of $\leq$ 1.5 mm. A bulk specimen size will first be selected that will provide adequate material for the measurement (15 to 60 g). This can be obtained from a larger specimen (typically the original core sample). The specimen identification will be maintained according to QAIP 20-03, "Sample Control." The entire piece will then be processed in order to include all the specimen mineralogy, regardless of hardness variations, in the final powder.

1. Reduce the particle size of the entire test specimen. Initially, break it up with a hammer and/or the mortar and pestle to a size that will be acceptable to the jaw crusher (usually "pea-size" is sufficient). Then run all the specimen pieces through the jaw crusher to further reduce the particle size for final grinding in the pulverizer. After passing through the pulverizer, the specimen will have a

particle size of $\leq$ 1.5 mm. The apparatus used for crushing and grinding will be cleaned prior to each use so that the powder is not contaminated by material from earlier specimen preparations.

2. Place the pulverized material into a clean drying pan of known mass.

3. Dry the specimen per TP-065, except do not allow the specimen to cool prior to weighing between drying cycles. This minimizes the rehydration that occurs as the tuff cools. Also do not allow the specimen to cool, any more than necessary while weighing, at any time prior to beginning the water pycnometry process.

4.4.3 Detailed Measurement Procedure

Ensure that all device calibrations are up to date and acceptable. The liquid-in-glass thermometer will be of adequate accuracy and precision for these purposes. Document the specimen ID, etc. on the Average Grain Density Data Sheet (AGDDS in Appendix C). Use the form entitled Water Pycnometer Verification Sheet (WPVS in Appendix B) to compile information gathered during the verification procedure.

The pycnometers will be verified per the procedure (below) prior to the first suite of measurements and at any time the calibration checks indicate unacceptable results. Calibration checks of the water pycnometers, using the procedure described below for specimen measurements, will be performed prior to the first measurements of tuff specimens and then periodically thereafter, or when results are suspect. The calibration checks will be performed by determining the grain density of a standard material consisting of a well characterized powder. The calibration checks must produce a grain density for the standard to within $\pm$1% of the expected value to be considered acceptable.

Verification Procedures—All weights and temperature measurements must be recorded on the WPVS form (Appendix B). A number of pycnometers may be verified simultaneously.

1. Weigh a clean, dry, and numbered 100-mL pycnometer with the analytical balance to $\pm$0.01 g.

2. Add distilled water to the pycnometer so that its level is just below the scribe line.

3. Place the pycnometer with water, and clean beaker of distilled water into an active vacuum for a minimum of 16 hours.

4. Remove the pycnometer from the vacuum.

5. Place the pycnometer into a water bath at a temperature between 18 and 26ºC. Allow the water in the pycnometer to equilibrate until it reaches the same temperature, ±0.5ºC.

6. Using a pipette, fill the pycnometer with the extra de-aired water until the bottom of the meniscus is equal in height to the scribe line. (It may be necessary to raise the water level higher than the scribe line so as to wet the sides of the pycnometer for suitable meniscus formation, then remove some water to obtain the correct height.)

7. Using a cotton swab, wipe the inside of the neck of the pycnometer dry.

8. Using a lint-free wipe, clean and dry the outside of the bottle.

9. Weigh the pycnometer and water to ±0.01 g.

10. Using the liquid-in-glass thermometer, measure the temperature of the water in the pycnometer and record it to the nearest 0.2ºC.

11. Repeat Steps 5 through 10 two additional times. The temperatures for all three runs (Step 5) must be within ±0.5ºC.

12. Using the verification sheet (i.e., the WPVS), calculate the volume of the pycnometer for each run. The pycnometer volume is calculated by dividing the weight of the water by its' density. Average the three volumes to determine the pycnometer volume. Averaging the volumes minimizes the effect of error involved in reading the meniscus level. Water densities are determined from the standard table at the bottom of the WPVS.

Specimen Measurement Procedure—All weights and temperature measurements must be recorded on the AGDDS. A number of pycnometers may be used simultaneously. This procedure is also used for calibration check measurements using a standard material.

1. Place the entire dried specimen powder into a clean, dry, and calibrated pycnometer by pouring it through a clean, dry transfer funnel. In order to minimize rehydration of the specimen, do not allow the specimen to cool prior to being placed into the pycnometer.

2. Using a lint-free wipe, clean the exterior of the pycnometer.

3. Immediately weigh the pycnometer, with dry specimen, to ±0.01 g.

4. Add 50 to 60 mL of distilled water to the pycnometer by pouring it down the neck of the pycnometer, and swirl it to moisten all of the specimen powder.

5. Place the pycnometer, with specimen and water, and a clean beaker of extra distilled water into an active vacuum for a minimum of 16 hours. For the first

one or two hours the pycnometer must be watched closely to ensure that the boiling action does not displace some of the specimen out of the pycnometer. The vacuum should be regulated accordingly. Also, after approximately one hour, release the vacuum, remove the pycnometer, and swirl it again to help dislodge air bubbles. The vacuum is then reapplied.

6. Remove the pycnometer from the vacuum chamber at the completion of the vacuum cycle.

7. Pour de-aired water, from the beaker, down the neck of the pycnometer until the water level is just below the scribe line. Pouring the water down the neck reduces the likelihood of it forming bubbles, and helps to keep the specimen from going into suspension.

8. Using the pipette, add more water until the bottom of the meniscus is at the height of the scribe line. It may be necessary to raise the water level higher than the scribe line so as to wet the sides of the pycnometer for suitable meniscus formation, then remove some water to obtain the correct height.

9. Using a cotton swab, dry the inside of the neck of the pycnometer.

10. Using a lint-free wipe, clean and dry the exterior of the pycnometer.

11. Weigh the pycnometer, and contents, to ±0.01 g.

12. Using the liquid-in-glass thermometer, measure the temperature of the water in the pycnometer, and record it to the nearest 0.2ºC.

13. Using the AGDDS, with all the preceding information recorded, calculate the average grain density of the specimen. Record the result on the form.

14. Pour excess water out of the pycnometer and then pour the wet specimen back into its respective drying pan. Allow the water to evaporate at ambient conditions until the powder is dry. Store the specimen powder in a clearly labeled container.

4.5 Calculated Matrix Porosity

Data acquired from the preceding procedures will be used to calculate the matrix porosity of the respective rock specimens. The formulae presented are commonly used for this purpose. The two equations below will be used in the calculation of the matrix porosity of all the specimens for which the necessary data are collected.

Equation I: $\phi_{mI} = [1 - (\rho_{db} / \rho_g)] \times 100\%$

and

Equation II: $\phi_{mII} = (\rho_{sb} - \rho_{db}) \times 100\%$,

where $\phi_{m/}$ is the matrix porosity calculated from Equation I (%); $\phi_{m//}$ is the matrix porosity calculated from Equation II (%) (where the density of water is assumed to be 1 g/cm^3); ρ_{db} is the dry bulk density (g/cm^3); ρ_g is the average grain density (g/cm^3); and ρ_{sb} is the saturated bulk density (g/cm^3).

The porosity that is calculated using Equation I will generally be larger than that calculated with Equation II, because the effects of occluded porosity are minimized in the measurement/calculation of average grain density. Also, the saturated bulk density measurements should be somewhat less accurate than the other two density measurements, because of the difficulty of saturating occluded porosity.. By providing results of both equations there will be a check on the consistency of the density measurements, and the effects of occluded porosity. Equation II may be more useful than Equation I for hydrologic applications because occluded porosity will have a negligible effect on fluid flow.

Record the relevant values of $\emptyset_{m/}$ and/or $\emptyset_{m//}$ on the appropriate data sheets.

5.0 Safety

There are no special safety hazards, only the normal hazards of the equipment. Operations will be in accordance with safety requirements of the facility where the work is being performed and that of the employer of person(s) performing the work.

6.0 Nonconformances, Deviations, and Corrective Actions

Any nonconformances or deviations must be reported to the PI as soon as possible. Deviations, deficiencies and corrective actions must be determined and documented in accordance with AP-16.1Q, *Condition Reporting and Resolution*.

7.0 QA Records

QA records, and any corrections or changes thereto, generated as a result of implementing this procedure will be prepared and submitted as inclusionary QA records (QA:QA) by the PI in accordance with AP-17.1Q, *Records Management*.

The QA records include:

- Proficiency Training Records (Section 2.0)
- Bulk Volume and Density Data Sheet (BVDDS) (Appendix A)
- Water Pycnometer Verification Sheet (APVS) (Appendix B)
- Average Grain Density Data Sheet (AGDDS) (Appendix C)

8.0 References

AP-12.1Q, *Control of Measuring and Test Equipment and Calibration Standards*

AP-16.1Q, *Condition Reporting and Resolution*

AP-17.1Q, *Records Management*

Boyd, P. J. et al., 1992, "*An Experimental Comparison of Laboratory Techniques in Determining Bulk Properties of Tuffaceous Rocks*," SAND92-0119, Sandia National Laboratories, Albuquerque, NM.

Dean, J. A. ed., 1973, *Lange's Handbook of Chemistry*, 11th Edition, Sect.10-127, Mcgraw-Hill, New York, NY.

Franklin, J. A. et al., 1979, "*Suggested Methods for Determining Water Content, Porosity, Density, Absorption and related Properties and Swelling and Slake-Durability Index Properties*," International Journal of Rock Mechanics & Mining Sciences & Geomechanical Abstracts, Vol. 16, No. 2, pp. 141-156. In: Brown, E. T., ed., 1981, "*Rock Testing and Monitoring ISRM Suggested Methods*," Pergamon Press, New York, NY.

QAIP 20-03, *Sample Control*

TP-051, *Preparing Cylindrical Samples, Including Inspection of Dimensional and Shape Tolerances*

TP-064, *Vacuum Saturation of Geologic Core to Constant Weight*

TP-065, *Drying Geological Samples to Constant Weight*

Appendix A

BULK VOLUME AND DENSITY DATA SHEET (BVDDS)

Specimen ID _____

BULK VOLUME:

via Linear dimensions: Diameter (cm) _____ (A) Radius (cm) _____ (B = A ÷ 2)

Length (cm) _____ (C) Volume (cm^3) _____ ($D = \pi B^2 C$)

via Buoyancy: Saturated Mass (g) _____ (E) Submerged Mass (g) _____ (F)

Water Density at T (g/cm^3) _____ (G) Volume (cm^3) _____ (H = [E – F] ÷ G)

SATURATED BULK DENSITY:

Saturated Mass (g) _____ (E) Volume (cm^3) _____ (I = either D or H, above)

Saturated Bulk Density (g/cm^3) _____ (J = E ÷ I)

DRY BULK DENSITY:

Dry Mass (g) _____ (K) Volume (cm^3) _____ (L = either D or H, above)

Dry Bulk Density (g/cm^3) _____ (M = K ÷ L)

MATRIX POROSITY: Equation II: _____ (N = [J – M] X 100%)

ABSOLUTE DENSITY OF WATER

(From Lange's Handbook of Chemistry, 1973, Edited by John A. Dean, 11th Edition, Sect. 10-127)

Temp ºC	Density	Temp ºC	Density	Temp ºC	Density	Temp ºC	Density
18.0	0.998595	20.8	0.998035	23.6	0.997394	26.4	0.996676
18.2	0.998553	21.0	0.997992	23.8	0.997345	26.6	0.996621
18.4	0.998520	21.2	0.997948	24.0	0.997296	26.8	0.996567
18.6	0.998482	21.4	0.997904	24.2	0.997246	27.0	0.996512
18.8	0.998444	21.6	0.997850	24.4	0.997196	27.2	0.996457
19.0	0.998405	21.8	0.997815	24.6	0.997146	27.4	0.996401
19.2	0.998365	22.0	0.997770	24.8	0.997095	27.6	0.996345
19.4	0.998325	22.2	0.997724	25.0	0.997044	27.8	0.996289
19.6	0.998285	22.4	0.997678	25.2	0.996992	28.0	0.996232
19.8	0.998244	22.6	0.997632	25.4	0.996941	28.2	0.996175
20.0	0.998203	22.8	0.997585	25.6	0.996888	28.4	0.996118
20.2	0.998162	23.0	0.997535	25.8	0.996835	28.6	0.996060
20.4	0.998120	23.2	0.997490	26.0	0.996783	28.8	0.996002
20.6	0.998078	23.4	0.997442	26.2	0.996729	29.0	0.995944

Work performed by: _____

Printed Signed Date

Company/Division: _____ Location of Work: _____

Appendix B

WATER PYCNOMETER VERIFICATION SHEET (WVPS)

Unique identifier of pycnometer _____

Date of verification _____ Date of last verification _____

Dry bottle weight (g) _____

Water Temperature (^oC)	Pycn. + Water Weight (g)	Water only Weight (g)	Water Density (g/cm^3)	Pycnometer Volume (cm^3) (Wt / Density)

Average volume: _____

ABSOLUTE DENSITY OF WATER

(From Lange's Handbook of Chemistry, 1973, Edited by John A. Dean, 11th Edition, Sect. 10-127)

Temp °C	Density	Temp°C	Density	Temp °C	Density	Temp °C	Density
18.0	0.998595	20.8	0.998035	23.6	0.997394	26.4	0.996676
18.2	0.998553	21.0	0.997992	23.8	0.997345	26.6	0.996621
18.4	0.998520	21.2	0.997948	24.0	0.997296	26.8	0.996567
18.6	0.998482	21.4	0.997904	24.2	0.997246	27.0	0.996512
18.8	0.998444	21.6	0.997850	24.4	0.997196	27.2	0.996457
19.0	0.998405	21.8	0.997815	24.6	0.997146	27.4	0.996401
19.2	0.998365	22.0	0.997770	24.8	0.997095	27.6	0.996345
19.4	0.998325	22.2	0.997724	25.0	0.997044	27.8	0.996289
19.6	0.998285	22.4	0.997678	25.2	0.996992	28.0	0.996232
19.8	0.998244	22.6	0.997632	25.4	0.996941	28.2	0.996175
20.0	0.998203	22.8	0.997585	25.6	0.996888	28.4	0.996118
20.2	0.9988162	23.0	0.997535	25.8	0.996835	28.6	0.96060
20.4	0.998120	23.2	0.997490	26.0	0.996783	28.8	0.996002
20.6	0.998078	23.4	0.997442	26.2	0.996729	29.0	0.995944

Work performed by: _____
Printed Signed Date

Company/Division: _____ Location of Work: _____

Appendix C

AVERAGE GRAIN DENSITY DATA SHEET (AGDDS)

Specimen ID _____

Pycnometer ID _____ Latest verification _____

Weight (g) of dry pycnometer _____ (A)

Weight (g) of dry pycnometer + dry sample _____ (B)

Weight (g) of dry sample _____ (C = B – A)

Weight (g) of pycnometer + specimen + water _____ (D)

Temperature (^{o}C) of water _____ (E) Density (g/cm^3) of water at E _____ (F)

Weight (g) of water only _____ (G = D – B)

Volume (cm^3) of water _____ (H = G ÷ F)

Volume (cm^3) of pycnometer from verification _____ (I)

Volume (cm^3) of specimen _____ (J = I – H)

Average grain density (g/cm^3) of specimen _____ (K = C ÷ J)

MATRIX POROSITY: Dry bulk density (from BVDDS) (g/cm^3) _____(L)

Matrix Porosity from Equation I: _____ (M = {1 - [L ÷ K]} X 100%)

ABSOLUTE DENSITY OF WATER

(From Lange's Handbook of Chemistry, 1973, Edited by John A. Dean, 11th Edition, Sect. 10-127)

Temp °C	Density	Temp°C	Density	Temp °C	Density	Temp °C	Density
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18.4	0.998520	21.2	0.997948	24.0	0.997296	26.8	0.996567
18.6	0.998482	21.4	0.997904	24.2	0.997246	27.0	0.996512
18.8	0.998444	21.6	0.997850	24.4	0.997196	27.2	0.996457
19.0	0.998405	21.8	0.997815	24.6	0.997146	27.4	0.996401
19.2	0.998365	22.0	0.997770	24.8	0.997095	27.6	0.996345
19.4	0.998325	22.2	0.997724	25.0	0.997044	27.8	0.996289
19.6	0.998285	22.4	0.997678	25.2	0.996992	28.0	0.996232
19.8	0.998244	22.6	0.997632	25.4	0.996941	28.2	0.996175
20.0	0.998203	22.8	0.997585	25.6	0.996888	28.4	0.996118
20.2	0.998162	23.0	0.997535	25.8	0.996835	28.6	0.996060
20.4	0.998120	23.2	0.997490	26.0	0.996783	28.8	0.996002
20.6	0.998078	23.4	0.997442	26.2	0.996729	29.0	0.995944

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