Measurement of LNG Density by Radar Tank Gauge.

Øivind Jensen
Kongsberg Maritime AS,
Trondheim, Norway

KONGSBERG

WORLD CLASS – through people, technology and dedication

AGENDA

1) Introduction
2) Apparatus
3) Refraction
4) Density versus refractive index
5) Measurements
6) Conclusion

1a. GIIGNL Custody Transfer Handbook, 3rd edition 2010

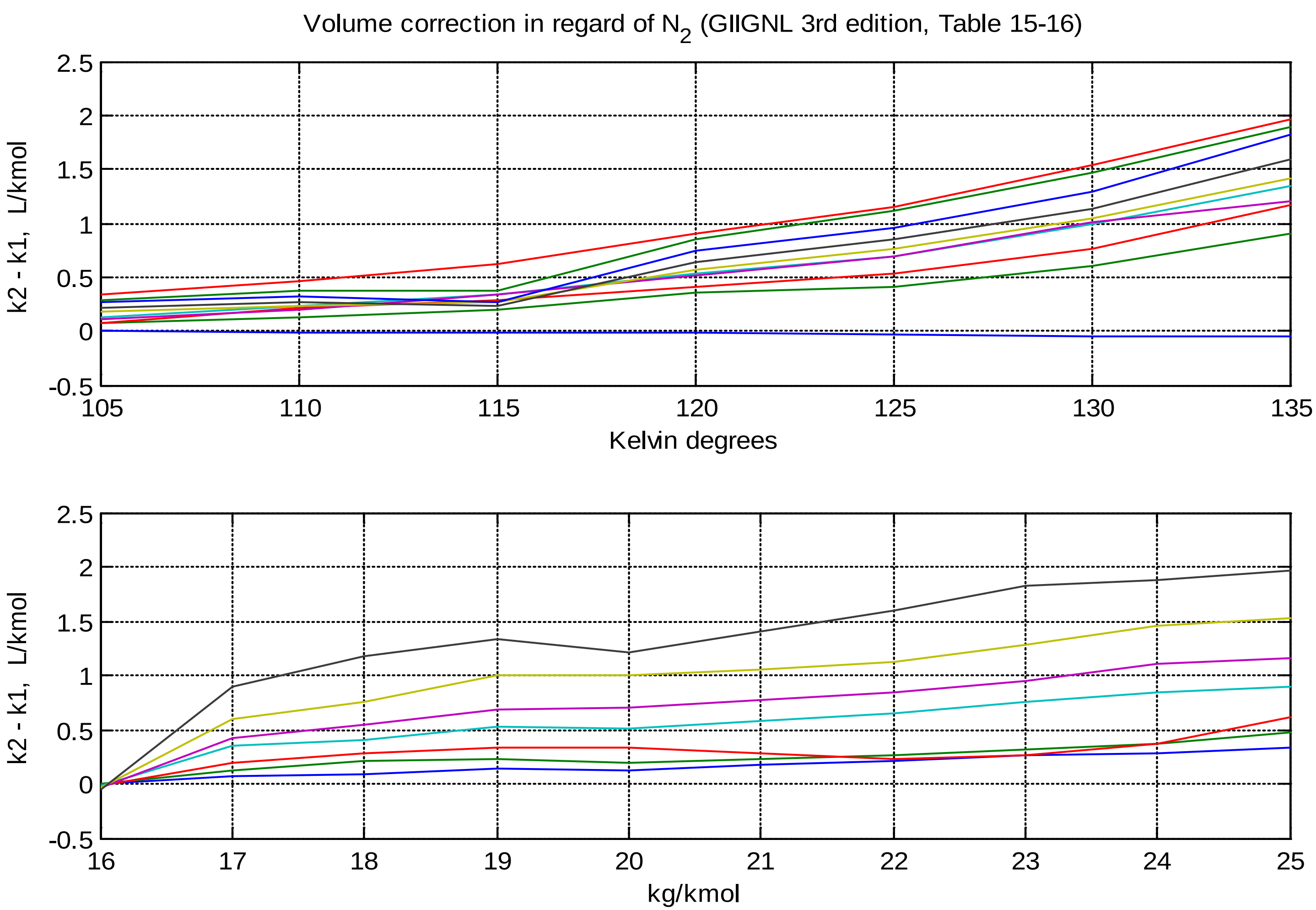
KONGSBERG

Chapter 9.1

” Unfortunately, technological progress has not reached the stage where it is possible for a reliable apparatus to be available on board a LNG carrier under normal operating conditions. This is why the second method, which enables the density to be calculated from the LNG average composition, is the one that has been selected here. ”

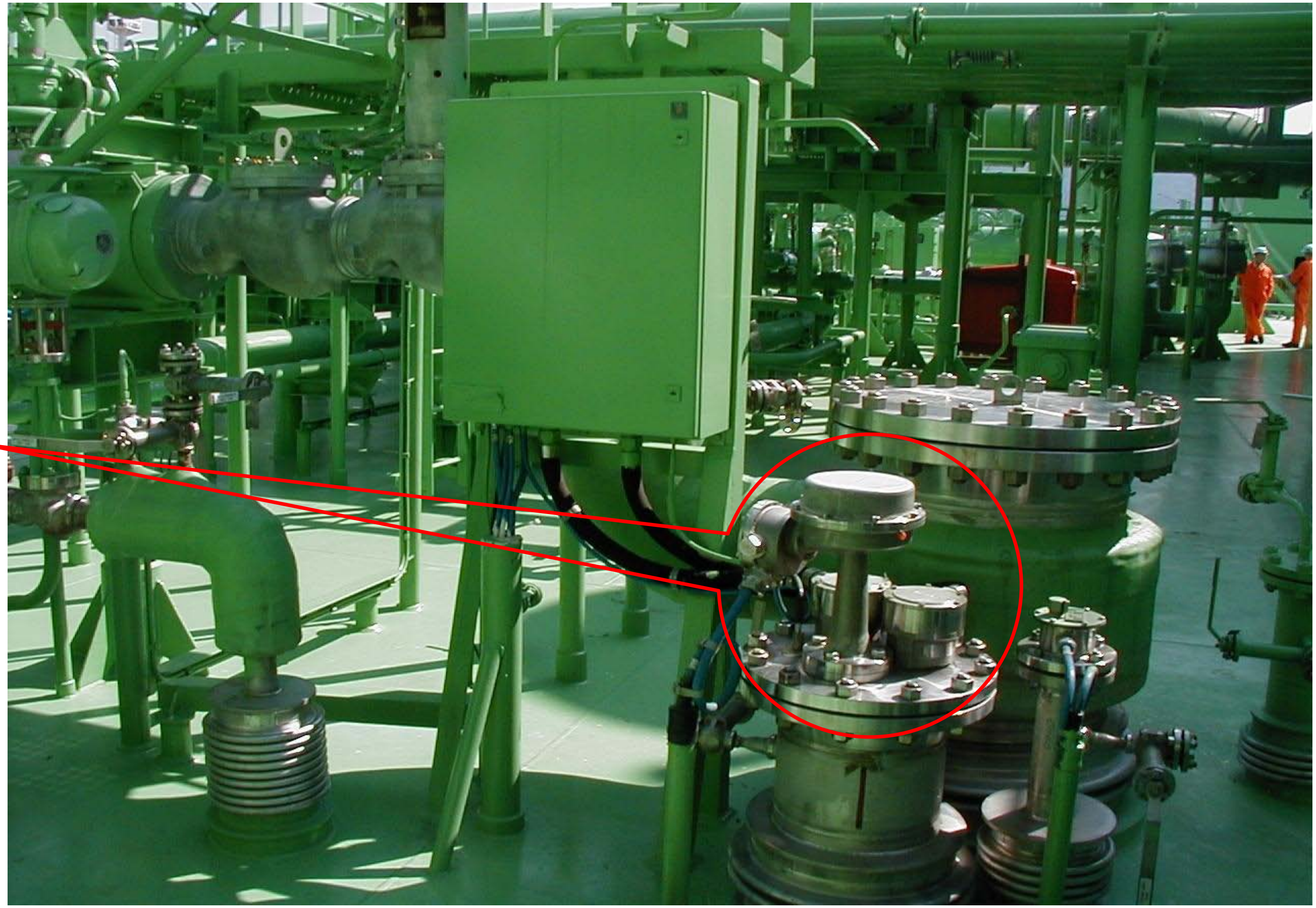
page 58

1b. RTG provides in-situ measurements of LNG density (avoids deficiencies of the KMcK method)



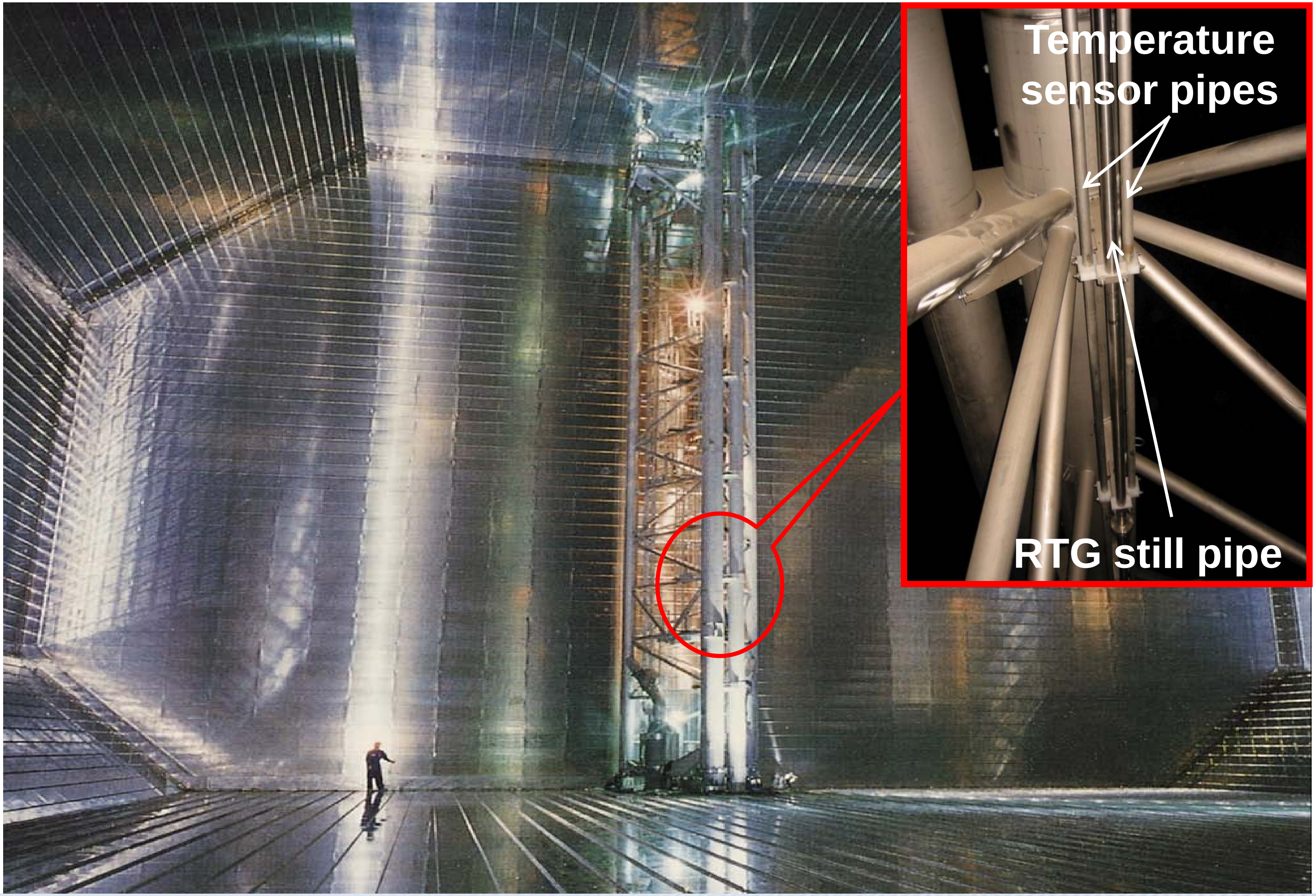
2a. AutroCAL® radar head on deck

Tank monitoring instruments supplied by Kongsberg, including the AutroCAL® RTG

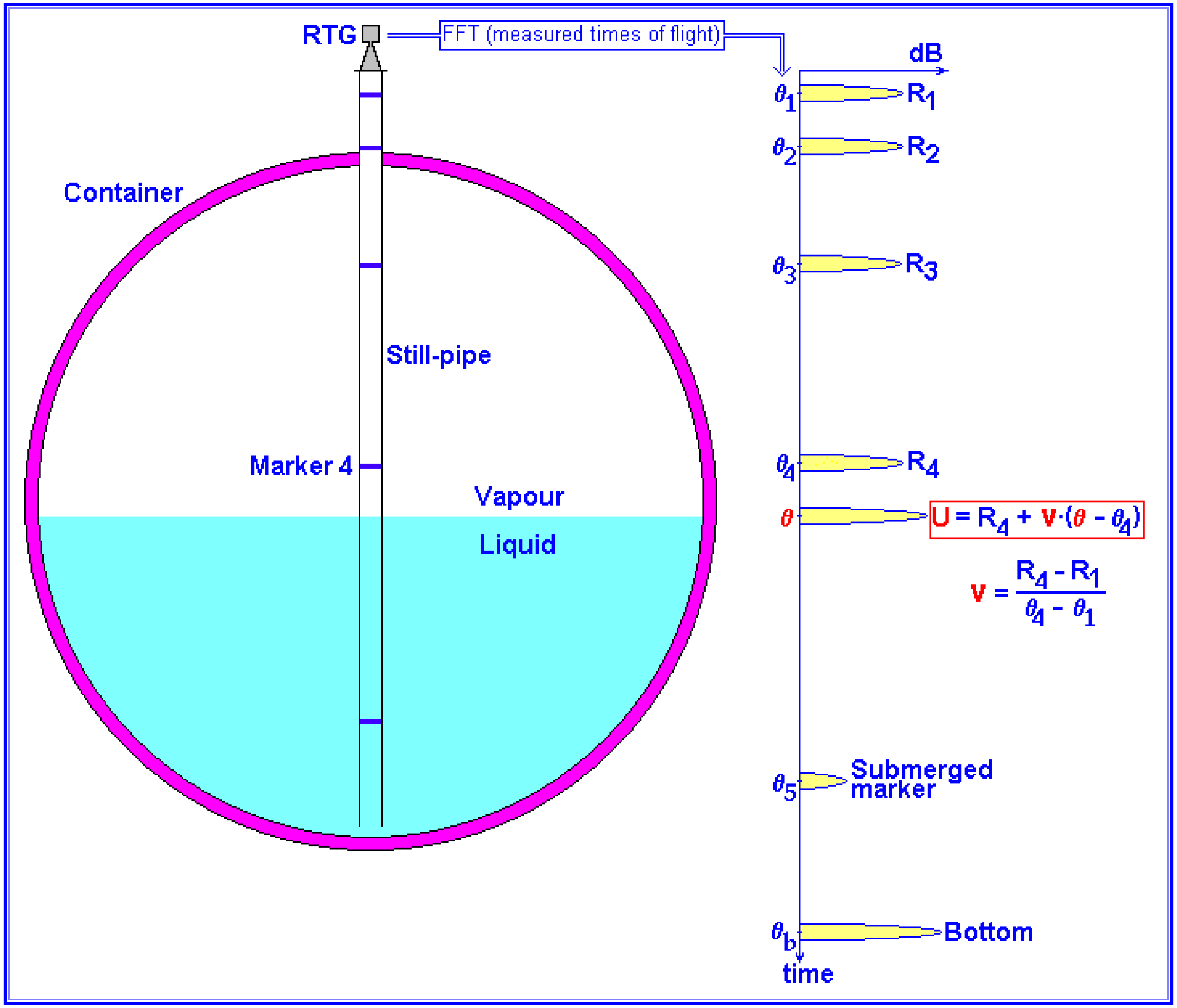


2b. AutroCAL® still pipe inside LNG storage tank

KONGSBERG



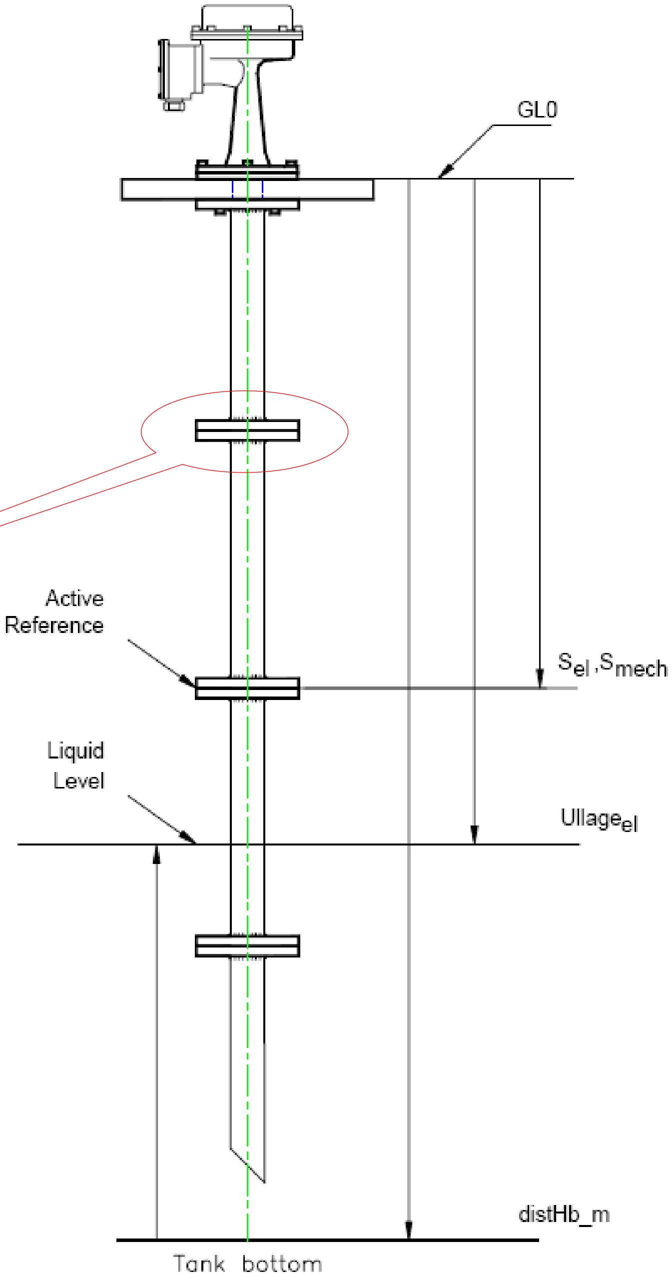
2c. AutroCAL®, multi target capability



Markers installed at known locations down the still pipe give rise to echoes which are employed to measure the propagation speed v of the radar signal.

Signal in liquid propagates at slower speed, and echoes produced in liquid will be delayed accordingly.

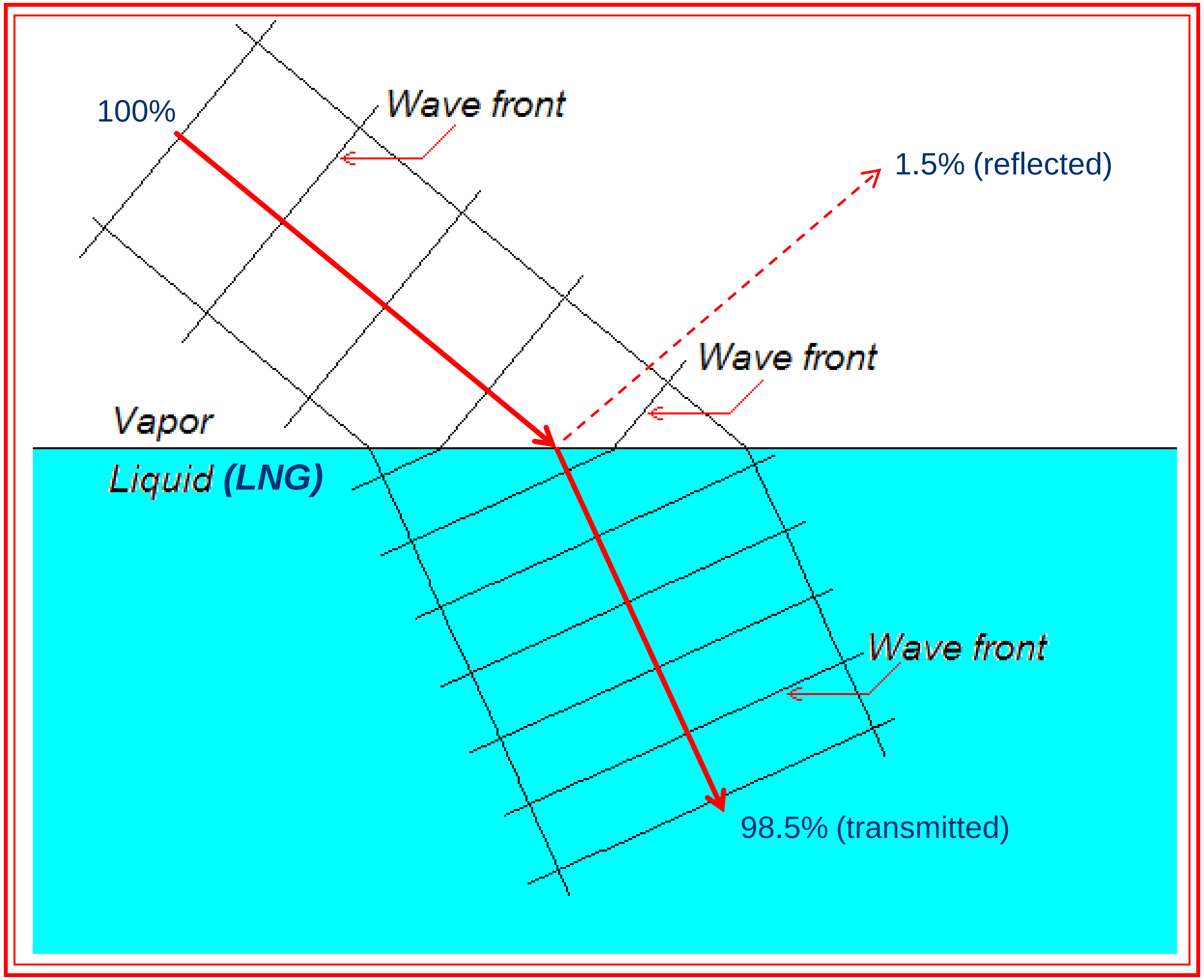
2d. Marker design



3a. Refractive index is a measure of speed

KONGSBERG

Distance between equiphase wave fronts = wave length



1. Change of wave length in liquid is a consequence of the change of refractive index (n) across the vapor-liquid interface.

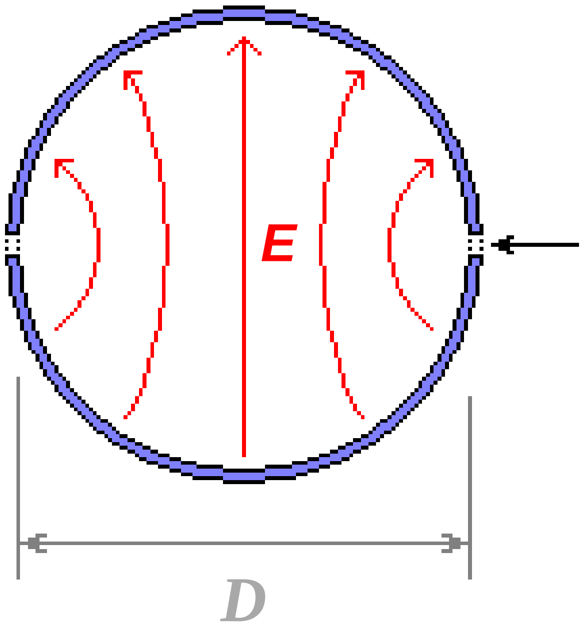
2. Change of wave length causes a change in the propagation speed (v).

Lesson learned:

Propagation speed (v) and refractive index (n) are two sides of the same coin.

3b. Speed of radar signal in still pipe

KONGSBERG



The venting holes do not affect the radar signal (***E***)

$$v = \frac{c}{n^2} \cdot \sqrt{n^2 - \left(\frac{k \cdot c}{D \cdot f}\right)^2}$$

$$c = 2.998 \cdot 10^8 \text{ m/s}$$

$$k = 0.586065....$$

n is the refractive index of the vapor/liquid

f is the operating frequency of the radar

4a. Clausius-Mosotti, density vs. refractive index

KONGSBERG

$$\frac{n^2 - 1}{n^2 + 2} = \frac{N}{3 \cdot \varepsilon_0} \cdot \alpha$$

$$N = \frac{\rho}{M}$$

$$\Rightarrow$$

$$\rho = \frac{1}{\kappa} \cdot \frac{n^2 - 1}{n^2 + 2}$$

$$\kappa = \frac{\alpha}{3 \cdot \varepsilon_0 \cdot M}$$

n	refractive index of the liquid (vapor)
N	number of molecules per unit of volume
ε_0	dielectric constant in vacuum
α	specific polarizability of the molecule
ρ	density of the liquid (vapor)
M	specific weight of the molecule
κ	specific CM constant of the molecule

The CM constant κ is a specific property of the molecule ($\kappa \sim 4.1 \cdot 10^{-4}$ m^3/kg for CH_4)

4b. LNG, a mixture of CH_4,..., C_nH_{2n+2},..., N_2,...

KONGSBERG

$$\rho = \frac{1}{\kappa} \cdot \frac{n^2 - 1}{n^2 + 2}$$

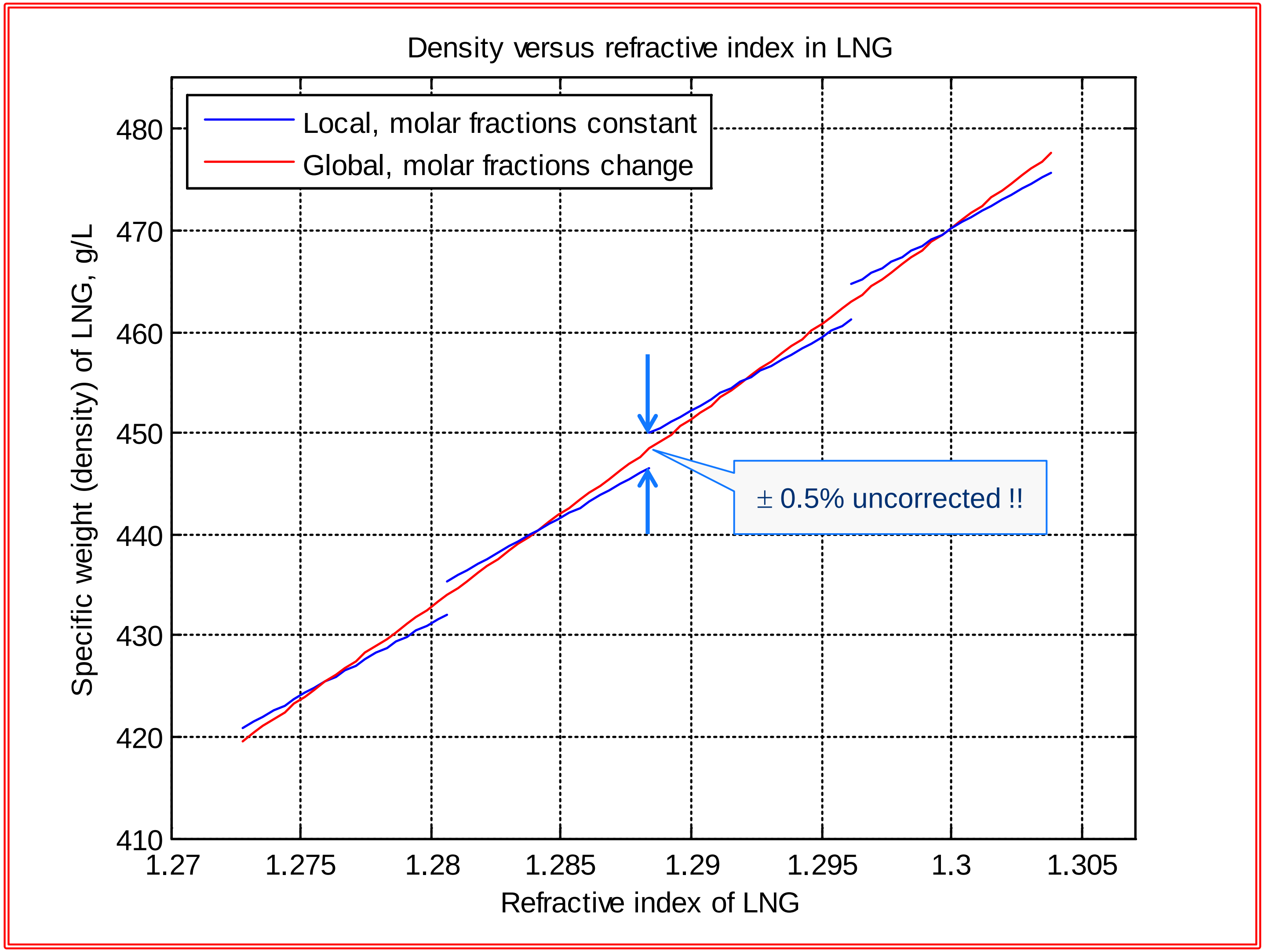
$$\kappa = \sum w_i \cdot \kappa_i$$

$$w_i = \frac{\mu_i \cdot M_i}{\sum \mu_i \cdot M_i}$$

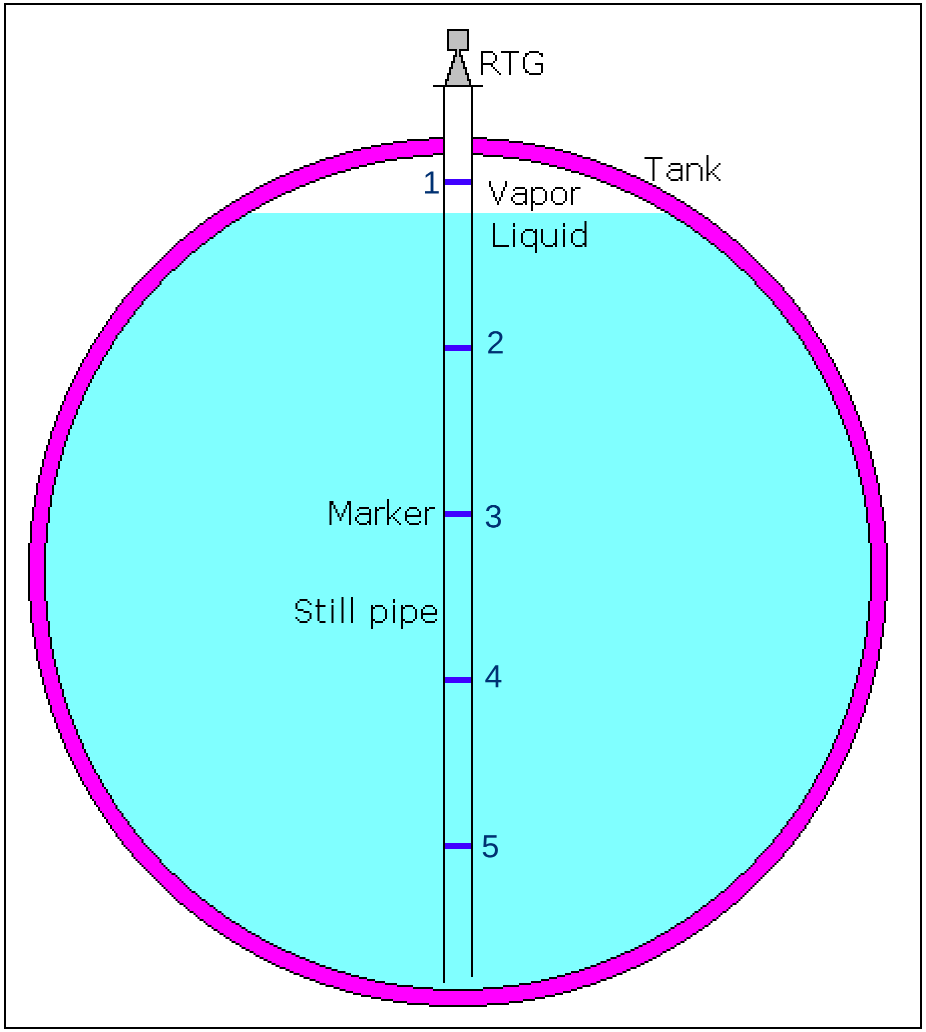
μ_i	molar fraction of component *i*, $\Sigma\mu_i = 1$
w_i	weight fraction of component *i*, $\Sigma w_i = 1$
κ	the Clausius-Mosotti constant of the mixture (LNG) is the weighted sum of all contributors according to the respective weight fractions

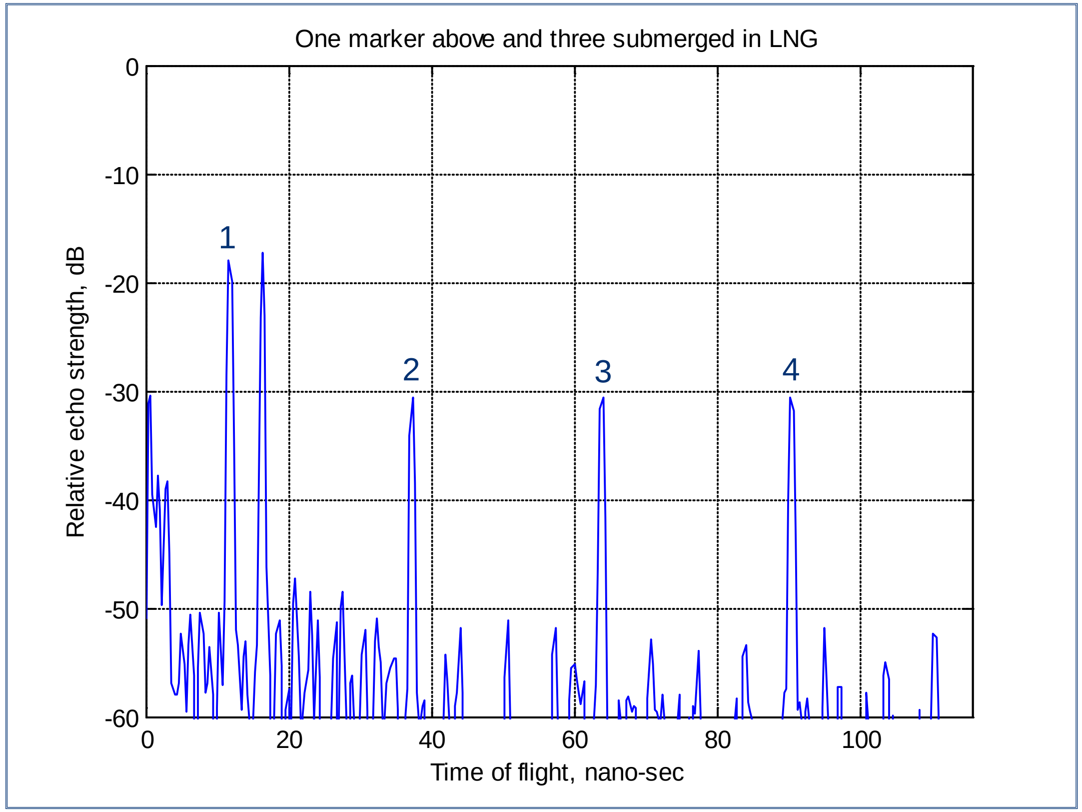
The CM constant κ of LNG is subjected to change, $\kappa \sim 3.9 - 4.05 \cdot 10^{-4}$ m^3/kg, which may be accounted for by employing the measured molar composition

4d. Molar composition, temperature



5a. Measurements





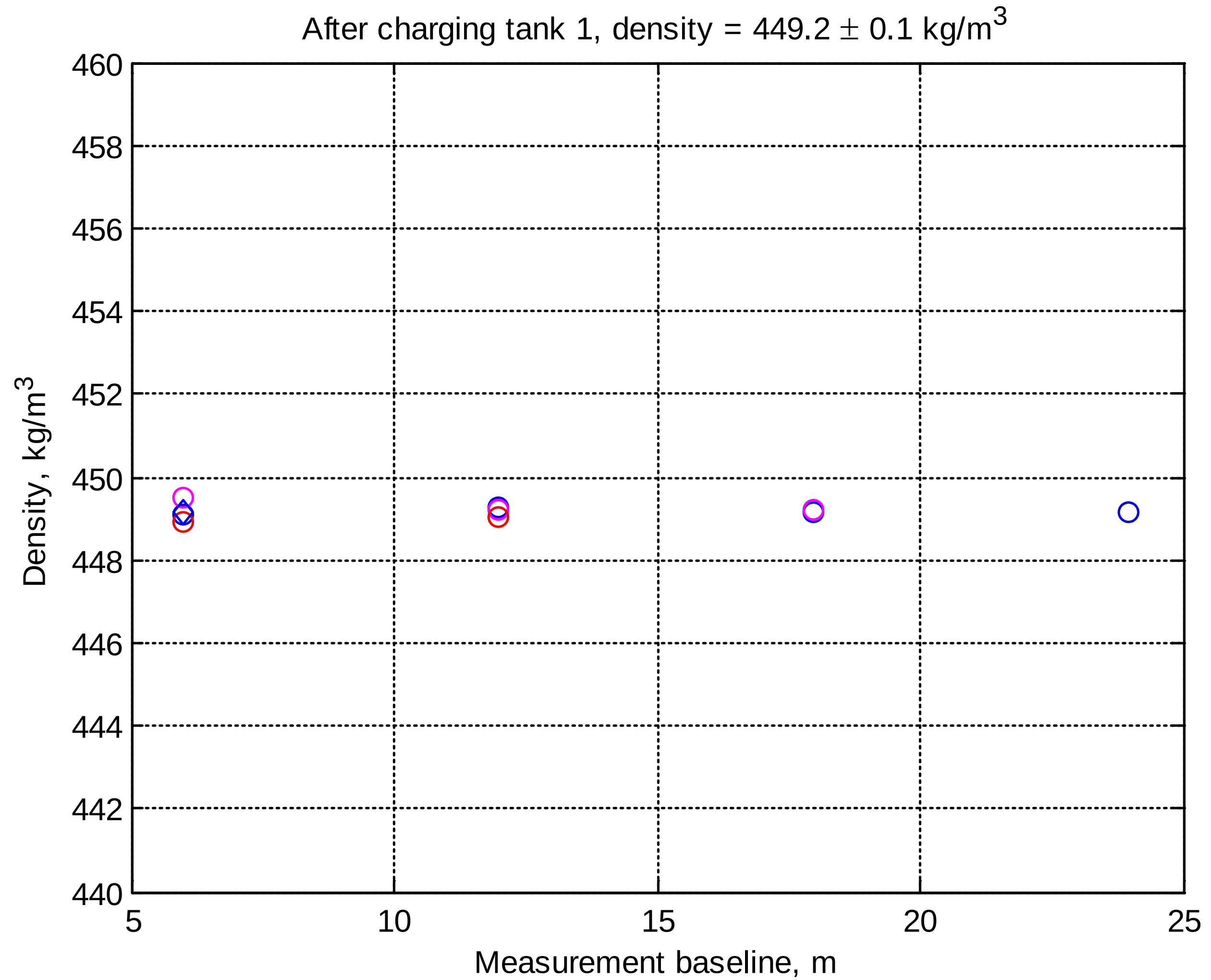
Speed of the radar signal is retarded in liquid due to increased **density**

The Clausius-Mosotti relation paves a **path** from **speed** to **density**

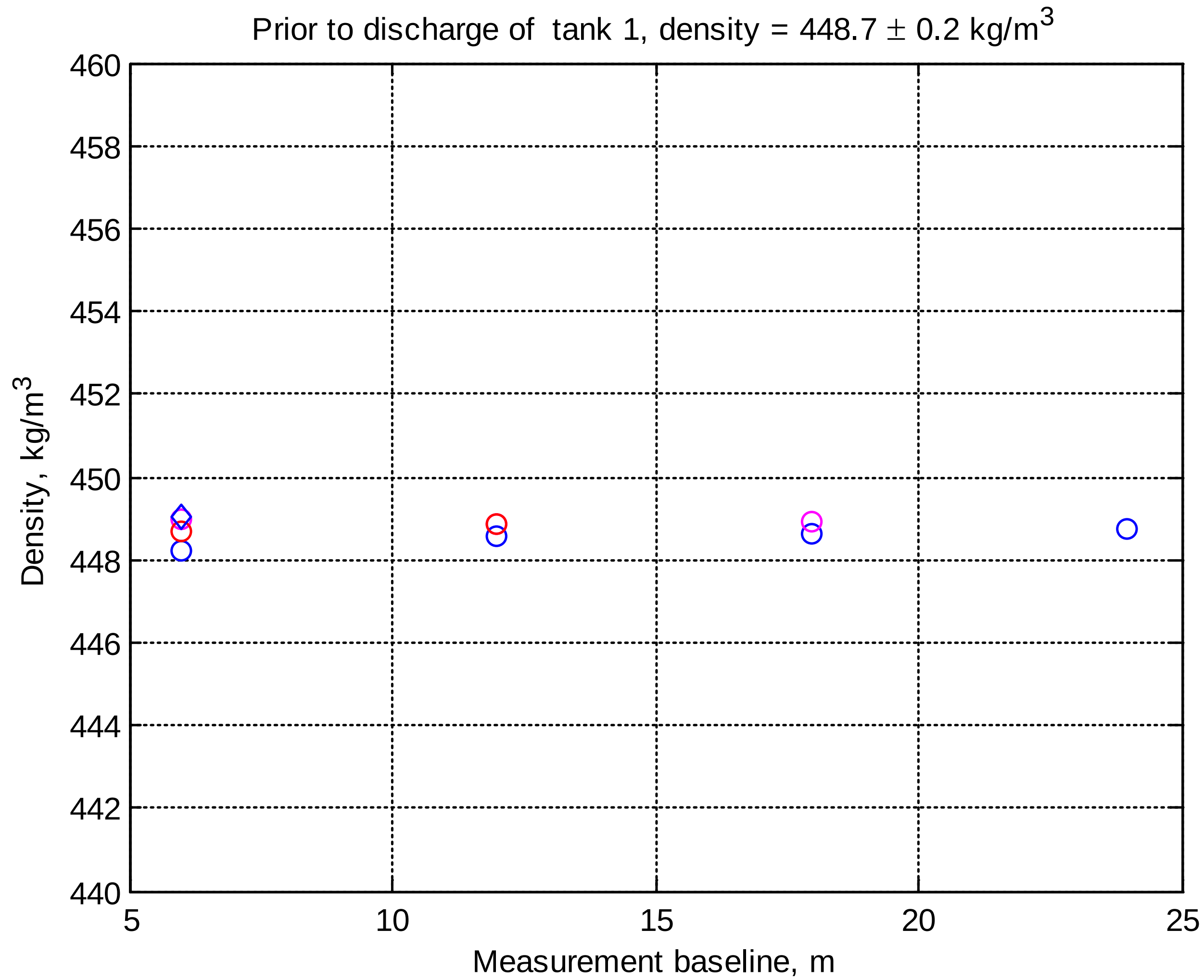
The **path** is straightened by molar composition as additional input

5b. RTG recording in tank 1 after loading (5 markers submerged in LNG)

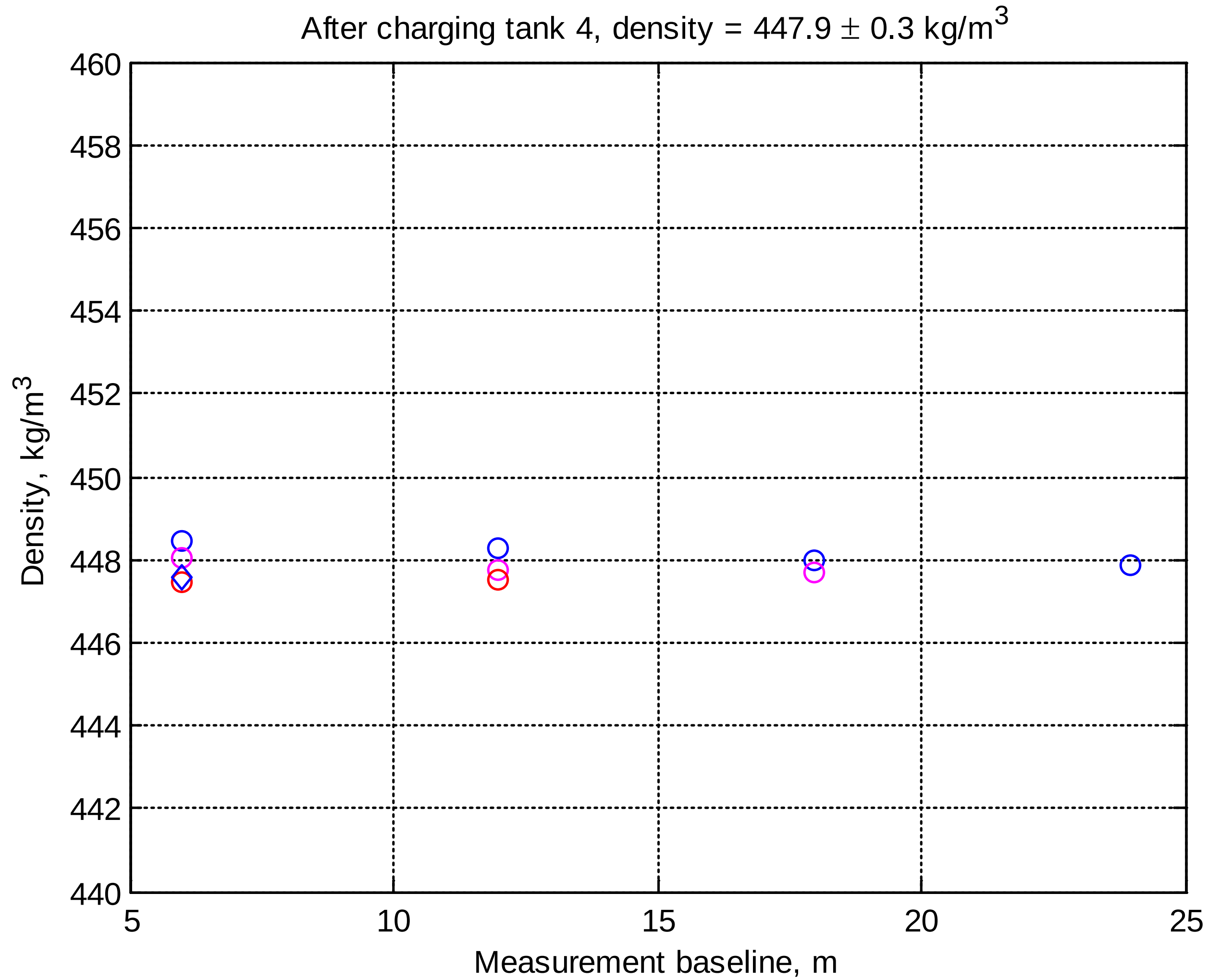
KONGSBERG



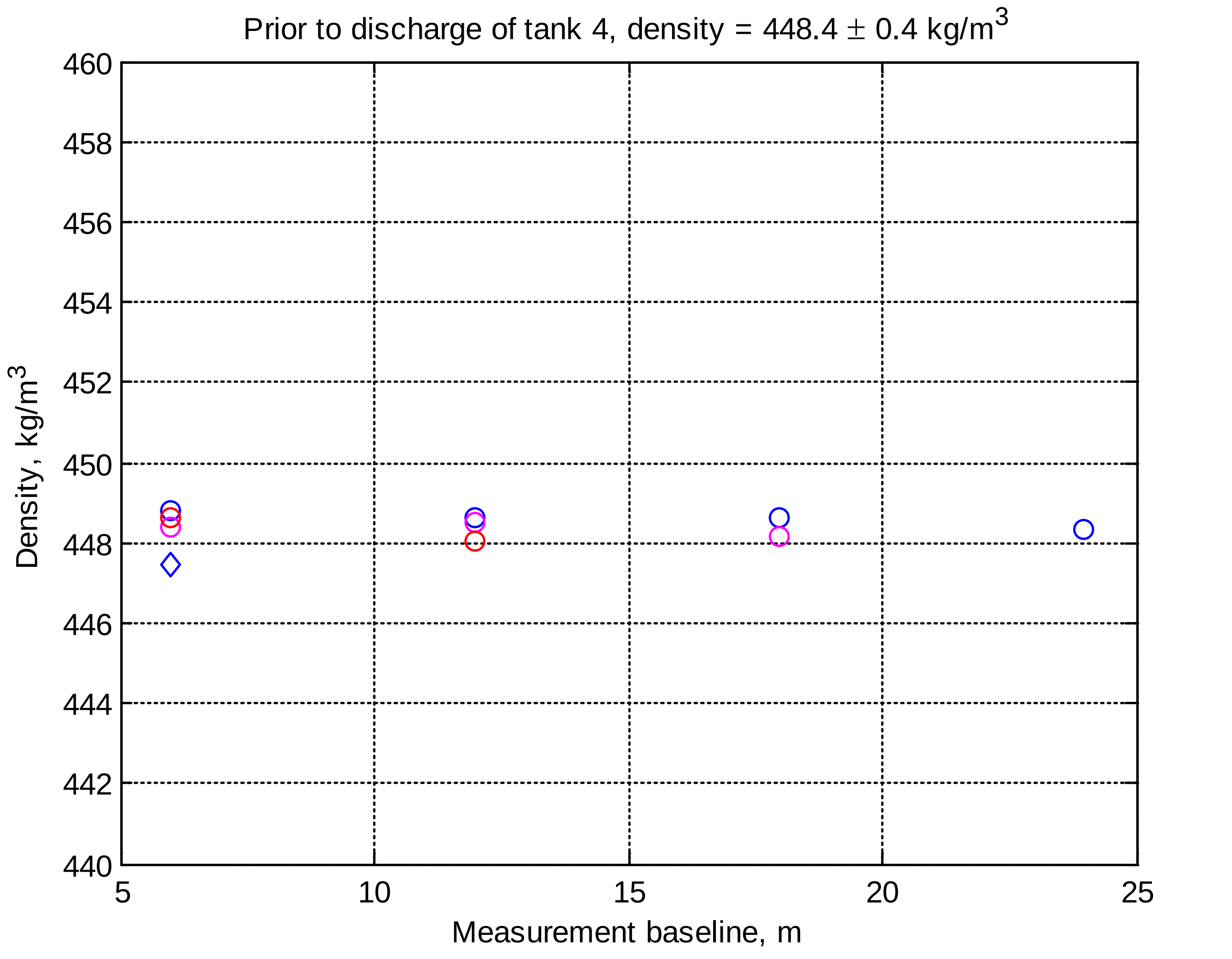
5c. RTG recording in tank 1 before discharge (5 markers submerged in LNG)



5d. RTG recording in tank 4 after loading (5 markers submerged in LNG)



5e. RTG recording in tank 4 before discharge (5 markers submerged in LNG)



5d. Measurement results

	Temp °C	RTG tank 1 kg/m³	RTG tank 2 kg/m³	RTG tank 3 kg/m³	RTG tank 4 kg/m³	RTG average kg/m³	KMcK kg/m³	RTG-KMcK deviation kg/m³	RTG-KMcK deviation %
Charge	**-161,6**	**449,12**	**448,75**	**447,87**	**447,78**	**448,43**	**450,60**	**-2,22**	**-0,49 %**
95 %		**0,07 %**	**0,11 %**	**0,09 %**	**0,09 %**	← **RTG recordings prove little spread**			
Discharge	**-160,1**	**449,22**	**449,29**	**448,13**	**448,44**	**448,77**	**450,64**	**-1,87**	**-0,42 %**
95 %		**0,19 %**	**0,03 %**	**0,06 %**	**0,07 %**	← **RTG recordings prove little spread**			

6. Concluding remarks

KONGSBERG

1. The RTG instrument AutroCAL® provides in-situ measurement of LNG density
2. The RTG recordings show slightly lighter product density then calculated by the Klosek-McKinley method
3. Density varies between tanks
4. The RTG recordings show very little spread
5. The RTG instrument AutroCAL® has potential for high accuracy in measuring LNG density
6. Instrument improvements in progress
   - ✓ Digital frequency control to improve performance
   - ✓ Markers redesigned to increase SNR in LNG

KONGSBERG

We maximize marine performance by providing

THE FULL PICTURE