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Estimated Accuracy of Calibration of Some Membrane-Type LNG Transport Tanks

W. C. Haight, R. J. Hocken, B. R. Borchardt, C. L. Carroll,
R. G. Hartsock, C. P. Reeve, F. E. Scire and R. C. Veale

Automated Production Technology Division
National Engineering Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

February 1980

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November 1980

Issued January 1981

U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*
Jordan J. Baruch, *Assistant Secretary for Productivity, Technology, and Innovation*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Washington, DC 20234

February 1980

These reports prepared for:

The LNG Custody Transfer Measurements Committee

and

The Maritime Administration of the
Department of Commerce

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I. Introduction

The National Bureau of Standards supported by the Department of Commerce Maritime Administration did some preliminary studies to establish an upper limit for the tank volume uncertainty of a spherical transport tank calibrated by photogrammetry [1]. Additional support from the Maritime Administration and the LNG Ship Custody Transfer Committee [2], has made possible a considerably expanded study of the calibration uncertainties of LNG transport tanks. The tank calibrations examined in this work are those of the three LNG Transports built by Newport News Shipbuilding and Drydock Company for El Paso Marine Company.

II. The Tanks

The cargo tanks on these 125000 m^3 (approximate) capacity ships are membrane types of the Technigaz design described in reference [3]. The tanks are ten-sided prismatic solids and rectangular in horizontal cross section. The walls are all plane surfaces. The end walls are vertical as are the side walls. The side walls are connected to the horizontal floor and ceiling by sloping chine planes. All eight of the longitudinal planes are parallel to the longitudinal axis of the ship. The supporting walls of the tanks are the inner hull of the ship. Layers of insulation are attached to these walls and the internal surfaces of the insulation are covered with a liquid-tight 1.2 mm stainless steel membrane. This membrane has corrugations stamped into it forming a waffle pattern.

III. Tank Calibration Methods

The measurements used to calculate the tank volume were generally made after the membrane installation was complete but before the removal of the construction scaffolding since it is needed to provide access to the tank surface. Briefly, the calibration method used by the calibration contractor consisted of measuring horizontal cross sectional areas of the tank at intervals from the bottom to the top of the tank. The products of these areas and the separation from the area immediately below summed to the level gives the volume to that level. This method is discussed in reference [4]. The cross sectional areas of these tanks were determined by measuring short distances to the wall from the sides of a horizontal rectangle of known dimensions defined by laser beams.

A calibration method developed at NBS and reported in reference [5] was used by NBS to assess the accuracy of the method used by the calibration contractor. The method used by NBS consists, in brief, of inscribing with laser planes a slightly smaller closed volume with the same shape as the tank. The dimensions of this laser-plane-defined volume are accurately measured. Perpendicular distances from the laser planes to the tank walls are measured at several hundred specified points distributed around the tank. The integration method used to determine volume as a function of height is also outlined in reference [5].

IV. Results

The calibration reports for each of the six tanks of the three ships, the El Paso Southern, the El Paso Arzew and the El Paso Howard Boyd, appear in Appendix I, II, and III respectively. Each individual tank report supplies the following information:

a. A calibration report or a report of test describing the measurement technique, measurement conditions, and error estimate.

b. A summary main gaging table showing tank volume as a function of gage height.

c. Summary list and trim correction tables to supplement the main table under expected conditions of ship list and trim.

d. A plot comparing the NBS main gaging tables at selected intervals to the gage books for each tank provided by the calibration contractor.

The staging was removed in four of the tanks before the NBS measurements were made; hence the calibration check was done only to the height accessible from the bottom of the tank.

The calibration accuracy required by the ship owner is $\pm 0.2\%$ of total tank volume. The NBS results range in accuracy from $\pm 0.05\%$ to $\pm 0.1\%$ as indicated in the Reports of Calibration. In every case, the calibration contractor's results are well within $\pm 0.2\%$ of the NBS results. It therefore appears that the accuracy requirement has been achieved for the tanks at ambient temperature. The tank volume tables at ambient temperature are used by the transporter to determine LNG volume at operating temperature because the tank dimensions have been assumed independent of cargo temperature. This assumption is based on the fact that the shape of the tank is determined by the external tank wall which is the inner hull of the ship. The membrane wall is supported by this wall via the insulation. The corregated design of the membrane allows the membrane to shrink on cooling without altering the internal volume.

In actual operation, the external tank wall might be as cold as 0°C depending on weather conditions. The temperature of the interior of the tanks was as high as 30°C during calibration of the tanks. Provided the external tank wall reached temperatures that high, the difference between the calibration and operating temperature could be as large as 30°C.

The thermal expansion coefficient of iron as well as iron containing small quantities of nickel [6] is approximately 11.6×10^{-6} m/m°C. This contraction only affects the length and width of the tank with regard to calibration since the liquid height is determined by the level gage rather than the tank height. Thus the tank volume change between the calibration and operating temperature could be as much as

$$\Delta V/V = -(2 \times 30 \times 11.6)/100$$
$$= -0.07\%$$

The shrinkage of the balsa wood insulation upon cooling (since the balsa is not a rigid body) as well as any bulging of the tank sides counteract the reduction in volume due to cooling the walls. The balsa shrinkage contributes a negligible change in tank volume. If this is also true with respect to tank wall bulging due to hydrostatic head, then the maximum systematic error introduced into the tank calibrations due to cooling is estimated to be no more than -0.07%.

References

[1] Jackson, R.H.F. et al. 1979. Custody Transfer Systems for LNG Ships: Tank Survey Techniques and Sounding Tables. NBSIR 79-1751.

[2] The members of the committee are: Ivan W. Schmitt, Chairman, El Paso Marine Company; Bland Osborn, Columbia LNG Corporation; Howard S. Joiner, Consolidated Systems LNG Company; and Ed Crenshaw, Southern Energy Company.

[3] Jackson, R. G. and Kotcharian M., 1968, Testing and Technology of Models of Integrated Tanks for LNG carriers, Paper No. 35, Session 6, First International Conference on LNG, Chicago, April.

[4] Jelffs, P.A., 1972. "Calibration of Containers and Gages" J. Inst. Pet. Vol. 58, p. 117.

[5] Hocken, R. J. and Haight, W. C., 1978. "Multiple Redundancy in the Measurement of Large Structures" Annals of the International Institution of Production Engineering Research (CIRP), Volume 27, p. 1.

[6] LNG Materials and Fluids User's Manual, 1977. D. B. Mann, Editor, National Bureau of Standards, Boulder, CO.

Appendix A

Calibration Reports for the Six Tanks of the El Paso Southern

FORM NBS-443
(REV. 12-65)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #1 on the LNG Tanker
El Paso Southern

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 1 of the liquefied natural gas tanker El Paso Southern while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 9.0°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 12566.0 m^3 with an uncertainty of 1.3 m^3 (0.01% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.05% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 17, 1979

EL PASO SOUTHERN

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 1

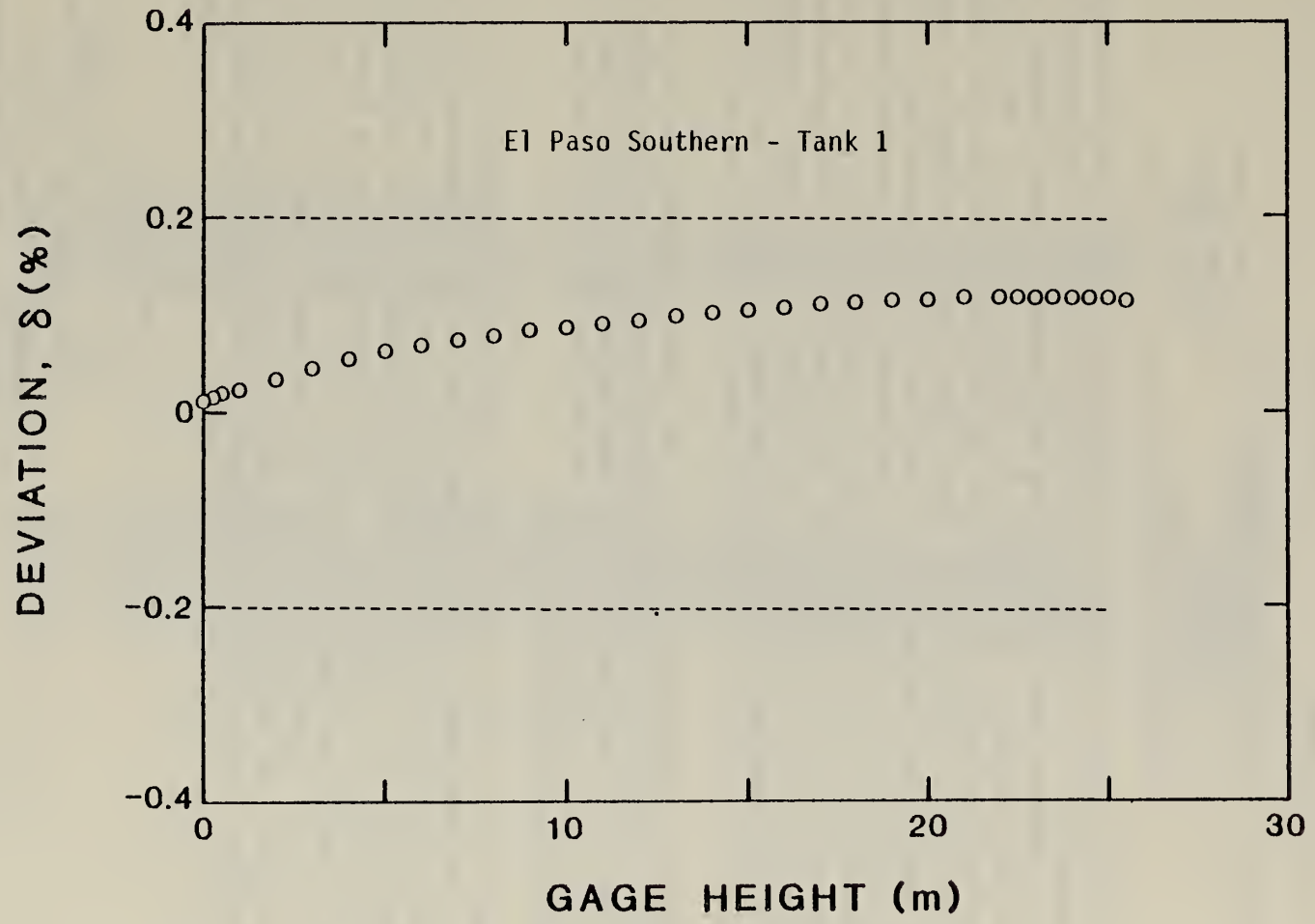
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	3.3
.050	18.6
.100	34.4
.200	66.5
.300	99.0
.400	132.0
.500	165.5
1.000	339.9
2.000	724.3
3.000	1156.1
4.000	1635.1
5.000	2144.7
6.000	2654.7
7.000	3164.7
8.000	3674.7
9.000	4184.7
10.000	4694.6
11.000	5204.5
12.000	5714.4
13.000	6224.3
14.000	6734.1
15.000	7243.9
16.000	7753.6
17.000	8263.3
18.000	8773.0
19.000	9282.7
20.000	9792.3
21.000	10301.9
22.000	10811.4
22.500	11066.2
23.000	11321.0
23.500	11575.7
24.000	11825.6
24.500	12063.7
25.000	12289.8
25.500	12504.1

EL PASO SOUTHERN TANK NO. 1

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	61.8	41.0	20.5	0.0	-24.8	-26.4	-26.9	-27.2	-27.4	-27.5
.100	61.9	41.1	20.4	-.3	-41.7	-56.4	-63.5	-66.9	-69.0	-70.4
.200	61.9	41.2	20.2	-.4	-41.7	-62.4	-83.0	-102.1	-117.3	-126.8
.500	61.9	41.1	20.5	-.4	-41.7	-62.4	-83.1	-103.8	-124.2	-144.8
1.000	61.8	41.2	20.3	-.5	-41.8	-62.4	-83.1	-103.6	-124.2	-144.7
5.000	61.7	41.0	20.3	-.4	-41.7	-62.4	-83.1	-103.8	-124.4	-145.1
10.000	61.7	41.0	20.3	-.4	-41.8	-62.5	-83.1	-103.8	-124.5	-145.2
15.000	61.7	41.0	20.3	-.3	-41.7	-62.4	-83.0	-103.7	-124.4	-145.1
20.000	61.6	41.0	20.4	-.5	-41.7	-62.4	-83.0	-103.6	-124.3	-145.1
23.000	61.6	41.0	20.3	-.3	-41.7	-62.4	-83.0	-103.6	-124.2	-145.1
25.000	61.4	40.9	20.3	-.3	-41.8	-62.4	-83.0	-103.7	-124.5	-145.4

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	41.8	27.6	14.2	3.4	-.2	7.1	20.2	35.2	51.1
.100	22.9	10.6	1.4	-1.4	-.3	1.1	7.3	18.8	32.8
.200	.8	-2.7	-2.1	-1.5	-.4	1.2	3.4	5.6	11.7
.500	-1.4	-2.0	-2.0	-1.5	-.4	1.2	3.3	6.0	9.3
1.000	-1.2	-1.9	-2.0	-1.5	-.5	1.1	3.4	6.2	9.6
5.000	-5.0	-3.9	-2.7	-1.5	-.4	.8	2.0	3.1	4.3
10.000	-5.0	-3.8	-2.7	-1.5	-.4	.8	2.0	3.2	4.4
15.000	-5.1	-3.9	-2.7	-1.5	-.3	.8	1.9	3.1	4.2
20.000	-5.0	-3.8	-2.7	-1.6	-.5	.7	1.9	3.0	4.2
23.000	-5.0	-3.8	-2.6	-1.5	-.3	.8	1.9	3.1	4.2
25.000	-10.1	-6.6	-3.8	-1.7	-.3	.3	.3	-.5	-2.0



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-65)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #2 on the LNG Tanker
El Paso Southern

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 2 of the liquefied natural gas tanker El Paso Southern while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 15.4°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 24858.8 m^3 with an uncertainty of 2.5 m^3 (0.01% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.05% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 17, 1979

EL PASO SOUTHERN

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 2

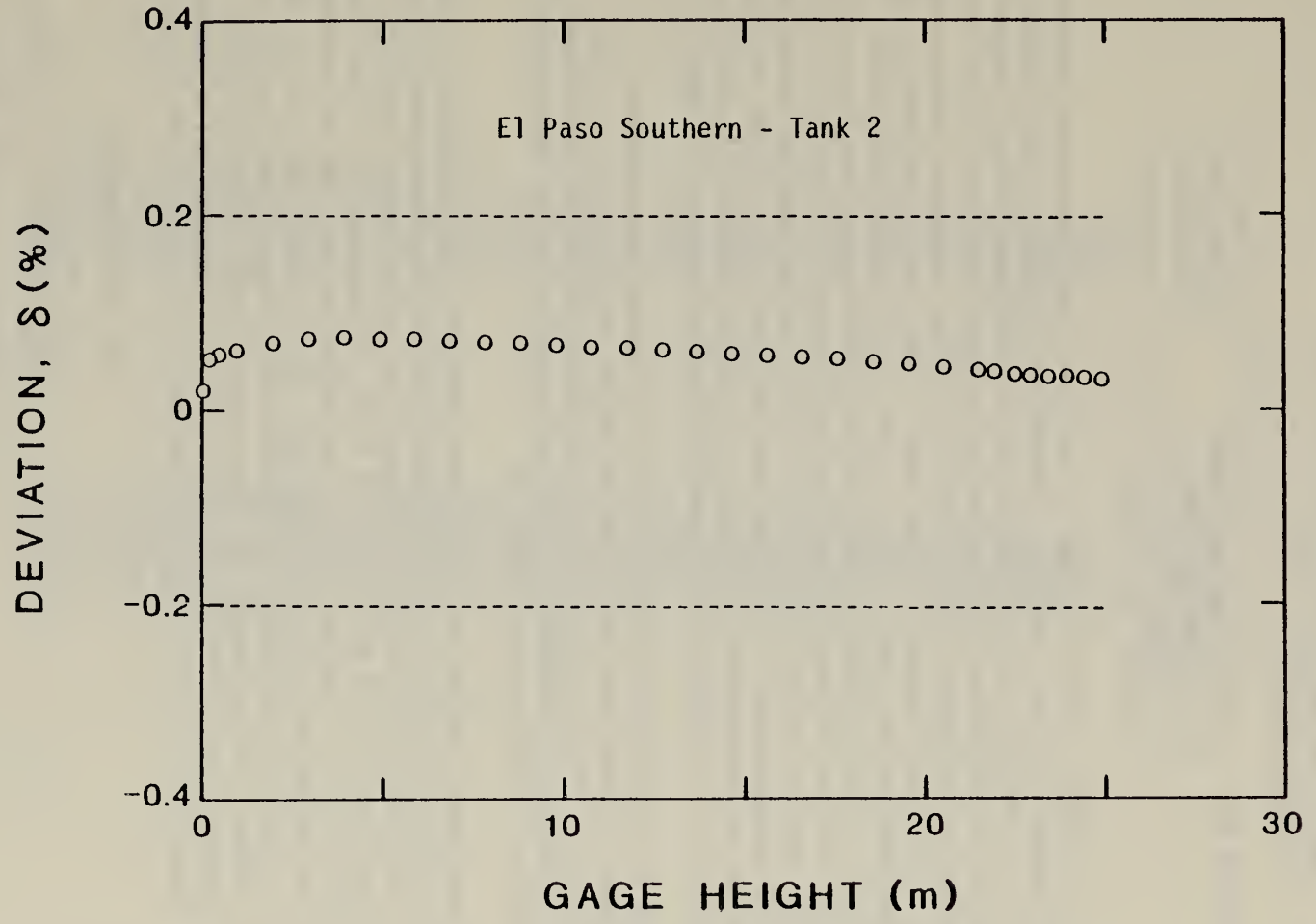
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	4.5
.050	43.1
.100	84.0
.200	166.1
.300	248.9
.400	332.3
.500	416.3
1.000	846.0
2.000	1752.4
3.000	2721.8
4.000	3754.1
5.000	4827.4
6.000	5901.4
7.000	6975.5
8.000	8049.5
9.000	9123.5
10.000	10197.5
11.000	11271.5
12.000	12345.5
13.000	13419.4
14.000	14493.4
15.000	15567.3
16.000	16641.3
17.000	17715.2
18.000	18778.7
19.000	19784.5
20.000	20726.8
21.000	21605.4
22.000	22420.4
22.500	22804.1
23.000	23171.9
23.500	23523.8
24.000	23859.8
24.500	24179.9
25.000	24484.1
25.500	24772.4

EL PASO SOUTHERN TANK NO. 2

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	+1.0	+1.5	+2.0	+2.5	+3.0	TRIM BY STERN (METERS) +3.5
.050	84.5	56.4	28.3	.5	-22.4	-22.8	-22.2	-22.4	-22.6	-22.7
.100	84.6	56.4	28.2	.1	-50.0	-59.6	-63.3	-65.4	-66.8	-67.7
.200	84.6	56.4	28.2	0.0	-56.2	-84.5	-107.9	-122.1	-131.0	-137.2
.500	84.6	56.4	28.2	.1	-56.1	-84.3	-112.3	-140.4	-168.4	-196.4
1.000	84.5	56.4	28.2	0.0	-56.2	-84.3	-112.3	-140.4	-168.4	-196.4
5.000	84.4	56.3	28.2	.1	-56.2	-84.3	-112.4	-140.5	-168.6	-196.8
10.000	84.4	56.2	28.2	.1	-56.1	-84.3	-112.4	-140.5	-168.6	-196.8
15.000	84.4	56.3	28.1	.1	-56.2	-84.3	-112.4	-140.5	-168.6	-196.7
20.000	84.2	56.2	28.1	.1	-56.2	-84.3	-112.4	-140.7	-168.9	-197.0
23.000	84.2	56.1	28.2	0.0	-56.2	-84.3	-112.4	-140.7	-168.8	-197.1
25.000	84.2	56.1	28.1	.1	-56.1	-84.3	-112.6	-140.7	-169.0	-197.2

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	98.0	69.6	41.6	14.9	.8	21.2	49.9	79.7	109.9
.100	75.9	48.3	22.3	2.0	.1	7.0	30.9	58.9	88.6
.200	40.4	17.2	.7	-1.2	0.0	2.2	8.5	28.3	54.0
.500	1.4	-.4	-1.3	-1.1	.1	2.3	5.4	9.6	14.9
1.000	1.5	-.4	-1.3	-1.2	0.0	2.3	5.6	9.9	15.2
5.000	-6.6	-4.9	-3.2	-1.6	.1	1.7	3.4	5.0	6.7
10.000	-6.7	-5.0	-3.3	-1.6	0.0	1.7	3.4	5.1	6.8
15.000	-6.8	-5.1	-3.4	-1.7	.1	1.8	3.5	5.2	6.9
20.000	-15.1	-9.7	-5.4	-2.1	.1	1.1	1.1	0.0	-2.3
23.000	-13.5	-8.8	-5.0	-2.0	0.0	1.2	1.6	1.0	-.3
25.000	-12.3	-8.2	-4.6	-1.9	.1	1.4	1.9	1.8	1.0



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-65)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #3 on the LNG Tanker
El Paso Southern

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 3 of the liquefied natural gas tanker El Paso Southern while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 16.4°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 27655.0 m^3 with an uncertainty of 5.5 m^3 (0.01% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 17, 1979

EL PASO SOUTHERN

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 3

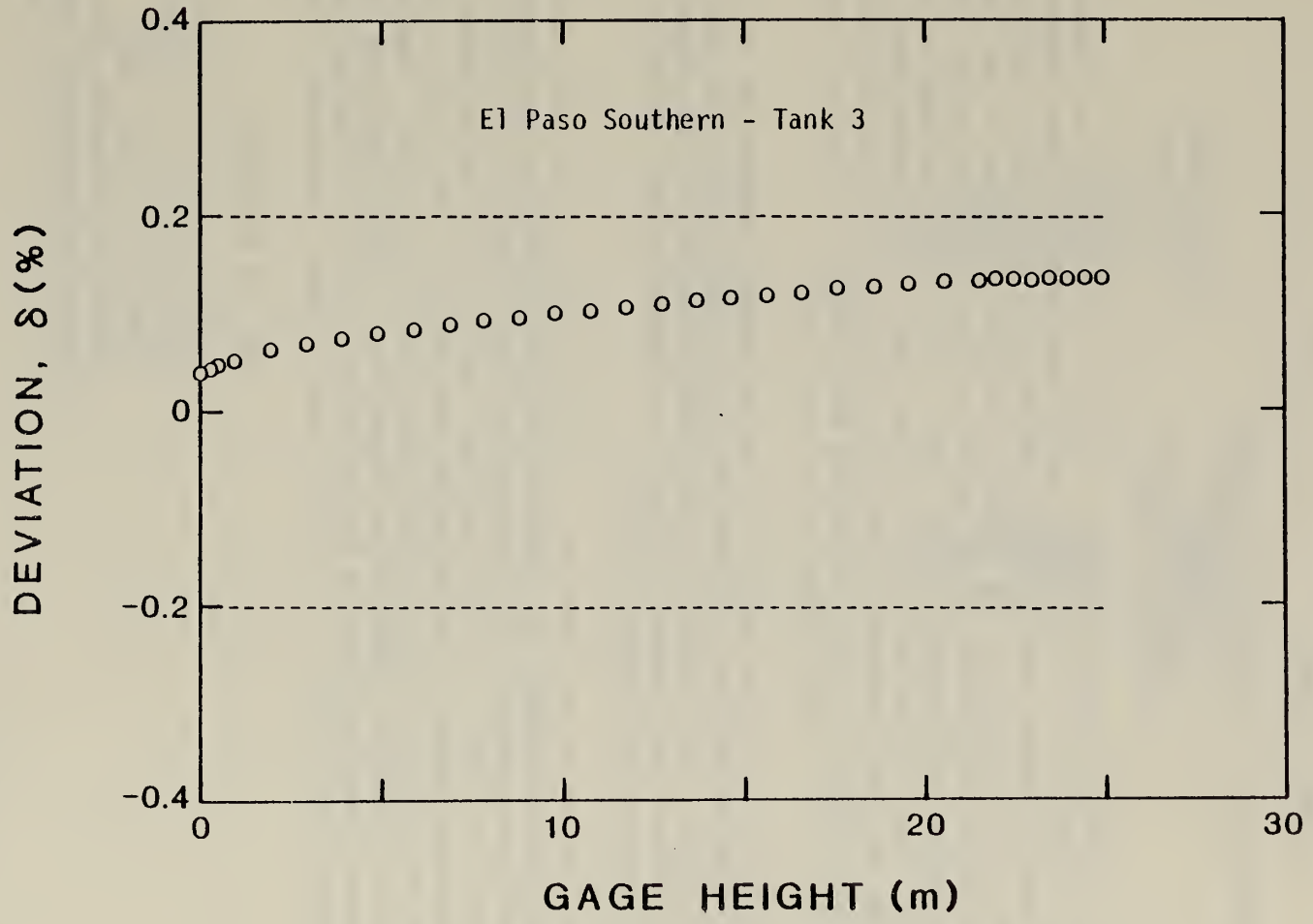
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	1.4
.050	43.1
.100	90.0
.200	184.4
.300	279.5
.400	375.2
.500	471.6
1.000	963.7
2.000	1998.1
3.000	3099.5
4.000	4267.9
5.000	5486.7
6.000	6694.4
7.000	7908.2
8.000	9121.8
9.000	10335.4
10.000	11548.9
11.000	12762.4
12.000	13975.8
13.000	15189.2
14.000	16402.5
15.000	17615.7
16.000	18828.9
17.000	20036.7
18.000	21170.7
19.000	22242.9
20.000	23247.4
21.000	24184.2
22.000	25053.2
22.500	25462.4
23.000	25854.5
23.500	26229.8
24.000	26588.1
24.500	26929.4
25.000	27253.9
25.500	27561.4

EL PASO SOUTHERN TANK NO. 3

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	+1.0	TRIM BY STERN (METERS) +1.5	+2.0	+2.5	+3.0	+3.5
.050	89.8	59.8	30.1	1.8	-14.1	-14.4	-14.6	-14.7	-14.3	-14.4
.100	89.8	59.7	29.6	-.3	-47.5	-53.5	-56.4	-58.1	-59.2	-59.9
.200	89.7	59.7	29.7	-.3	-60.4	-89.2	-108.7	-120.0	-127.6	-132.8
.500	89.8	59.7	29.6	-.4	-60.3	-90.4	-120.2	-150.2	-180.1	-210.0
1.000	89.8	59.7	29.7	-.4	-60.3	-90.4	-120.3	-150.2	-180.1	-209.9
5.000	89.6	59.6	29.6	-.4	-60.4	-90.4	-120.4	-150.4	-180.4	-210.4
10.000	89.7	59.7	29.6	-.4	-60.4	-90.4	-120.4	-150.4	-180.4	-210.4
15.000	89.6	59.6	29.6	-.4	-60.4	-90.4	-120.4	-150.5	-180.5	-210.5
20.000	89.5	59.5	29.6	-.4	-60.4	-90.5	-120.5	-150.6	-180.8	-210.9
23.000	89.5	59.5	29.6	-.3	-60.4	-90.5	-120.6	-150.7	-180.8	-211.0
25.000	89.4	59.5	29.6	-.4	-60.4	-90.5	-120.6	-150.8	-180.9	-211.1

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	111.1	80.1	49.8	20.3	.9	27.1	58.0	89.9	122.3
.100	88.6	58.2	28.8	3.8	-.3	9.6	37.3	68.3	100.3
.200	51.4	24.8	3.6	-1.2	-.4	1.6	11.1	35.1	63.6
.500	1.9	.2	-1.0	-1.3	-.4	1.5	4.6	8.7	13.2
1.000	2.8	.3	-1.1	-1.3	-.4	1.6	4.7	8.9	14.3
5.000	-7.0	-5.3	-3.7	-2.0	-.4	1.3	2.9	4.5	6.2
10.000	-7.6	-5.8	-4.0	-2.2	-.4	1.4	3.2	5.0	6.8
15.000	-8.2	-6.2	-4.3	-2.3	-.4	1.6	3.5	5.5	7.4
20.000	-17.1	-11.3	-6.5	-2.9	-.4	1.0	1.4	.6	-1.2
23.000	-15.7	-10.6	-6.3	-2.9	-.4	1.3	2.1	2.0	1.1
25.000	-14.7	-10.1	-6.2	-2.9	-.4	1.4	2.5	2.9	2.6



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-259
(3-68)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF TEST

For: Tank #4 on the LNG Tanker
El Paso Southern

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 4 of the liquefied natural gas tanker El Paso Southern while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull.

The tank was measured empty while at an average temperature of 10.0°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

These tables are not based on a complete survey of the tank, since scaffolding necessary for complete interior access was not present at the time of measurement. As a consequence, geometrically redundant cross checks reported of tanks 1, 2 and 3 were not made on this tank to assess random measurement errors. The estimated uncertainty of the tables is instead based on the comparison of measurements on tanks 1, 2 and 3 against their respective nominal construction dimensions. These comparisons showed measured dimensions were in general within 0.2% of the nominals so an estimated uncertainty of $\pm$ 0.2% of total volume is assigned to the tables.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 17, 1979

EL PASO SOUTHERN

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 4

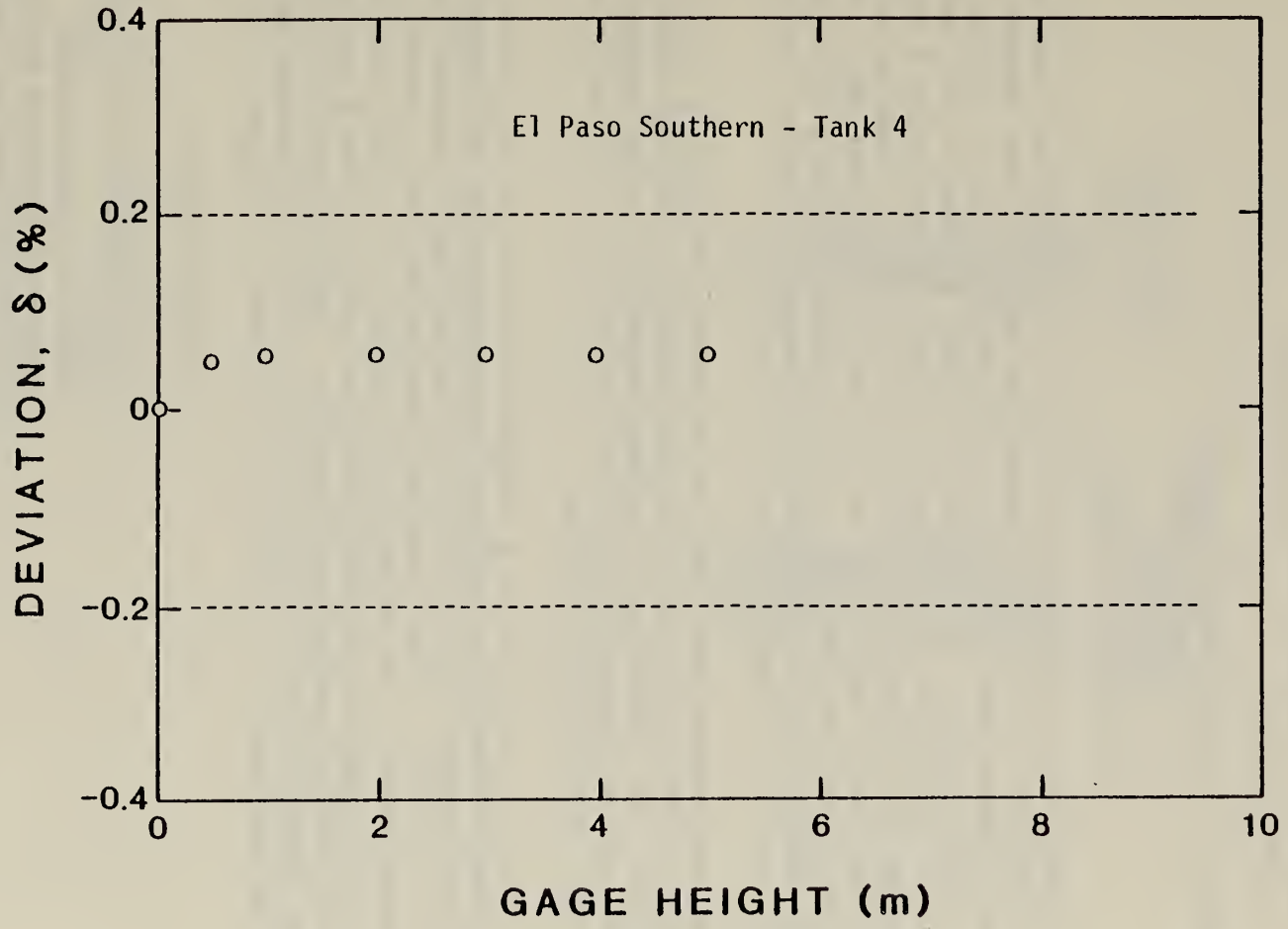
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	0.0
.050	11.2
.100	23.4
.200	48.0
.300	72.5
.400	97.0
.500	121.6

EL PASO SOUTHERN TANK NO. 4

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	29.0	19.1	9.6	.2	-4.7	-13.0	-17.6	-20.0	-21.5	-22.5
.100	28.6	19.2	9.5	.3	-19.0	-28.7	-34.8	-41.7	-48.1	-52.3
.200	28.7	18.9	9.6	.2	-19.1	-28.5	-38.2	-47.6	-57.4	-66.7
.500	28.7	18.9	9.6	0.0	-19.0	-28.5	-38.2	-47.6	-57.4	-66.7

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	LIST TO STARBOARD (DEGREES) 0.0	+0.5	+1.0	+1.5	+2.0
.050	77.5	55.1	33.2	13.2	0.0	18.3	42.1	66.3	90.5
.100	55.8	34.6	15.2	1.7	0.0	4.3	23.2	45.1	68.6
.200	22.1	6.8	-1.2	-1.2	0.0	1.4	4.1	16.1	34.5
.500	-5.6	-4.3	-2.9	-1.5	-.2	1.3	2.8	4.2	5.7



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-259
(3-66)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF TEST

For: Tank #5 on the LNG Tanker
El Paso Southern

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 5 of the liquefied natural gas tanker El Paso Southern while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull.

The tank was measured empty while at an average temperature of 6.4°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

These tables are not based on a complete survey of the tank, since scaffolding necessary for complete interior access was not present at the time of measurement. As a consequence, geometrically redundant cross checks reported of tanks 1, 2 and 3 were not made on this tank to assess random measurement errors. The estimated uncertainty of the tables is instead based on the comparison of measurements on tanks 1, 2 and 3 against their respective nominal construction dimensions. These comparisons showed measured dimensions were in general within 0.2% of the nominals so an estimated uncertainty of $\pm$ 0.2% of total volume is assigned to the tables.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 17, 1979

EL PASO SOUTHERN

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 5

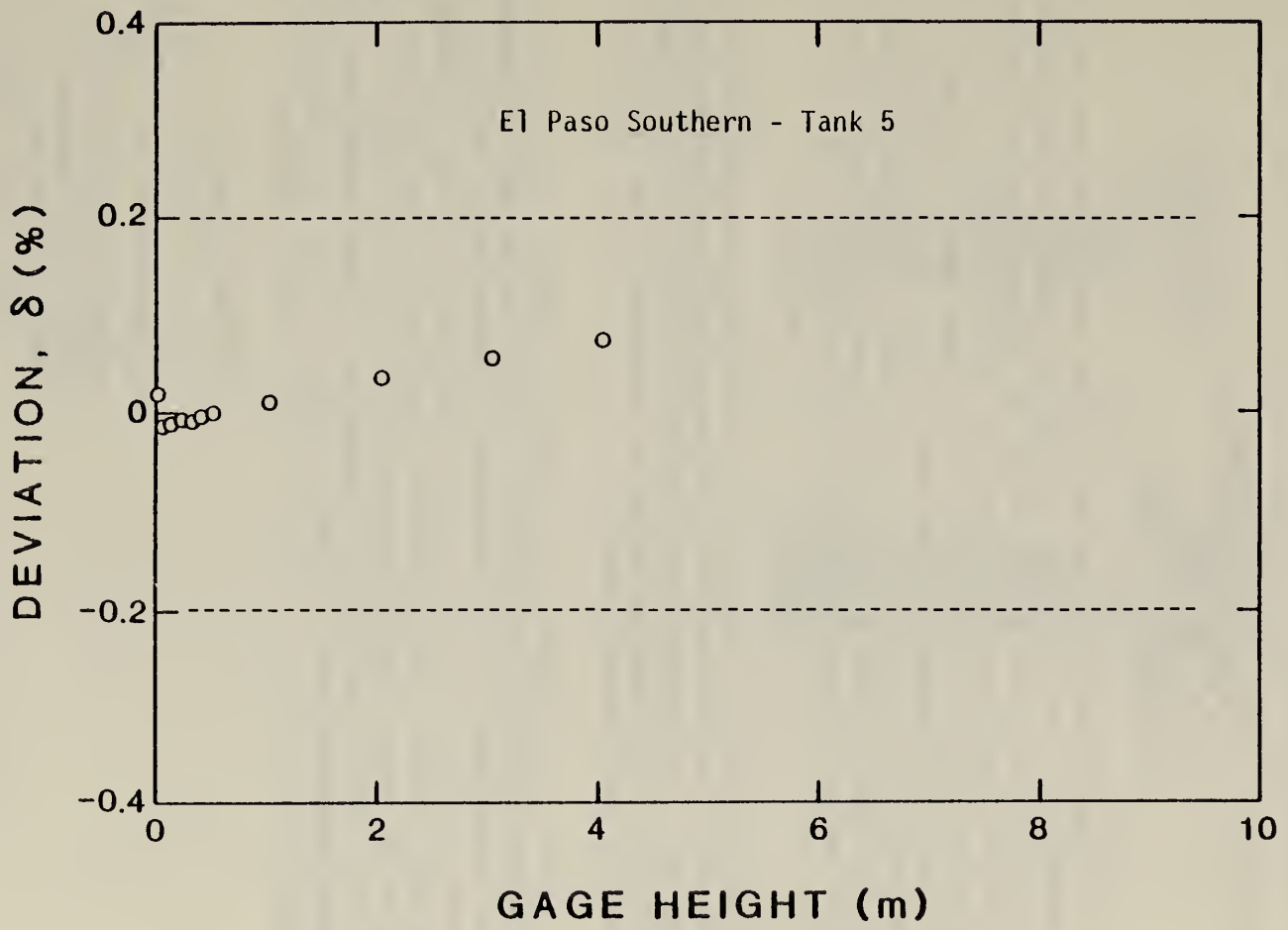
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	8.5
.050	37.8
.100	83.9
.200	178.6
.300	274.0
.400	370.1
.500	466.9
1.000	960.6
2.000	1998.2
3.000	3102.5
4.000	4273.5

EL PASO SOUTHERN TANK NO. 5

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	91.4	61.8	34.0	8.5	-24.5	-37.0	-44.4	-50.1	-53.9	-56.8
.100	89.8	59.7	30.0	.7	-51.9	-64.1	-74.1	-81.0	-85.9	-89.7
.200	89.9	59.8	30.1	-.1	-59.4	-92.0	-118.0	-124.6	-134.8	-142.5
.500	89.9	59.7	30.0	-.1	-59.7	-89.8	-119.8	-149.7	-179.7	-210.0

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	LIST TO STARBOARD (DEGREES) 0.0	+0.5	+1.0	+1.5	+2.0
.050	124.5	93.4	63.0	33.7	8.7	12.9	40.3	71.3	103.3
.100	102.2	71.6	42.3	15.6	.8	4.7	22.5	51.0	82.0
.200	64.6	37.1	13.4	.4	0.0	3.1	6.7	22.6	48.3
.500	6.5	1.7	0.0	-.6	0.0	3.0	5.5	9.2	13.9



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-259
(3-65)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF TEST

For: Tank #6 on the LNG Tanker
El Paso Southern

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 6 of the liquefied natural gas tanker El Paso Southern while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull.

The tank was measured empty while at an average temperature of 3.8°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

These tables are not based on a complete survey of the tank, since scaffolding necessary for complete interior access was not present at the time of measurement. As a consequence, geometrically redundant cross checks reported of tanks 1, 2 and 3 were not made on this tank to assess random measurement errors. The estimated uncertainty of the tables is instead based on the comparison of measurements on tanks 1, 2 and 3 against their respective nominal construction dimensions. These comparisons showed measured dimensions were in general within 0.2% of the nominals so an estimated uncertainty of $\pm$ 0.2% of total volume is assigned to the tables.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 17, 1979

EL PASO SOUTHERN

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 6

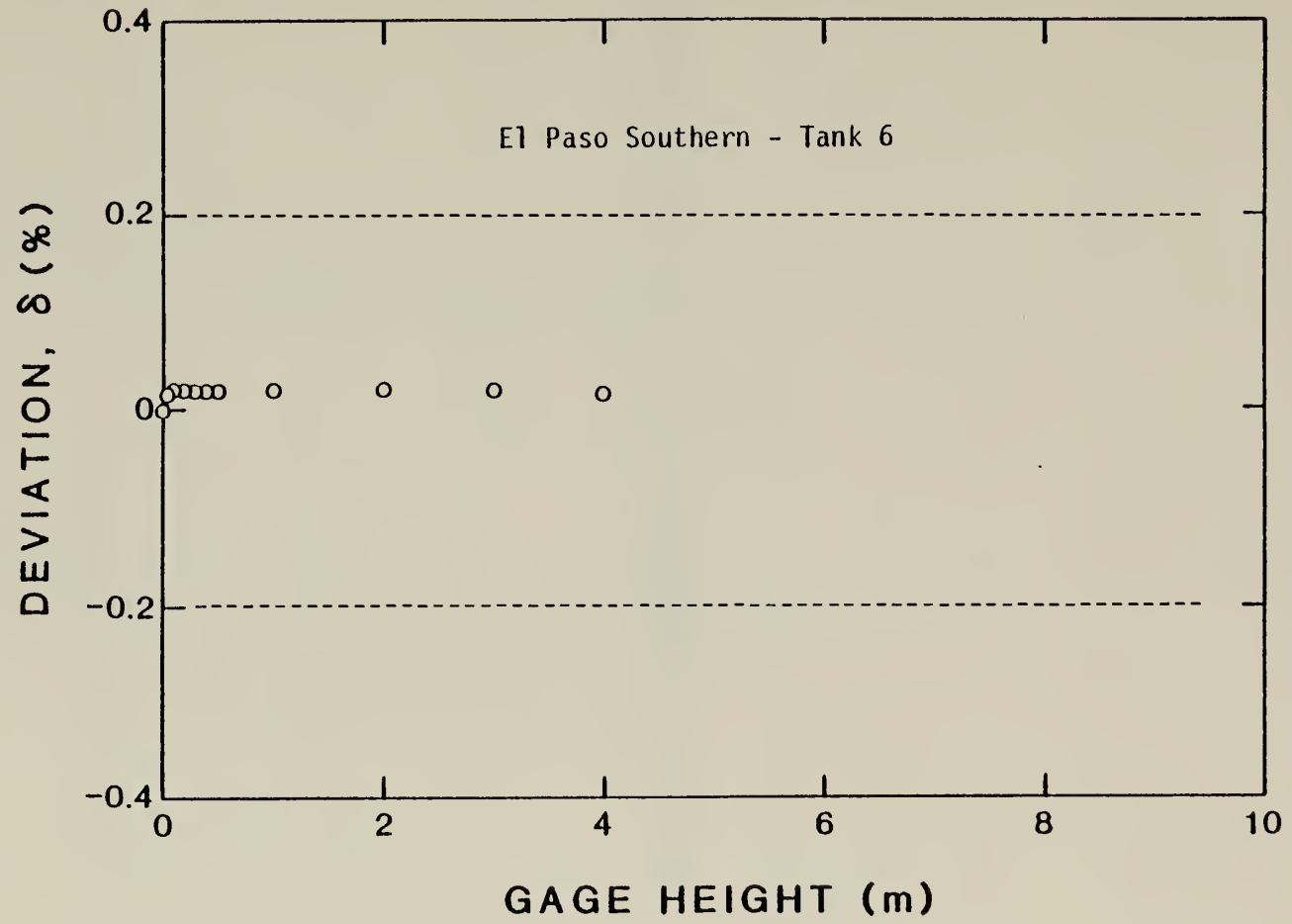
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	.6
.050	34.3
.100	81.1
.200	175.1
.300	269.9
.400	365.3
.500	461.4
1.000	951.9
2.000	1983.5
3.000	3082.5
4.000	4248.9

EL PASO SOUTHERN TANK NO. 6

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	90.4	60.6	31.2	8.3	-4.4	-4.6	-4.8	-4.9	-4.6	-4.7
.100	90.1	60.1	30.0	.1	-39.8	-44.5	-47.0	-48.6	-49.6	-50.3
.200	90.1	60.0	30.1	0.0	-59.9	-86.9	-102.8	-112.8	-119.4	-124.2
.500	90.1	60.1	30.0	.1	-59.9	-89.8	-119.8	-149.7	-179.6	-209.4
1.000	90.2	60.0	30.1	0.0	-59.9	-89.9	-119.8	-149.7	-179.6	-209.4
4.000	90.1	60.1	30.0	0.0	-59.9	-89.9	-119.8	-149.7	-179.7	-209.5

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	LIST TO STARBOARD (DEGREES) 0.0	+0.5	+1.0	+1.5	+2.0
.050	123.7	92.5	62.1	32.4	7.2	24.0	54.9	86.6	118.9
.100	100.4	69.8	40.2	12.3	.1	6.6	33.7	64.7	96.5
.200	61.6	33.9	10.4	-.8	0.0	1.9	8.6	31.6	59.7
.500	3.9	1.1	-.4	-.7	.1	1.9	4.8	8.8	12.9
1.000	3.9	1.2	-.3	-.7	0.0	1.9	4.9	9.0	14.2
4.000	2.5	.9	-.2	-.5	0.0	1.9	4.9	8.6	12.9



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

Appendix B

Calibration Reports for the Six Tanks of the El Paso Arzew

FORM NBS-443
(REV. 12-65)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #1 on the LNG Tanker
El Paso Arzew

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 1 of the liquefied natural gas tanker El Paso Arzew while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 23.0°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 12571.8 m^3 with an uncertainty of 6.3 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 16, 1979

EL PASO ARZEW

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 1

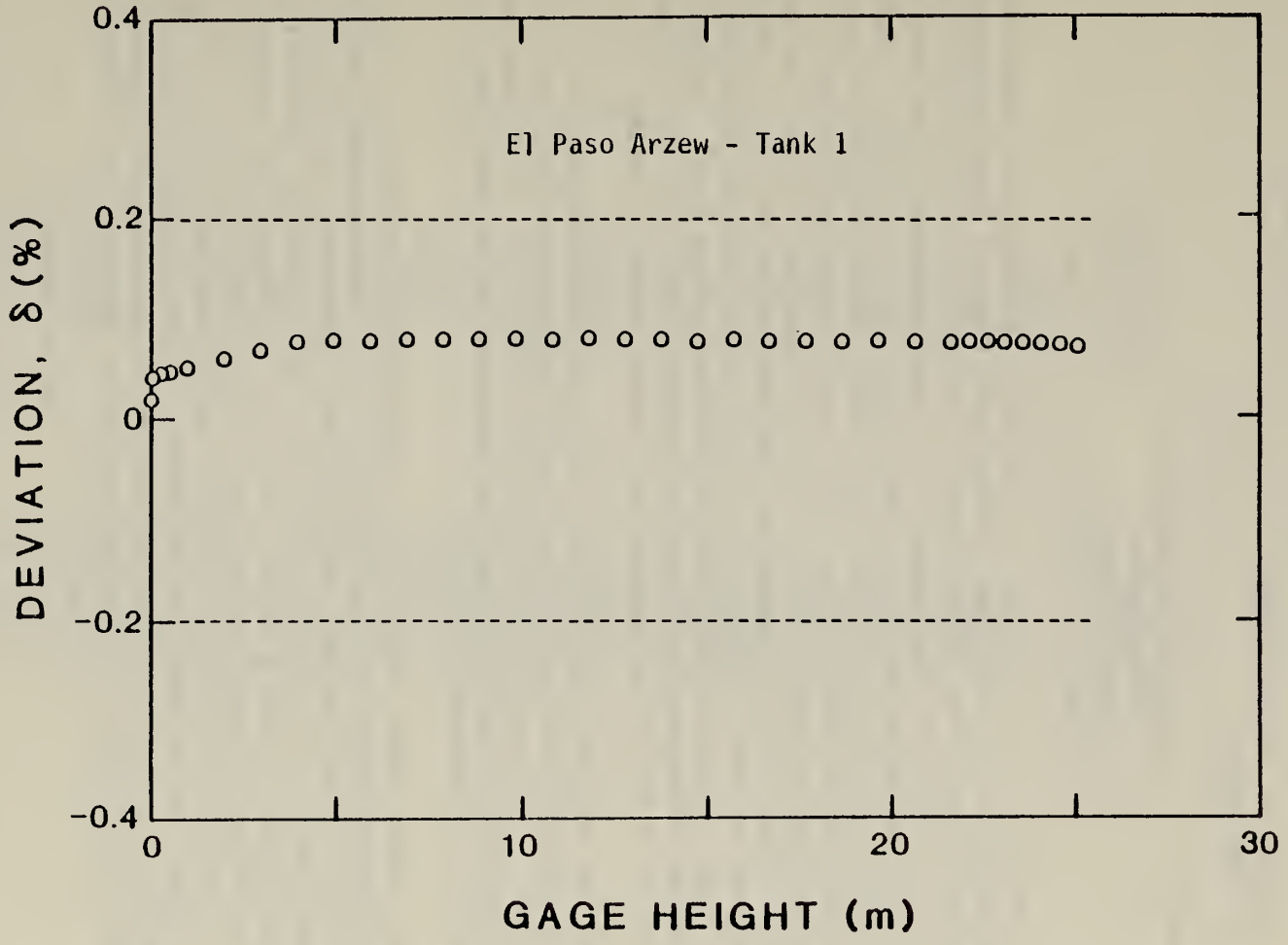
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	2.4
.050	17.8
.100	33.6
.200	65.7
.300	98.3
.400	131.3
.500	164.8
1.000	339.3
2.000	723.9
3.000	1155.8
4.000	1634.9
5.000	2144.2
6.000	2654.1
7.000	3164.0
8.000	3673.8
9.000	4183.7
10.000	4693.6
11.000	5203.4
12.000	5713.3
13.000	6223.1
14.000	6732.9
15.000	7242.7
16.000	7752.6
17.000	8262.4
18.000	8772.2
19.000	9282.0
20.000	9791.8
21.000	10301.6
22.000	10811.4
22.500	11066.3
23.000	11321.2
23.500	11576.1
24.000	11825.9
24.500	12064.1
25.000	12290.4
25.500	12504.9

EL PASO ARZEW TANK NO. 1

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	63.3	42.0	21.1	0.0	-21.9	-23.6	-24.5	-25.1	-25.6	-26.0
.100	63.2	42.2	21.1	.2	-40.8	-54.5	-60.6	-64.2	-66.5	-68.2
.200	63.1	42.1	21.0	.1	-41.9	-62.9	-83.8	-102.2	-116.0	-125.1
.500	63.2	42.1	21.2	0.0	-41.9	-62.9	-84.0	-104.9	-125.7	-146.5
1.000	63.2	42.1	21.0	.1	-41.9	-63.0	-83.9	-104.8	-125.7	-146.6
5.000	63.1	42.1	21.1	.1	-42.0	-63.0	-84.0	-105.0	-126.0	-147.0
10.000	63.1	41.9	20.9	-.1	-42.1	-63.1	-84.1	-105.1	-126.1	-147.1
15.000	63.1	42.1	21.1	.1	-42.1	-63.1	-84.1	-105.1	-126.1	-147.1
20.000	63.0	42.0	21.0	0.0	-42.0	-63.0	-84.0	-105.0	-126.0	-147.0
23.000	63.1	41.9	20.9	-.1	-42.1	-63.1	-84.1	-105.1	-126.1	-147.1
25.000	63.0	41.9	21.0	0.0	-42.0	-63.0	-84.1	-105.2	-126.3	-147.3

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	LIST TO STARBOARD (DEGREES) 0.0	+0.5	+1.0	+1.5	+2.0
.050	44.8	30.7	17.2	5.5	0.0	6.4	18.7	32.7	47.5
.100	26.3	13.9	3.8	-.1	.2	1.0	5.7	16.4	29.4
.200	5.0	1.1	0.0	-.2	.1	.9	2.2	4.2	8.9
.500	2.1	.8	-.1	-.3	0.0	.8	2.1	4.0	6.5
1.000	2.5	1.1	.2	-.1	.1	1.0	2.3	4.3	6.8
5.000	-2.2	-1.6	-1.1	-.5	.1	.6	1.2	1.8	2.3
10.000	-2.4	-1.8	-1.2	-.7	-.1	.5	1.1	1.6	2.2
15.000	-2.2	-1.6	-1.1	-.5	.1	.7	1.2	1.8	2.4
20.000	-2.3	-1.7	-1.2	-.6	0.0	.6	1.2	1.7	2.3
23.000	-2.4	-1.8	-1.2	-.7	-.1	.5	1.1	1.7	2.2
25.000	-8.1	-5.0	-2.6	-1.0	0.0	.2	-.3	-1.5	-3.4



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-45)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #2 on the LNG Tanker
El Paso Arzew

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 2 of the liquefied natural gas tanker El Paso Arzew while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 23.5°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 24885.3 m^3 with an uncertainty of 12.4 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 16, 1979

EL PASO ARZEW

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 2

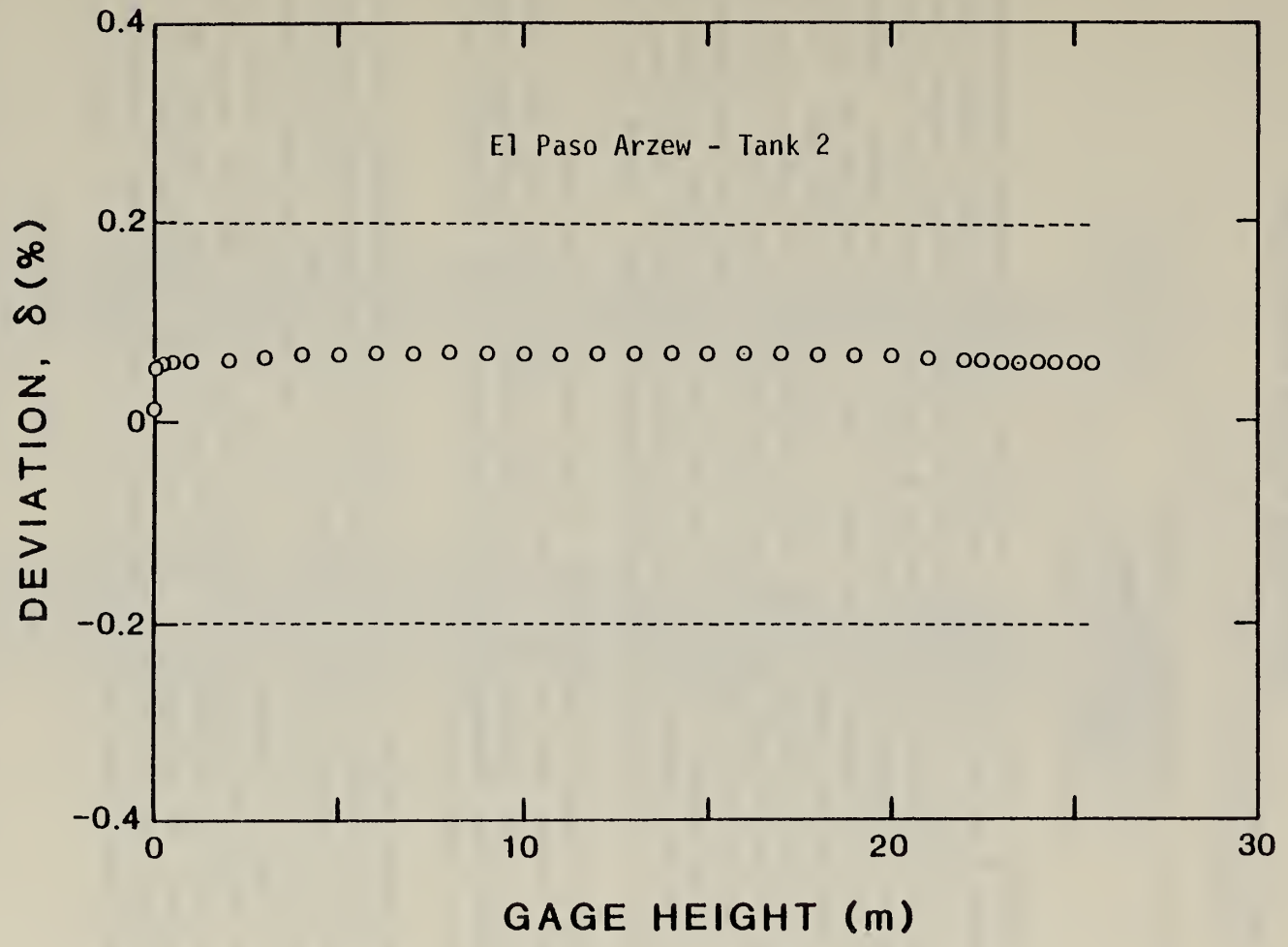
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	6.3
.050	45.3
.100	86.1
.200	168.1
.300	250.8
.400	334.2
.500	418.1
1.000	847.5
2.000	1754.1
3.000	2724.3
4.000	3758.1
5.000	4832.5
6.000	5907.5
7.000	6982.6
8.000	8057.8
9.000	9132.9
10.000	10208.1
11.000	11283.3
12.000	12358.5
13.000	13433.8
14.000	14509.1
15.000	15584.4
16.000	16659.8
17.000	17735.1
18.000	18799.6
19.000	19805.9
20.000	20748.6
21.000	21627.9
22.000	22443.6
22.500	22827.6
23.000	23195.7
23.500	23548.0
24.000	23884.4
24.500	24204.9
25.000	24509.5
25.500	24798.2

EL PASO ARZEW TANK NO. 2

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	+1.0	+1.5	+2.0	+2.5	+3.0	TRIM BY STERN (METERS) +3.5
.050	86.1	57.5	29.0	1.0	-22.9	-23.8	-24.4	-24.9	-25.3	-25.7
.100	85.8	57.2	28.6	0.0	-51.0	-61.4	-65.4	-67.7	-69.3	-70.5
.200	85.8	57.1	28.5	0.0	-57.1	-85.6	-109.7	-124.2	-133.4	-139.9
.500	85.8	57.1	28.6	0.0	-57.1	-85.5	-114.1	-142.5	-171.0	-199.3
1.000	85.7	57.1	28.6	0.0	-57.1	-85.6	-114.0	-142.5	-171.0	-199.4
5.000	85.6	57.1	28.5	0.0	-57.1	-85.7	-114.2	-142.7	-171.2	-199.8
10.000	85.6	57.1	28.5	0.0	-57.1	-85.6	-114.2	-142.7	-171.3	-199.8
15.000	85.6	57.1	28.6	0.0	-57.1	-85.7	-114.2	-142.7	-171.2	-199.8
20.000	85.5	57.0	28.5	0.0	-57.1	-85.6	-114.3	-142.8	-171.5	-200.1
23.000	85.5	57.0	28.5	0.0	-57.1	-85.6	-114.3	-143.0	-171.6	-200.3
25.000	85.4	57.1	28.6	0.0	-57.1	-85.6	-114.2	-143.0	-171.7	-200.4

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	97.5	69.5	42.0	15.9	1.0	19.2	46.6	75.2	104.5
.100	76.1	48.8	23.1	2.8	0.0	5.6	28.0	55.0	83.6
.200	41.6	18.7	2.2	-.6	0.0	1.6	7.0	25.4	49.8
.500	3.5	1.1	-.3	-.6	0.0	1.6	4.3	8.0	12.7
1.000	3.8	1.3	-.2	-.6	0.0	1.6	4.3	8.1	13.0
5.000	-4.4	-3.3	-2.2	-1.1	0.0	1.1	2.2	3.3	4.4
10.000	-4.4	-3.3	-2.2	-1.1	0.0	1.1	2.2	3.3	4.4
15.000	-4.4	-3.3	-2.2	-1.1	0.0	1.1	2.2	3.3	4.4
20.000	-12.8	-8.0	-4.3	-1.6	0.0	.4	-.2	-1.9	-4.7
23.000	-11.0	-6.9	-3.7	-1.4	0.0	.6	.3	-.8	-2.8
25.000	-9.7	-6.2	-3.4	-1.4	0.0	.6	.6	-.2	-1.6



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-45)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #3 on the LNG Tanker
El Paso Arzew

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 3 of the liquefied natural gas tanker El Paso Arzew while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 23.5°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 27646.0 m^3 with an uncertainty of 13.8 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 16, 1979

EL PASO ARZEW

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 3

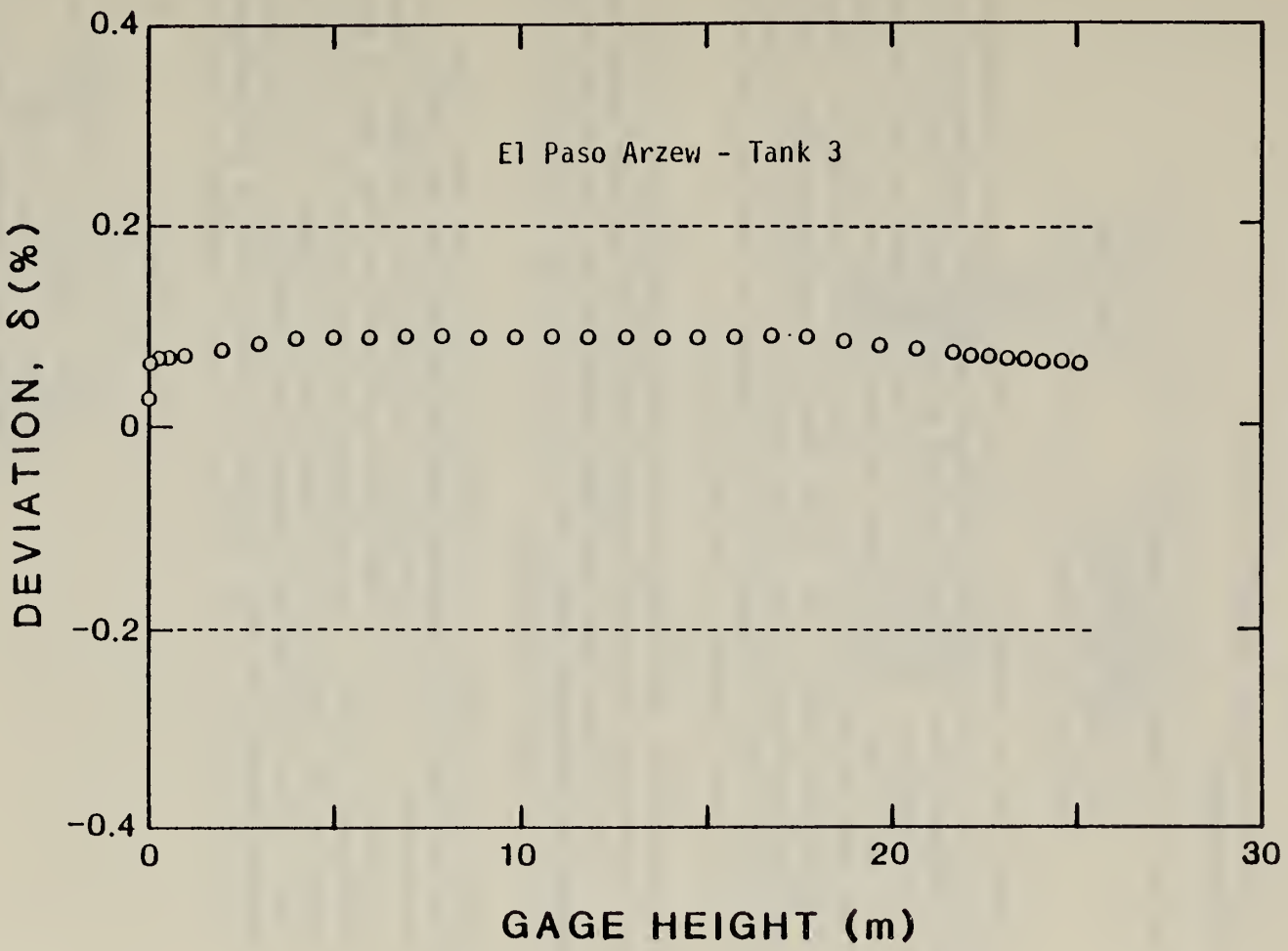
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	13.1
.050	59.3
.100	106.1
.200	200.3
.300	295.1
.400	390.7
.500	486.9
1.000	978.1
2.000	2011.6
3.000	3113.1
4.000	4282.6
5.000	5494.8
6.000	6707.7
7.000	7920.7
8.000	9133.7
9.000	10346.8
10.000	11559.9
11.000	12773.1
12.000	13986.3
13.000	15199.6
14.000	16412.9
15.000	17626.3
16.000	18839.7
17.000	20040.3
18.000	21178.3
19.000	22248.7
20.000	23251.6
21.000	24186.8
22.000	25054.4
22.500	25462.9
23.000	25854.4
23.500	26229.1
24.000	26586.8
24.500	26927.7
25.000	27251.6
25.500	27558.7

EL PASO ARZEW TANK NO. 3

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	91.5	61.0	30.5	0.0	-29.7	-31.1	-31.9	-32.5	-32.9	-33.3
.100	91.4	60.9	30.5	0.0	-55.5	-67.2	-71.8	-74.4	-76.2	-77.5
.200	91.4	60.9	30.5	0.0	-60.8	-91.2	-116.3	-131.1	-140.6	-147.1
.500	91.4	60.9	30.5	0.0	-60.9	-91.2	-121.6	-151.9	-182.3	-212.6
1.000	91.4	61.0	30.4	0.0	-60.8	-91.2	-121.6	-151.9	-182.3	-212.5
5.000	91.3	60.9	30.4	0.0	-60.9	-91.3	-121.8	-152.2	-182.6	-213.0
10.000	91.3	60.9	30.4	0.0	-60.9	-91.3	-121.7	-152.2	-182.6	-213.0
15.000	91.3	60.9	30.4	0.0	-60.9	-91.3	-121.7	-152.2	-182.6	-213.0
20.000	91.1	60.8	30.4	0.0	-60.9	-91.3	-121.8	-152.4	-182.9	-213.4
23.000	91.0	60.8	30.4	0.0	-60.8	-91.4	-121.9	-152.4	-182.9	-213.5
25.000	91.1	60.8	30.4	0.0	-60.8	-91.4	-121.8	-152.4	-183.0	-213.6

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	LIST TO STARBOARD (DEGREES) 0.0	+0.5	+1.0	+1.5	+2.0
.050	102.8	72.6	42.9	14.9	0.0	18.5	47.8	78.6	110.1
.100	81.7	52.1	24.4	2.7	0.0	5.6	29.6	58.5	89.3
.200	47.0	21.8	3.2	-.5	0.0	1.7	8.0	28.6	55.2
.500	4.5	1.7	0.0	-.5	0.0	1.6	4.4	8.2	13.2
1.000	4.8	1.9	.2	-.5	0.0	1.7	4.4	8.3	13.4
5.000	-3.7	-2.8	-1.8	-.9	0.0	.9	1.9	2.8	3.7
10.000	-3.7	-2.8	-1.9	-1.0	0.0	.9	1.9	2.8	3.7
15.000	-3.8	-2.8	-1.9	-.9	0.0	.9	1.9	2.8	3.8
20.000	-12.3	-7.6	-4.0	-1.5	0.0	.3	-.5	-2.3	-5.3
23.000	-10.4	-6.4	-3.4	-1.3	0.0	.5	0.0	-1.2	-3.4
25.000	-9.2	-5.8	-3.2	-1.2	0.0	.5	.3	-.6	-2.2



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-259
(3-68)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF TEST

For: Tank #4 on the LNG Tanker
El Paso Arzew

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 4 of the liquefied natural gas tanker El Paso Arzew while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull.

The tank was measured empty while at an average temperature of 27.3°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

These tables are not based on a complete survey of the tank, since scaffolding necessary for complete interior access was not present at the time of measurement. As a consequence, geometrically redundant cross checks reported of tanks 1, 2, 3, 5, and 6 were not made on this tank to assess random measurement errors. The estimated uncertainty of the tables is instead based on the comparison of measurements on tanks 1, 2, 3, 5, and 6 against their respective nominal construction dimensions. These comparisons showed measured dimensions were in general within 0.2% of the nominals so an estimated uncertainty of $\pm$ 0.2% of total volume is assigned to the tables.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 16, 1979

EL PASO ARZEW

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 4

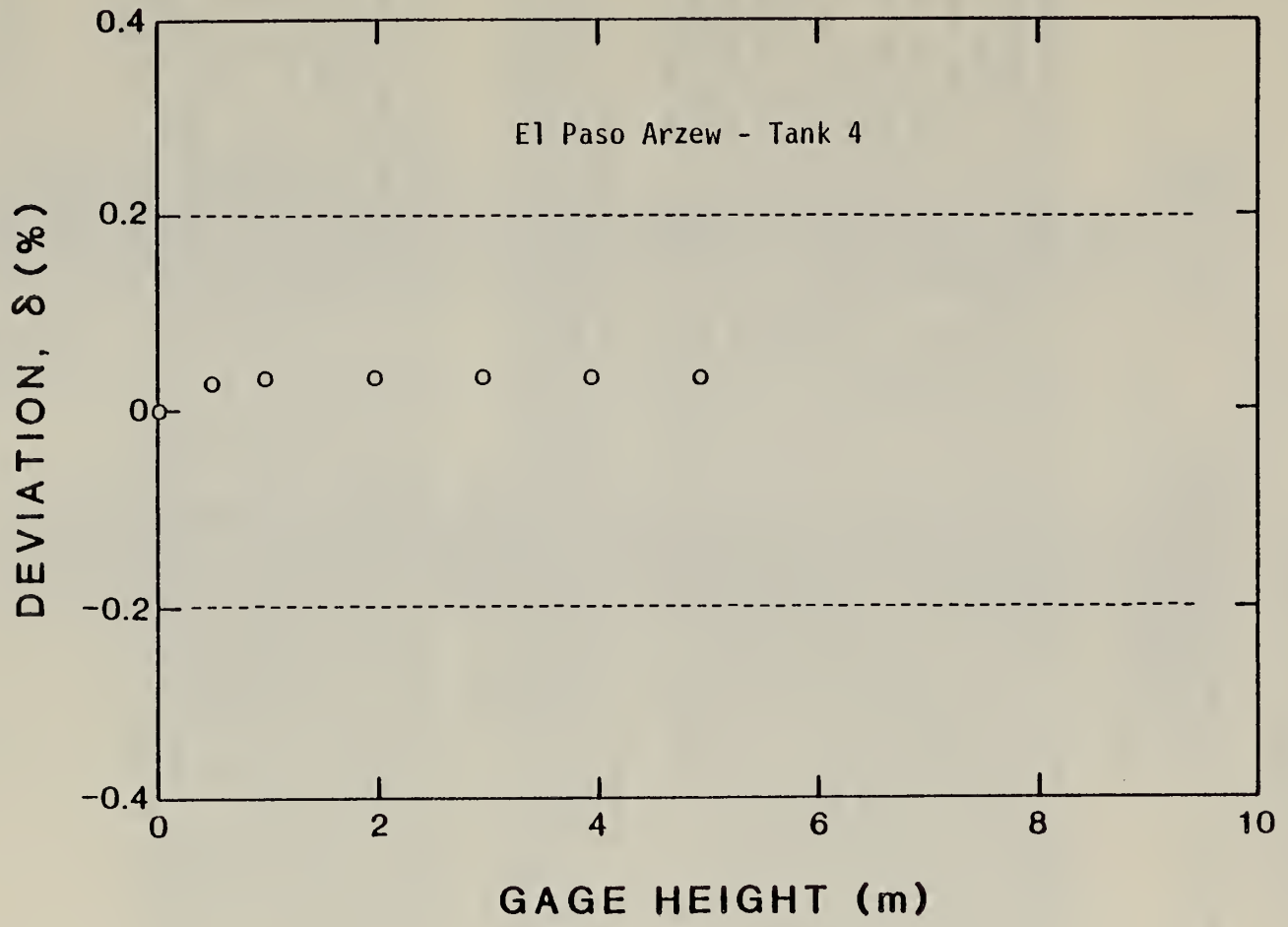
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	.1
.050	11.4
.100	23.7
.200	48.2
.300	72.8
.400	97.3
.500	121.9

EL PASO ARZEW TANK NO. 4

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	29.4	19.7	10.0	.4	-5.5	-11.9	-13.2	-14.1	-14.7	-15.2
.100	29.0	19.4	9.6	-.1	-19.3	-29.0	-34.9	-42.5	-46.7	-49.5
.200	29.1	19.3	9.7	-.1	-19.3	-29.0	-38.8	-48.5	-58.2	-67.9
.500	29.1	19.4	9.6	0.0	-19.5	-29.0	-38.7	-48.5	-58.2	-67.9

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	81.7	59.7	38.1	16.6	.4	17.0	39.9	63.1	86.6
.100	59.4	38.3	18.2	1.7	-.1	3.9	20.9	42.4	65.0
.200	24.5	8.4	-1.9	-1.6	-.1	1.4	3.9	14.5	32.0
.500	-6.0	-4.5	-3.0	-1.5	0.0	1.4	2.9	4.4	5.8



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-45)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #5 on the LNG Tanker
El Paso Arzew

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 5 of the liquefied natural gas tanker El Paso Arzew while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 27.1°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 27622.9 m^3 with an uncertainty of 13.8 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 16, 1979

EL PASO ARZEW

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 5

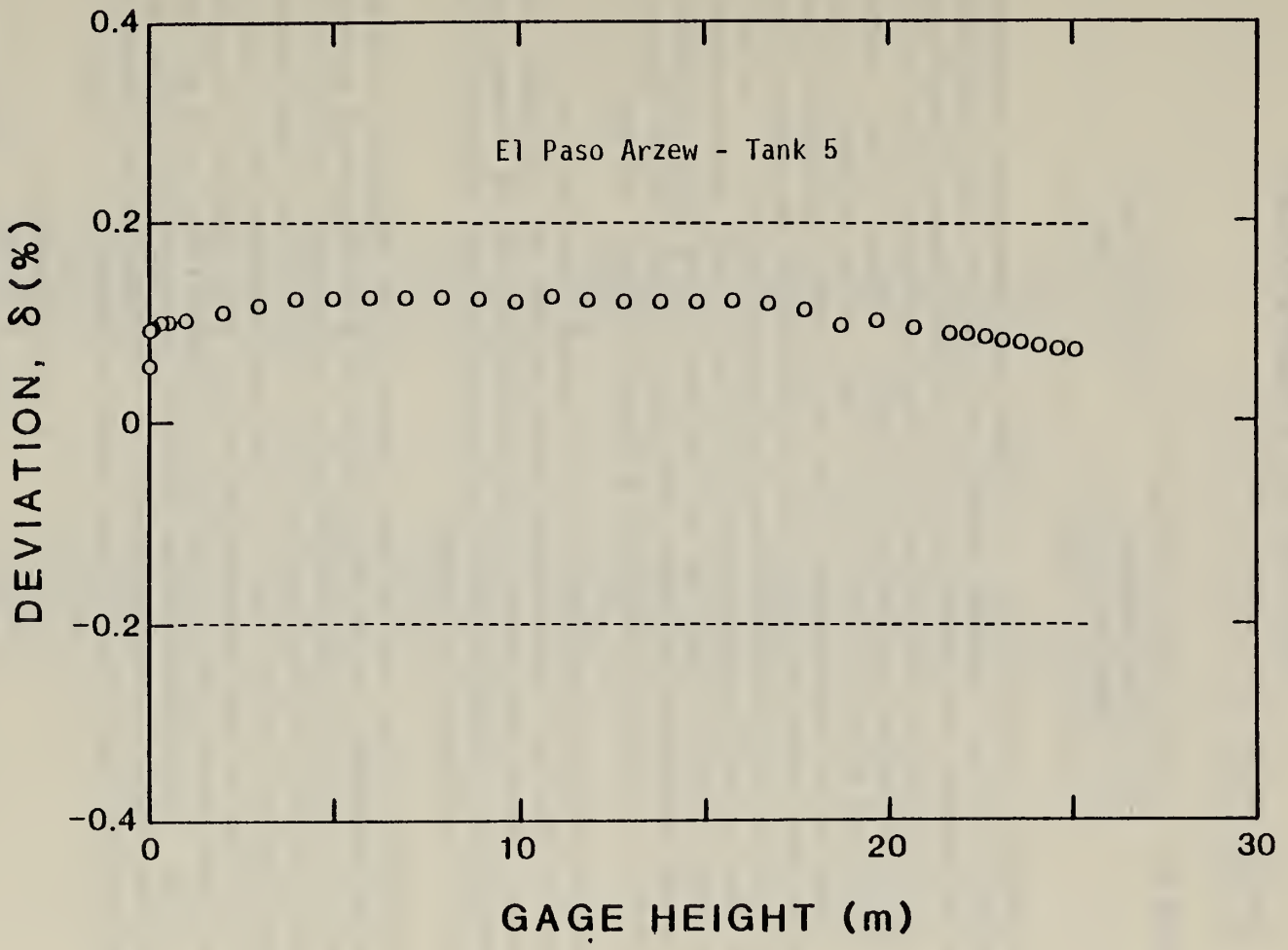
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	14.4
.050	59.7
.100	106.5
.200	200.8
.300	295.7
.400	391.3
.500	487.5
1.000	979.0
2.000	2012.8
3.000	3114.2
4.000	4283.3
5.000	5495.1
6.000	6707.6
7.000	7920.2
8.000	9132.7
9.000	10345.2
10.000	11557.8
11.000	12770.3
12.000	13982.9
13.000	15195.5
14.000	16408.1
15.000	17620.7
16.000	18833.4
17.000	20033.0
18.000	21170.0
19.000	22239.2
20.000	23240.9
21.000	24174.9
22.000	25041.3
22.500	25449.1
23.000	25840.0
23.500	26214.0
24.000	26571.1
24.500	26911.3
25.000	27234.5
25.500	27540.9

EL PASO ARZEW TANK NO. 5

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	+1.0	TRIM BY STERN (METERS) +1.5	+2.0	+2.5	+3.0	+3.5
.050	91.7	61.2	30.9	1.0	-30.7	-31.9	-32.6	-33.1	-33.5	-33.9
.100	91.4	61.0	30.4	0.0	-55.8	-68.5	-73.0	-75.6	-77.3	-78.5
.200	91.4	60.9	30.5	0.0	-60.8	-91.2	-117.0	-132.3	-142.0	-148.5
.500	91.4	60.9	30.5	0.0	-60.8	-91.2	-121.6	-151.9	-182.2	-212.4
1.000	91.4	60.9	30.4	0.0	-60.9	-91.2	-121.5	-151.9	-182.2	-212.5
5.000	91.2	60.8	30.4	0.0	-60.8	-91.2	-121.7	-152.1	-182.5	-212.9
10.000	91.3	60.9	30.4	0.0	-60.8	-91.3	-121.7	-152.1	-182.5	-212.9
15.000	91.2	60.8	30.4	0.0	-60.8	-91.2	-121.6	-152.0	-182.5	-212.9
20.000	91.1	60.8	30.4	0.0	-60.8	-91.3	-121.8	-152.2	-182.8	-213.2
23.000	91.1	60.8	30.4	0.0	-60.9	-91.3	-121.8	-152.3	-182.8	-213.4
25.000	91.0	60.7	30.4	.1	-60.9	-91.3	-121.8	-152.4	-182.9	-213.5

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	100.2	70.0	40.8	13.2	1.0	20.4	50.0	81.0	112.8
.100	78.9	49.7	22.3	1.7	0.0	6.9	31.6	61.1	92.0
.200	44.3	19.6	1.7	-1.0	0.0	2.1	9.6	31.0	58.0
.500	2.5	.2	-1.0	-1.0	0.0	2.1	5.3	9.6	15.2
1.000	2.7	.4	-.9	-1.0	0.0	2.2	5.4	9.9	15.4
5.000	-5.8	-4.3	-2.9	-1.5	0.0	1.4	2.9	4.3	5.8
10.000	-5.7	-4.3	-2.9	-1.4	0.0	1.4	2.8	4.3	5.7
15.000	-5.6	-4.2	-2.8	-1.4	0.0	1.4	2.8	4.2	5.6
20.000	-14.0	-8.9	-4.8	-1.9	0.0	.7	.4	-1.0	-3.5
23.000	-12.2	-7.8	-4.4	-1.8	0.0	.9	.9	.1	-1.6
25.000	-11.0	-7.1	-4.0	-1.6	.1	1.1	1.3	.9	-.2



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 11-45)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #6 on the LNG Tanker
El Paso Arzew

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 6 of the liquefied natural gas tanker El Paso Arzew while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 29.0°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 27639.1 m^3 with an uncertainty of 13.8 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: August 16, 1979

EL PASO ARZEW

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 6

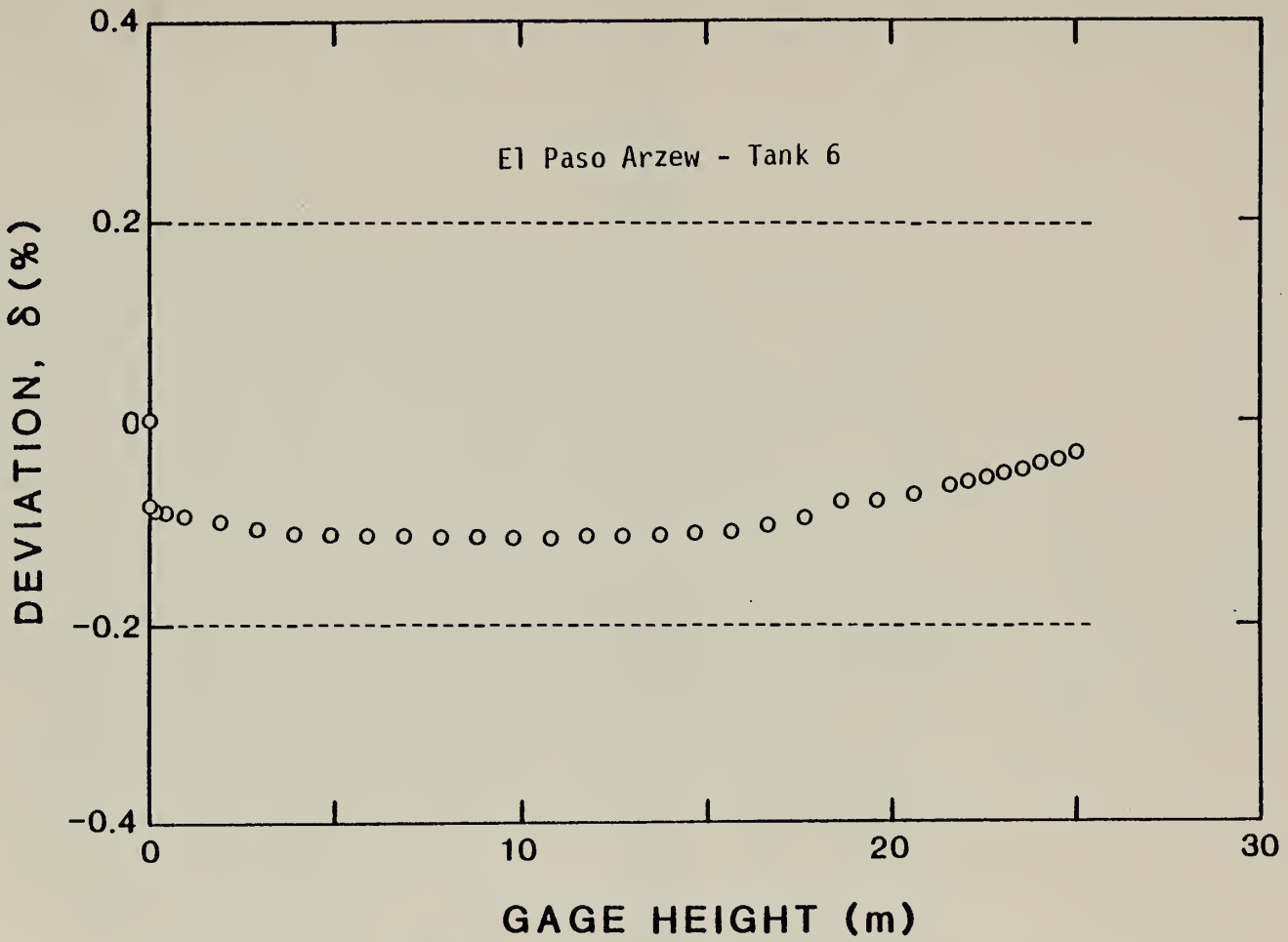
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	0.0
.050	12.6
.100	55.6
.200	149.4
.300	243.9
.400	339.1
.500	435.0
1.000	924.6
2.000	1954.4
3.000	3052.0
4.000	4217.4
5.000	5428.6
6.000	6641.1
7.000	7853.7
8.000	9066.3
9.000	10279.0
10.000	11491.8
11.000	12704.6
12.000	13917.5
13.000	15130.5
14.000	16343.5
15.000	17556.6
16.000	18769.7
17.000	19972.2
18.000	21113.4
19.000	22187.1
20.000	23193.2
21.000	24131.7
22.000	25002.6
22.500	25412.7
23.000	25805.9
23.500	26182.2
24.000	26541.6
24.500	26884.1
25.000	27209.6
25.500	27518.3

EL PASO ARZEW TANK NO. 6

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	91.9	62.0	38.2	23.7	21.6	21.1	20.7	20.3	19.9	19.5
.100	91.3	60.8	30.5	2.7	-18.3	-21.1	-22.9	-24.2	-25.2	-26.1
.200	91.3	60.8	30.4	0.0	-58.0	-75.8	-86.4	-93.5	-98.6	-102.6
.500	91.3	60.8	30.4	0.0	-60.7	-91.1	-121.4	-151.7	-182.0	-211.0
1.000	91.3	60.9	30.4	0.0	-60.7	-91.1	-121.5	-151.8	-182.0	-212.2
5.000	91.2	60.8	30.4	0.0	-60.8	-91.2	-121.6	-152.1	-182.5	-212.9
10.000	91.2	60.8	30.4	0.0	-60.8	-91.2	-121.6	-152.1	-182.5	-212.9
15.000	91.2	60.8	30.4	0.0	-60.8	-91.2	-121.6	-152.0	-182.4	-212.8
20.000	91.2	60.8	30.4	0.0	-60.9	-91.4	-121.9	-152.4	-182.9	-213.5
23.000	91.1	60.8	30.4	0.0	-60.9	-91.4	-121.9	-152.5	-183.0	-213.6
25.000	91.1	60.8	30.4	0.0	-60.9	-91.5	-122.0	-152.5	-183.1	-213.8

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	134.3	103.8	74.1	45.3	23.7	39.6	68.7	99.2	130.4
.100	110.3	79.7	49.8	21.2	2.7	15.9	44.8	75.3	106.7
.200	69.8	41.4	16.2	.7	0.0	1.4	13.7	38.6	67.3
.500	7.9	2.7	.7	-.2	0.0	1.3	3.6	7.0	12.3
1.000	6.1	2.9	.8	-.2	0.0	1.3	3.7	7.3	11.9
5.000	-3.3	-2.4	-1.6	-.8	0.0	.8	1.6	2.5	3.3
10.000	-3.3	-2.5	-1.7	-.8	0.0	.8	1.7	2.5	3.3
15.000	-3.4	-2.5	-1.7	-.9	0.0	.8	1.7	2.5	3.4
20.000	-12.5	-7.7	-4.1	-1.5	0.0	.4	-.3	-2.1	-5.0
23.000	-10.6	-6.6	-3.6	-1.4	0.0	.4	0.0	-1.3	-3.4
25.000	-9.2	-5.8	-3.1	-1.2	0.0	.5	.3	-.6	-2.2



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

Appendix C

Calibration Reports for the Six Tanks of the El Paso Howard Boyd

FORM NBS-443
(REV. 12-65)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #1 on the LNG Tanker
El Paso Howard Boyd

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 1 of the liquefied natural gas tanker El Paso Howard Boyd while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 22.6°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 12554.3 m^3 with an uncertainty of 6.3 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: September 14, 1979

EL PASO HOWARD BOYD

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 1

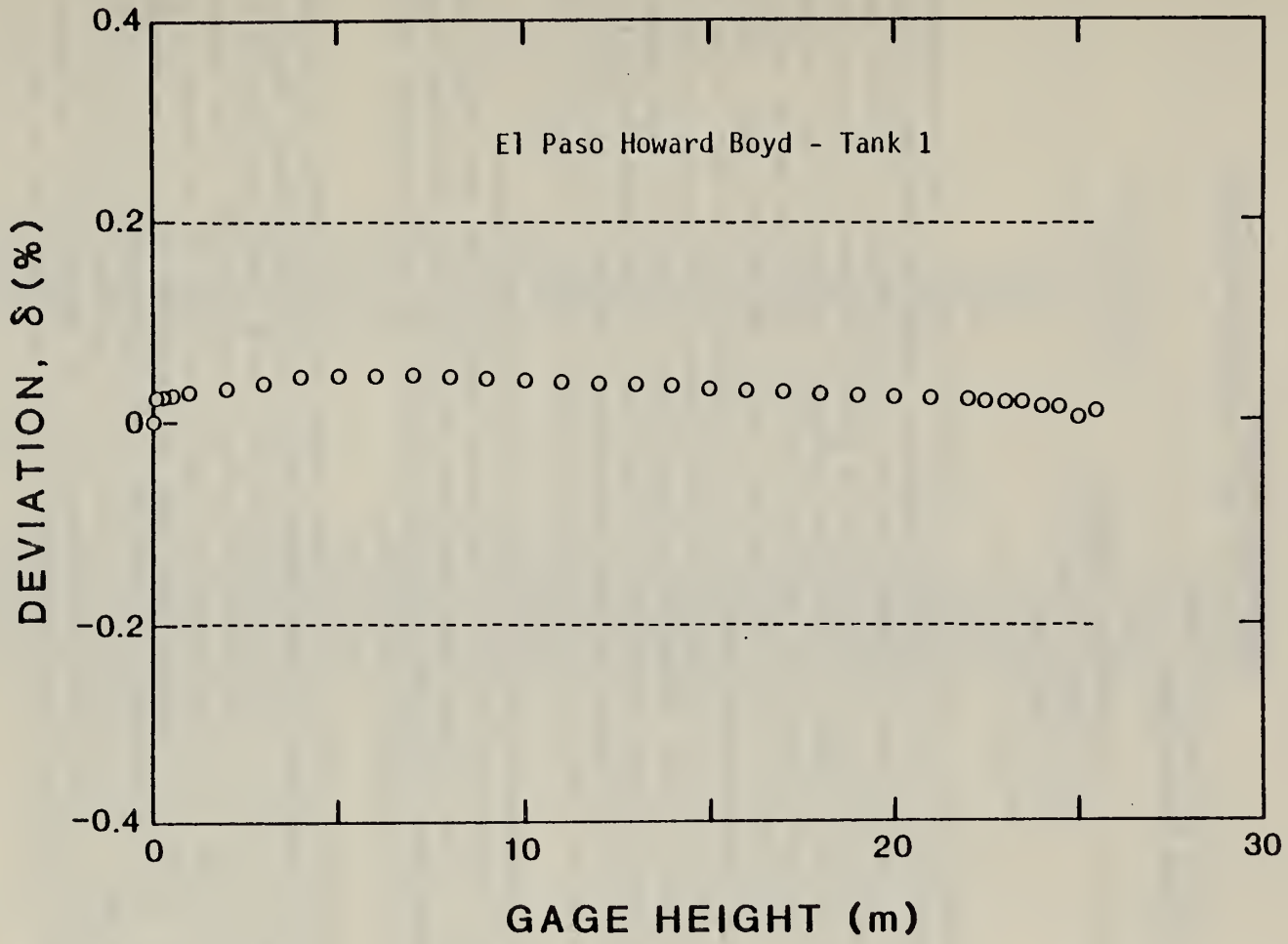
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	.5
.050	15.6
.100	31.4
.200	63.4
.300	95.9
.400	128.8
.500	162.3
1.000	336.5
2.000	720.3
3.000	1151.4
4.000	1629.7
5.000	2138.6
6.000	2648.1
7.000	3157.6
8.000	3667.1
9.000	4176.5
10.000	4686.0
11.000	5195.4
12.000	5704.8
13.000	6214.2
14.000	6723.6
15.000	7233.0
16.000	7742.4
17.000	8251.8
18.000	8761.1
19.000	9270.4
20.000	9779.7
21.000	10289.1
22.000	10798.3
22.500	11053.0
23.000	11307.6
23.500	11562.3
24.000	11811.9
24.500	12049.8
25.000	12275.8
25.500	12490.0

EL PASO HOWARD BOYD TANK NO. 1

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	+1.0	+1.5	+2.0	+2.5	+3.0	TRIM BY STERN (METERS) +3.5
.050	63.3	42.0	20.9	.1	-16.8	-18.1	-18.9	-19.4	-19.9	-20.3
.100	63.2	42.1	21.1	-.1	-38.5	-50.9	-56.2	-59.3	-61.4	-62.9
.200	63.1	42.1	21.1	-.1	-41.9	-62.9	-83.6	-101.3	-113.1	-121.5
.500	63.2	42.2	21.0	.1	-41.9	-62.9	-83.9	-104.7	-125.7	-146.5
1.000	63.0	42.1	21.0	-.1	-42.0	-62.9	-83.8	-104.8	-125.6	-146.6
5.000	63.1	42.1	20.9	-.1	-42.0	-63.0	-84.0	-104.9	-125.9	-146.9
10.000	63.0	42.0	21.1	.1	-42.1	-63.0	-84.0	-105.0	-126.0	-146.9
15.000	63.0	41.9	21.0	0.0	-42.0	-62.9	-83.9	-105.1	-126.1	-147.0
20.000	62.9	42.0	21.0	0.0	-41.9	-63.1	-84.1	-105.0	-126.0	-147.0
23.000	63.1	41.9	20.9	0.0	-42.0	-62.9	-83.9	-105.1	-126.1	-147.0
25.000	62.9	41.9	20.9	0.0	-42.0	-63.1	-84.1	-105.2	-126.3	-147.4

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	47.4	33.3	19.3	6.9	.1	7.7	20.6	34.8	49.3
.100	28.6	15.7	4.9	-.1	-.1	.6	6.2	17.5	30.7
.200	6.4	1.8	.4	-.1	-.1	.5	1.6	3.6	8.8
.500	3.2	1.7	.6	.1	.1	.7	1.8	3.4	5.6
1.000	3.4	1.7	.5	-.1	-.1	.5	1.7	3.4	5.7
5.000	-.9	-.7	-.5	-.3	-.1	.1	.3	.5	.7
10.000	-.7	-.5	-.3	-.1	.1	.3	.5	.7	.9
15.000	-.8	-.6	-.4	-.2	0.0	.2	.4	.6	.8
20.000	-.8	-.6	-.4	-.2	0.0	.2	.4	.6	.8
23.000	-.8	-.6	-.4	-.2	0.0	.2	.4	.6	.8
25.000	-6.6	-3.9	-1.9	-.6	0.0	-.2	-1.0	-2.6	-4.9



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-45)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #2 on the LNG Tanker
El Paso Howard Boyd

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 2 of the liquefied natural gas tanker El Paso Howard Boyd while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 15.2°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 24844.4 m^3 with an uncertainty of 12.4 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: September 14, 1979

EL PASO HOWARD BOYD

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 2

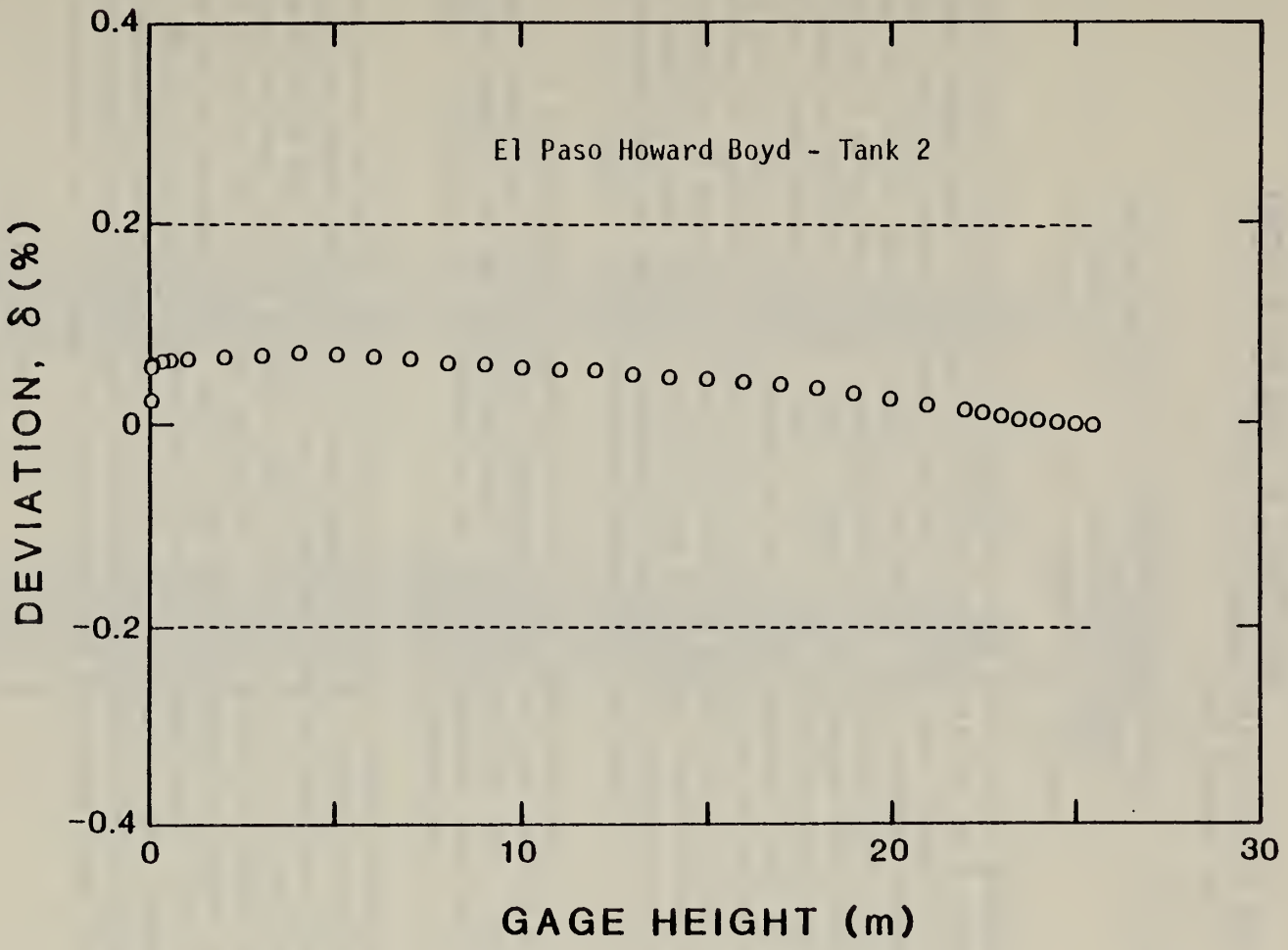
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	5.7
.050	45.6
.100	86.4
.200	168.3
.300	250.9
.400	334.1
.500	417.9
1.000	846.7
2.000	1751.9
3.000	2720.5
4.000	3752.7
5.000	4825.8
6.000	5899.7
7.000	6973.6
8.000	8047.4
9.000	9121.3
10.000	10195.1
11.000	11269.0
12.000	12342.9
13.000	13416.7
14.000	14490.6
15.000	15564.5
16.000	16638.3
17.000	17712.2
18.000	18774.9
19.000	19779.5
20.000	20720.5
21.000	21598.0
22.000	22412.1
22.500	22795.3
23.000	23162.6
23.500	23514.0
24.000	23849.6
24.500	24169.3
25.000	24473.1
25.500	24761.0

EL PASO HOWARD BOYD TANK NO. 2

GAGE CORRECTION IN MILLIMETERS

	TRIM BY BOW (METERS)				TRIM BY STERN (METERS)					
GAGE HEIGHT (METERS)	-1.5	-1.0	-0.5	0.0	+1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	85.7	57.1	28.5	0.0	-24.2	-25.5	-26.2	-26.8	-27.2	-27.7
.100	85.7	57.1	28.5	0.0	-51.3	-61.6	-66.0	-68.6	-70.3	-71.7
.200	85.7	57.1	28.6	0.0	-57.0	-85.5	-109.4	-124.0	-133.4	-140.1
.500	85.7	57.1	28.6	0.0	-57.0	-85.5	-114.0	-142.3	-170.8	-199.2
1.000	85.6	57.1	28.6	0.0	-57.0	-85.5	-113.9	-142.4	-170.8	-199.2
5.000	85.5	57.1	28.5	0.0	-57.1	-85.6	-114.1	-142.6	-171.1	-199.6
10.000	85.5	57.0	28.6	0.0	-57.0	-85.6	-114.1	-142.6	-171.2	-199.6
15.000	85.6	57.0	28.5	0.0	-57.0	-85.5	-114.1	-142.6	-171.1	-199.7
20.000	85.5	57.0	28.5	0.0	-57.0	-85.6	-114.2	-142.7	-171.4	-200.0
23.000	85.4	56.9	28.5	.1	-57.0	-85.6	-114.2	-142.8	-171.4	-200.1
25.000	85.4	57.0	28.4	0.0	-57.1	-85.6	-114.3	-142.9	-171.5	-200.2

	LIST TO PORT (DEGREES)					LIST TO STARBOARD (DEGREES)			
GAGE HEIGHT (METERS)	-2.0	-1.5	-1.0	-0.5	0.0	+0.5	+1.0	+1.5	+2.0
.050	98.5	70.2	42.5	16.0	0.0	17.2	44.2	72.5	101.3
.100	77.3	49.7	23.8	3.1	0.0	4.3	25.7	52.2	80.3
.200	43.3	20.1	3.3	0.0	0.0	1.0	5.3	22.9	46.7
.500	6.0	3.0	1.0	0.0	0.0	1.0	3.0	6.0	10.1
1.000	6.4	3.2	1.1	0.0	0.0	1.0	3.1	6.3	10.4
5.000	-2.0	-1.5	-1.0	-.5	0.0	.5	1.0	1.5	2.0
10.000	-2.0	-1.5	-1.0	-.5	0.0	.5	1.0	1.5	2.0
15.000	-2.0	-1.5	-1.0	-.5	0.0	.5	1.0	1.5	2.1
20.000	-10.7	-6.4	-3.2	-1.1	0.0	-.1	-1.2	-3.5	-6.8
23.000	-8.9	-5.3	-2.7	-.9	.1	.1	-.7	-2.3	-4.9
25.000	-7.6	-4.6	-2.3	-.8	0.0	.2	-.4	-1.6	-3.6



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-45)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #3 on the LNG Tanker
El Paso Howard Boyd

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 3 of the liquefied natural gas tanker El Paso Howard Boyd while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 15.0°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 27615.6 m^3 with an uncertainty of 13.8 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: September 14, 1979

EL PASO HOWARD BOYD

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 3

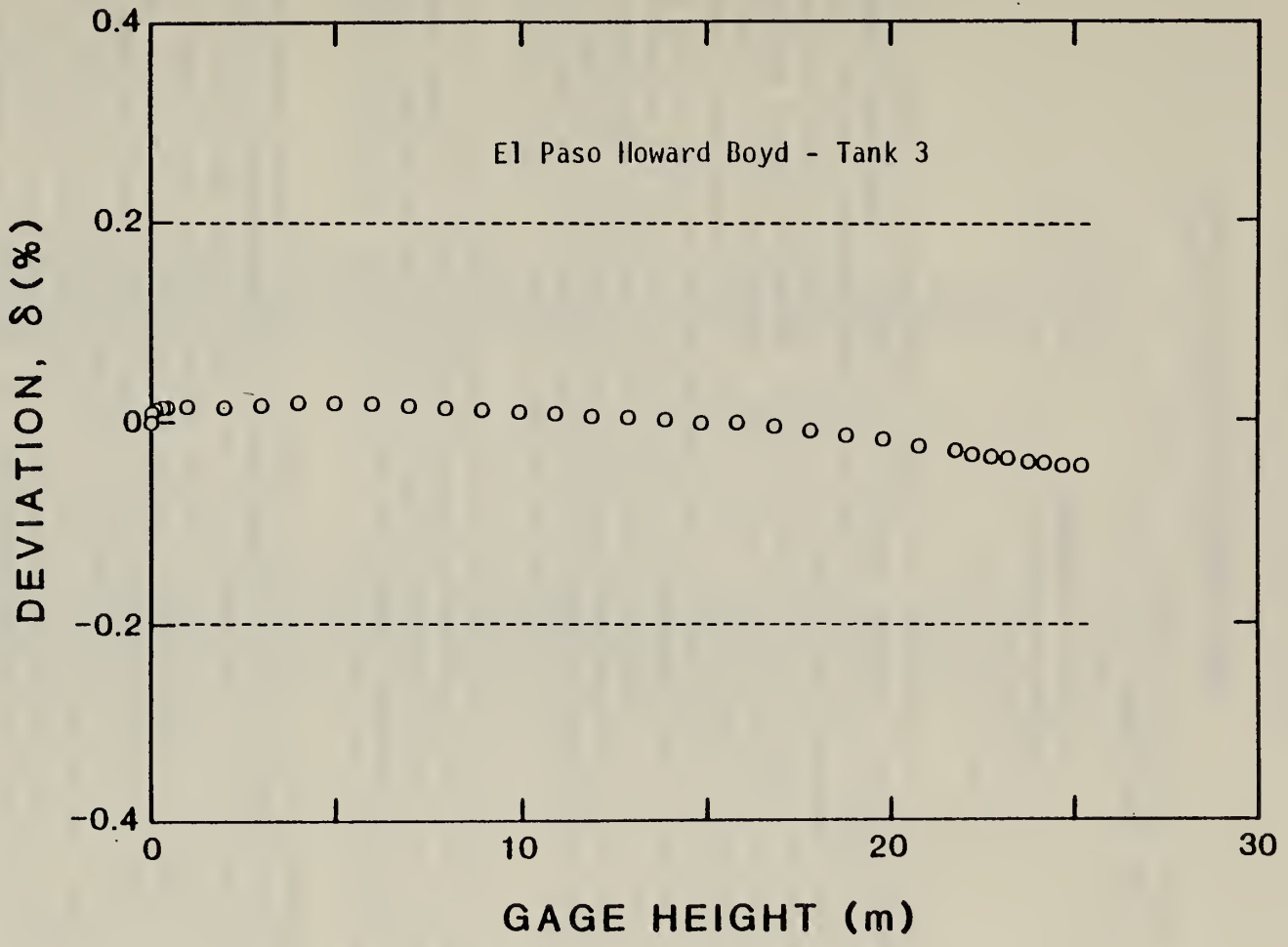
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	.1
.050	40.2
.100	87.0
.200	181.0
.300	275.8
.400	371.2
.500	467.3
1.000	957.9
2.000	1989.7
3.000	3089.2
4.000	4256.2
5.000	5467.6
6.000	6680.1
7.000	7892.5
8.000	9104.9
9.000	10317.3
10.000	11529.7
11.000	12742.1
12.000	13954.5
13.000	15166.9
14.000	16379.3
15.000	17591.7
16.000	18804.1
17.000	20004.3
18.000	21142.3
19.000	22212.6
20.000	23215.3
21.000	24150.3
22.000	25017.7
22.500	25426.0
23.000	25817.4
23.500	26191.9
24.000	26549.5
24.500	26890.2
25.000	27213.9
25.500	27520.8

EL PASO HOWARD BOYD TANK NO. 3

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	91.8	61.5	31.4	4.5	-11.2	-11.8	-12.2	-12.6	-13.0	-13.3
.100	91.4	60.9	30.4	0.0	-46.5	-52.2	-55.0	-56.7	-58.0	-58.9
.200	91.3	60.9	30.4	0.0	-60.8	-89.1	-108.6	-119.7	-127.0	-132.3
.500	91.3	60.9	30.4	0.0	-60.8	-91.1	-121.5	-151.8	-182.1	-212.4
1.000	91.4	60.9	30.4	0.0	-60.8	-91.2	-121.5	-151.9	-182.2	-212.4
5.000	91.3	60.8	30.4	0.0	-60.8	-91.3	-121.7	-152.1	-182.6	-213.0
10.000	91.3	60.9	30.4	0.0	-60.8	-91.3	-121.7	-152.1	-182.5	-213.0
15.000	91.3	60.8	30.4	0.0	-60.9	-91.3	-121.7	-152.1	-182.5	-212.9
20.000	91.1	60.8	30.4	0.0	-60.8	-91.3	-121.8	-152.4	-182.9	-213.4
23.000	91.1	60.8	30.4	0.0	-60.9	-91.3	-121.9	-152.4	-182.9	-213.6
25.000	91.0	60.8	30.4	0.0	-60.9	-91.3	-121.9	-152.5	-183.0	-213.7

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	115.3	84.6	54.6	25.3	4.5	24.1	54.1	85.0	116.4
.100	93.0	62.8	33.8	8.0	0.0	7.6	33.8	63.5	94.5
.200	56.1	29.3	7.5	-.3	0.0	1.3	9.0	31.1	58.6
.500	5.9	2.5	.6	-.2	0.0	1.3	3.7	7.2	12.1
1.000	5.8	2.6	.6	-.3	0.0	1.3	3.8	7.4	12.1
5.000	-3.5	-2.6	-1.7	-.9	0.0	.9	1.7	2.6	3.5
10.000	-3.5	-2.6	-1.7	-.9	0.0	.8	1.7	2.6	3.4
15.000	-3.4	-2.6	-1.7	-.8	0.0	.9	1.7	2.6	3.4
20.000	-12.2	-7.5	-3.9	-1.4	0.0	.3	-.4	-2.3	-5.2
23.000	-10.4	-6.5	-3.4	-1.3	0.0	.5	.1	-1.2	-3.3
25.000	-9.2	-5.8	-3.2	-1.2	0.0	.5	.3	-.6	-2.2



δ = 100*(NBS Vol. - Calib Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-45)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #4 on the LNG Tanker
El Paso Howard Boyd

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 4 of the liquefied natural gas tanker El Paso Howard Boyd while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 25.8°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 6249.3 m^3 with an uncertainty of 3.1 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: September 14, 1979

EL PASO HOWARD BOYD

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 4

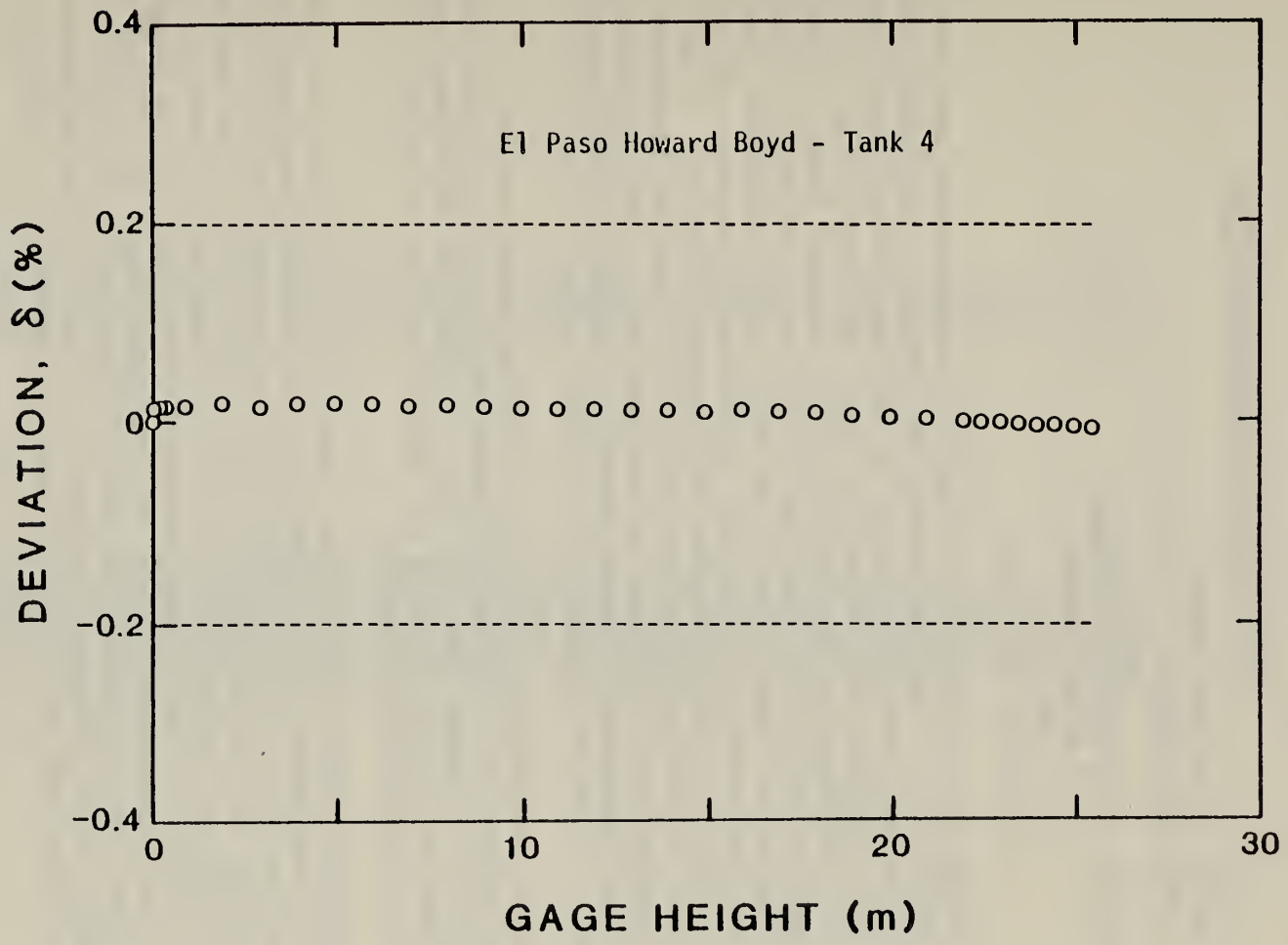
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	.1
.050	10.2
.100	22.5
.200	47.0
.300	71.6
.400	96.2
.500	120.7
1.000	243.5
2.000	489.2
3.000	734.8
4.000	980.4
5.000	1226.0
6.000	1471.6
7.000	1717.2
8.000	1962.7
9.000	2208.3
10.000	2453.9
11.000	2699.4
12.000	2945.0
13.000	3190.5
14.000	3436.1
15.000	3681.6
16.000	3927.2
17.000	4172.7
18.000	4418.2
19.000	4663.7
20.000	4909.2
21.000	5154.7
22.000	5400.2
22.500	5522.9
23.000	5645.7
23.500	5768.4
24.000	5888.8
24.500	6003.6
25.000	6112.7
25.500	6216.0

EL PASO HOWARD BOYD TANK NO. 4

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	30.0	20.4	11.5	6.4	-5.2	-8.0	-9.0	-9.7	-10.2	-10.7
.100	29.1	19.3	9.7	-.1	-19.3	-27.1	-33.9	-40.0	-43.5	-46.1
.200	29.1	19.4	9.6	0.0	-19.4	-29.0	-38.7	-48.4	-58.1	-67.8
.500	29.0	19.4	9.6	0.0	-19.3	-29.0	-38.7	-48.4	-58.2	-67.9
1.000	29.1	19.5	9.6	0.0	-19.4	-28.9	-38.7	-48.4	-58.1	-67.8
5.000	29.1	19.3	9.7	-.1	-19.3	-29.0	-38.7	-48.4	-58.1	-67.8
10.000	29.2	19.3	9.7	-.1	-19.5	-29.1	-38.7	-48.4	-58.1	-67.8
15.000	29.0	19.4	9.6	0.0	-19.4	-29.0	-38.7	-48.4	-58.1	-67.8
20.000	28.9	19.3	9.8	0.0	-19.4	-29.0	-38.8	-48.5	-58.2	-67.9
23.000	29.1	19.3	9.7	-.1	-19.2	-29.0	-38.7	-48.4	-58.1	-67.8
25.000	29.1	19.3	9.5	.1	-19.4	-29.2	-38.8	-48.5	-58.4	-68.0

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	80.8	58.8	36.8	15.3	6.4	21.9	44.8	68.2	91.8
.100	58.2	36.9	16.7	1.3	-.1	6.1	25.2	47.2	70.0
.200	23.3	7.2	-1.7	-1.4	0.0	1.4	4.3	17.6	35.8
.500	-5.6	-4.2	-2.8	-1.4	0.0	1.3	2.7	4.1	5.5
1.000	-5.6	-4.2	-2.8	-1.4	0.0	1.4	2.8	4.2	5.6
5.000	-5.8	-4.4	-3.0	-1.5	-.1	1.3	2.8	4.2	5.7
10.000	-5.8	-4.4	-3.0	-1.5	-.1	1.4	2.8	4.3	5.7
15.000	-5.7	-4.2	-2.8	-1.4	0.0	1.4	2.8	4.2	5.6
20.000	-5.7	-4.3	-2.9	-1.4	0.0	1.5	2.9	4.4	5.9
23.000	-5.8	-4.4	-3.0	-1.6	-.1	1.4	2.8	4.3	5.7
25.000	-11.2	-7.2	-4.0	-1.6	.1	1.1	1.4	1.0	-.1



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-45)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #5 on the LNG Tanker
El Paso Howard Boyd

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 5 of the liquefied natural gas tanker El Paso Howard Boyd while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 22.2°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 27637.4 m^3 with an uncertainty of 13.8 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: September 14, 1979

EL PASO HOWARD BOYD

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 5

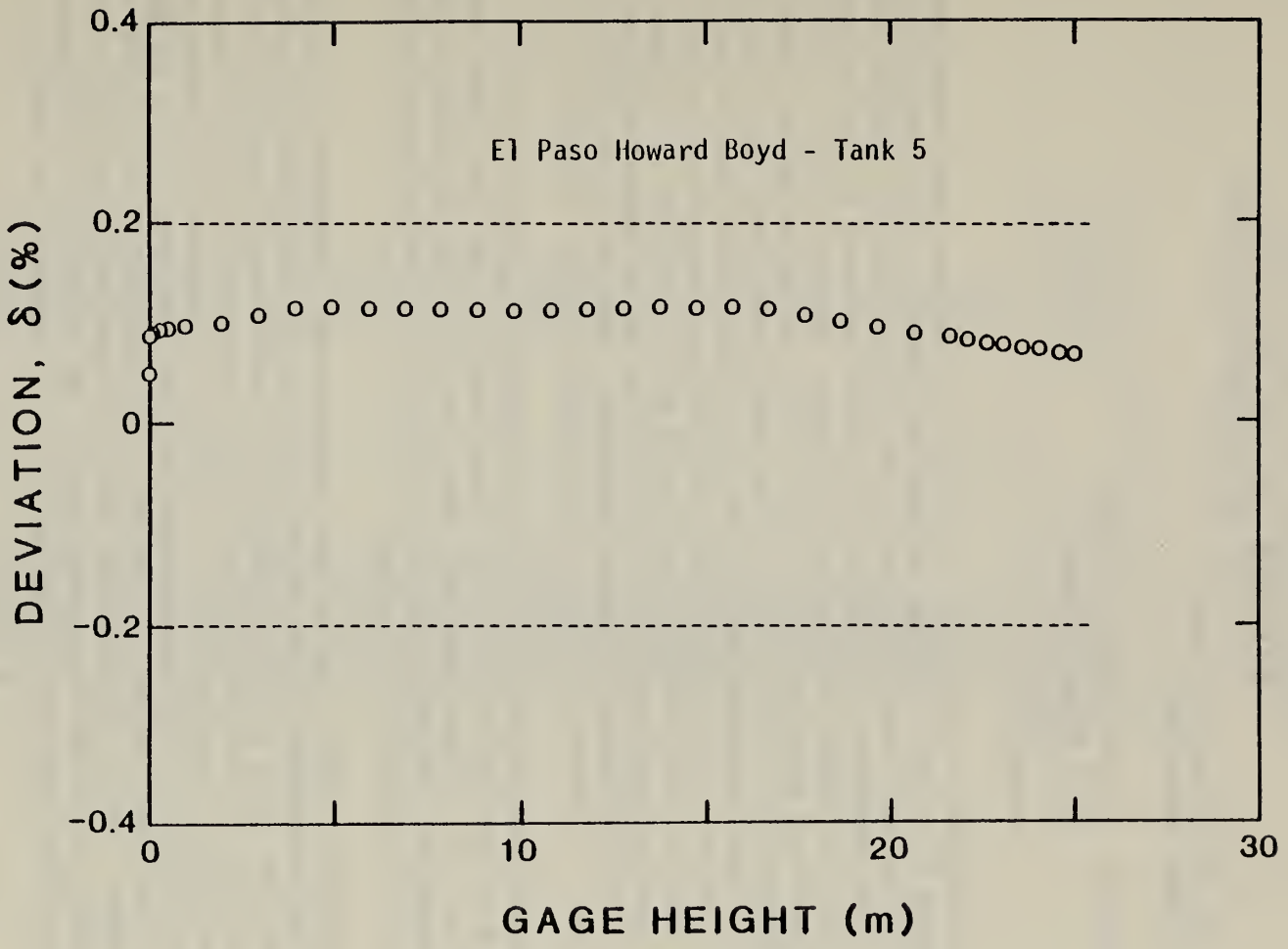
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	4.0
.050	48.3
.100	95.1
.200	189.2
.300	284.0
.400	379.5
.500	475.6
1.000	966.4
2.000	1998.8
3.000	3098.9
4.000	4266.8
5.000	5478.6
6.000	6691.3
7.000	7904.0
8.000	9116.7
9.000	10329.4
10.000	11542.1
11.000	12754.8
12.000	13967.5
13.000	15180.2
14.000	16392.9
15.000	17605.6
16.000	18818.3
17.000	20018.8
18.000	21157.1
19.000	22227.8
20.000	23230.8
21.000	24166.3
22.000	25034.2
22.500	25442.8
23.000	25834.4
23.500	26209.2
24.000	26567.1
24.500	26908.1
25.000	27232.2
25.500	27539.4

EL PASO HOWARD BOYD TANK NO. 5

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	91.4	60.9	30.5	0.0	-18.7	-20.0	-20.9	-21.5	-22.0	-22.5
.100	91.4	61.0	30.5	0.0	-48.9	-56.4	-60.4	-62.9	-64.7	-66.0
.200	91.3	60.9	30.5	0.0	-60.8	-89.3	-109.8	-121.9	-130.2	-136.2
.500	91.4	60.9	30.5	0.0	-60.8	-91.2	-121.5	-151.8	-182.2	-212.5
1.000	91.4	60.9	30.5	0.0	-60.8	-91.1	-121.5	-151.8	-182.2	-212.4
5.000	91.3	60.9	30.5	0.0	-60.9	-91.3	-121.7	-152.1	-182.6	-213.0
10.000	91.2	60.8	30.4	0.0	-60.9	-91.3	-121.7	-152.1	-182.5	-213.0
15.000	91.2	60.8	30.4	0.0	-60.9	-91.3	-121.7	-152.1	-182.5	-213.0
20.000	91.2	60.8	30.4	0.0	-60.9	-91.3	-121.9	-152.4	-183.0	-213.5
23.000	91.1	60.9	30.5	0.0	-60.9	-91.3	-121.9	-152.5	-183.1	-213.7
25.000	91.2	60.7	30.4	0.0	-60.9	-91.4	-122.0	-152.6	-183.1	-213.8

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	110.4	79.3	49.9	20.9	0.0	19.9	49.7	80.5	112.0
.100	88.6	58.7	30.2	5.6	0.0	5.6	30.5	59.8	90.7
.200	52.7	26.5	5.7	-.4	0.0	1.4	7.8	28.9	55.7
.500	5.4	2.2	.4	-.4	0.0	1.4	3.9	7.6	12.4
1.000	5.5	2.4	.4	-.4	0.0	1.4	4.0	7.7	12.6
5.000	-3.3	-2.5	-1.7	-.8	0.0	.8	1.6	2.5	3.3
10.000	-3.2	-2.4	-1.6	-.8	0.0	.8	1.6	2.4	3.3
15.000	-3.2	-2.4	-1.6	-.8	0.0	.8	1.6	2.4	3.2
20.000	-11.8	-7.2	-3.7	-1.3	0.0	.3	-.6	-2.6	-5.6
23.000	-10.1	-6.3	-3.3	-1.2	0.0	.4	-.1	-1.5	-3.7
25.000	-9.0	-5.7	-3.0	-1.2	0.0	.5	.2	-.7	-2.4



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

FORM NBS-443
(REV. 12-45)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

For: Tank #6 on the LNG Tanker
El Paso Howard Boyd

Requested by: El Paso Marine Company
2919 Allen Parkway
P. O. Box 1592
Houston, TX 77001

The following tables have been calculated from dimensional measurements on tank number 6 of the liquefied natural gas tanker El Paso Howard Boyd while berthed at Newport News Shipbuilding and Drydock Company, Newport News, VA. These tables represent the volume of a liquid enclosed in the tank as a function of the height of the liquid surface, measured along a straight line, fixed with respect to the tank. This line is defined as being located at the longitudinal center line of the tank's capacitance gage. Secondary tables are also presented which allow correction of the main tables for specific angles of ship orientation with respect to gravity, as referred to the six sets of draft marks on the ship's hull. Both the measurement method and the computational algorithms are outlined in the paper "Multiple Redundancy in the Measurement of Large Structures," Annals of the International Institution of Production Engineering Research (CIRP), Volume 27/1, 1978.

The tank was measured empty while at an average temperature of 20.6°C. The tabulated volumes and the error estimates apply to the tank under these conditions. The volumes have also been corrected for the volume occupied by the corregations (deadwood) which was measured in the laboratory using a hydrostatic displacement technique.

The measurement method used includes geometrically redundant cross checks which allow assessment of the random error in the measurement process. For this tank, the total volume, excluding the vapor domes, was 27631.2 m^3 with an uncertainty of 13.8 m^3 (0.05% of total volume) at the three standard deviation limit of random error. Including an analysis of probable systematics by adding the absolute magnitude of the error sources, we estimate that the total uncertainty, at the 99% confidence level, is $\pm$ 0.10% of the total volume. No estimates of the errors in the individual table entries are included, since without an estimate of the height error introduced by the liquid level gage such estimates would of necessity be incomplete.

For the Director,

Russell D. Young

Russell D. Young, Chief
Mechanical Processes Division
Center for Mechanical Engineering
and Process Technology

Date: September 14, 1979

EL PASO HOWARD BOYD

MAIN VOLUME VS. HEIGHT TABLE

TANK NO. 6

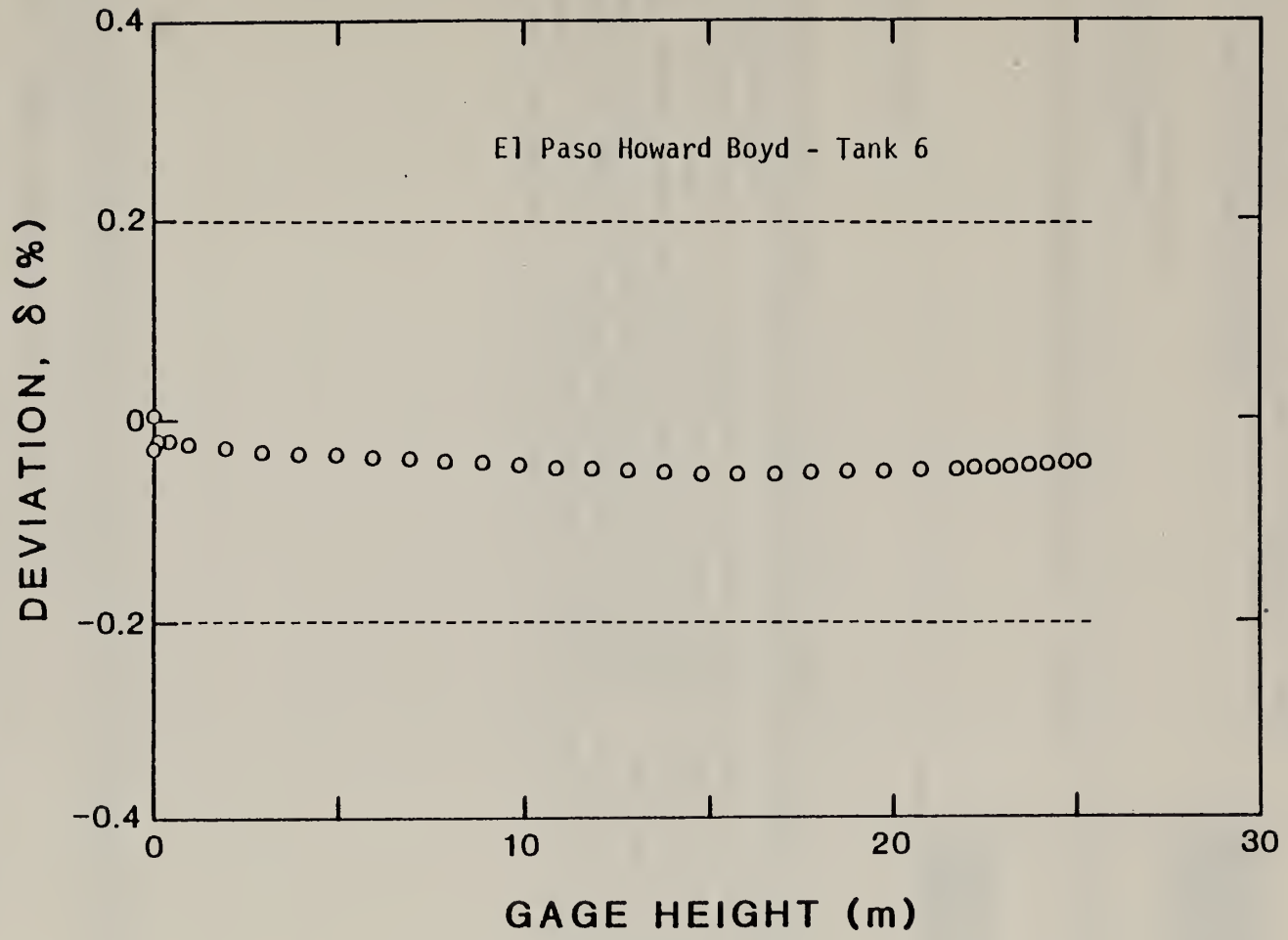
GAGE HEIGHT (METERS)	VOLUME (CUBIC METERS)
0.000	0.0
.050	25.6
.100	72.3
.200	166.3
.300	260.9
.400	356.2
.500	452.2
1.000	942.3
2.000	1973.3
3.000	3071.9
4.000	4238.2
5.000	5449.5
6.000	6661.9
7.000	7874.4
8.000	9086.8
9.000	10299.3
10.000	11511.9
11.000	12724.4
12.000	13937.0
13.000	15149.6
14.000	16362.2
15.000	17574.9
16.000	18787.6
17.000	19988.8
18.000	21128.5
19.000	22200.5
20.000	23205.0
21.000	24142.0
22.000	25011.3
22.500	25420.7
23.000	25813.1
23.500	26188.6
24.000	26547.3
24.500	26889.0
25.000	27213.9
25.500	27521.8

EL PASO HOWARD BOYD TANK NO. 6

GAGE CORRECTION IN MILLIMETERS

GAGE HEIGHT (METERS)	TRIM BY BOW (METERS) -1.5	-1.0	-0.5	0.0	TRIM BY STERN (METERS) +1.0	+1.5	+2.0	+2.5	+3.0	+3.5
.050	91.3	60.9	30.5	13.0	3.5	2.8	2.2	1.8	1.4	1.0
.100	91.4	60.8	30.4	0.0	-33.5	-37.6	-40.1	-41.8	-43.0	-44.0
.200	91.4	60.8	30.4	0.0	-60.7	-84.2	-98.1	-107.0	-113.2	-117.9
.500	91.3	60.9	30.4	0.0	-60.8	-91.1	-121.4	-151.8	-182.0	-212.0
1.000	91.3	60.8	30.4	0.0	-60.8	-91.1	-121.4	-151.8	-182.1	-212.3
5.000	91.3	60.8	30.4	0.0	-60.9	-91.3	-121.6	-152.1	-182.5	-212.9
10.000	91.2	60.9	30.4	0.0	-60.8	-91.3	-121.7	-152.1	-182.5	-212.9
15.000	91.3	60.8	30.4	0.0	-60.8	-91.2	-121.7	-152.1	-182.5	-212.8
20.000	91.1	60.8	30.4	0.0	-60.9	-91.3	-121.8	-152.3	-182.9	-213.5
23.000	91.2	60.7	30.4	0.0	-60.9	-91.4	-121.9	-152.4	-183.0	-213.6
25.000	91.1	60.7	30.3	0.0	-61.0	-91.4	-121.9	-152.6	-183.1	-213.7

GAGE HEIGHT (METERS)	LIST TO PORT (DEGREES) -2.0	-1.5	-1.0	-0.5	0.0	LIST TO STARBOARD (DEGREES) +0.5	+1.0	+1.5	+2.0
.050	121.5	90.9	61.0	31.7	13.0	31.5	61.6	92.4	123.8
.100	98.5	68.1	38.7	11.6	0.0	11.9	39.7	69.9	101.1
.200	60.2	32.8	9.6	-.3	0.0	1.3	11.7	35.5	63.6
.500	6.1	2.4	.5	-.3	0.0	1.3	3.8	7.3	12.4
1.000	5.8	2.6	.6	-.2	0.0	1.4	3.9	7.5	12.2
5.000	-3.3	-2.5	-1.7	-.8	0.0	.9	1.7	2.5	3.4
10.000	-3.4	-2.6	-1.7	-.9	0.0	.8	1.7	2.5	3.4
15.000	-3.4	-2.6	-1.7	-.9	0.0	.8	1.7	2.6	3.4
20.000	-12.2	-7.5	-3.9	-1.4	0.0	.4	-.4	-2.3	-5.3
23.000	-10.2	-6.3	-3.3	-1.2	0.0	.4	0.0	-1.4	-3.6
25.000	-9.0	-5.6	-3.0	-1.1	0.0	.5	.2	-.7	-2.4



δ = 100*(NBS Vol. - Calib. Contractor Vol.)/Tank Vol.
Dashed lines are +0.2% and -0.2% error limits.

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The National Bureau of Standards has completed a study on the calibration uncertainty of ship cargo tanks used to transport Liquid Natural Gas (LNG). The data from measurements made on 18 such tanks is presented, along with a comparison to measurement determined from an independent technique. Calibration reports for each tank measured by NBS are presented, including tables that relate tank volume to liquid level in the tank. The measurement technique used was accurate to ±0.05% of total volume and agreed with the independent measurement data to ±0.2%.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Laser; LNG; tanks; ships; volume; dimensions.

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