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VOID FRACTION MEASUREMENT IN TWO-PHASE HELIUM FLOW WITH ELECTRON ENERGY ATTENUATION DETECTOR.

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ABSTRACT

A void fraction measurement system has been developed using a small electron source (Sr90) associated with a commercial semiconductor detector. This system has been designed for measurements in two-phase helium flow near saturated conditions at atmospheric pressure (4.2 K). Both elements of the system, the source and the detector, are located in vacuum and have their temperature controlled around 80 K. Energy attenuation and particle counting are both used to measure void fraction variation through a stainless steel tube 0.25 mm thick. Ease of use and sensitivity of this method are demonstrated. We present preliminary tests in static liquid nitrogen and measurements in helium two-phase flow for an upward forced flow. Measurements have been performed up to 1 g/s mass flow for the full range of quality factor.

INTRODUCTION

Void fraction measurement on liquid-gas two-phase flow in cryogenic fluids is a very important factor in the study of stability in cooling circuits using saturated liquid. Many methods [1], local or global, are used to detect and measure volumetric gas rate in flow such as quick-valves method, pressure drop, electrical resistivity, dielectric (capacitance or resonance methods), acoustic or optical measurements. Unfortunately, low temperature, reliability and no moving parts are often strong limitations for using these methods. If capacitance or resonating sensors have been currently implemented in cryogenic loops for their easy technical fabrication and their low cost in materials [2-4], limitations appear because of low signal variation in particular in GHe/LHe mixture ($\Delta\varepsilon/\varepsilon \approx 4\%$ around 0.1MPa) associated with intrusive disposition and dependence of signal at once on volumetric part of each phase and on electrical field distribution. A radio-frequency system could also be used with better results than pure capacitance probes[5-8].

For a long time, the attenuation technique was considered as not applicable in cryogenic fluids because of the small density changes between two-phase flow systems (for LHe/GHe near 0.1 Mpa, $\rho_l/\rho_g \approx 7$, whereas, for example, in H_20 $\rho_l/\rho_g \approx 1296$). Gamma ray or X-ray densitometers are commonly described in non cryogenic void fraction measurement [9-10]. Private communications in proximity physics laboratories and various experiences in the two-phase flow domain led us to test these attenuation methods. Our first aim was to measure void fraction in 4.2 K LHe/GHe vertical two-phase flow [11] more precisely than with our first sensor which was a capacitor probe.

Based on beta radiation attenuation technique, our development combines a non-intrusive concept , global evaluation of void fraction and a commercial element as sensor. The radiation source is chosen to be not "dangerous" during and after use, i.e not activating proximity materials. An electron source (Beta source made of Sr90, 6 mC) is used in tis respect. A Germanium (Ge) semiconductor detector with enough thickness to absorb all the particle energy is used to measure energy of incident particles.

MEASUREMENT PRINCIPLE

Energy attenuation measurement is a widely used method to know average density or detect different phases in a mixture. If we consider electrons emitted from a source (a Sr90 punctual source in our case), these electrons will interact with matter into two ways. The first is scattering with direction modification, which, to first order, does not modify the number of electrons reaching the detector. This type of interaction will be neglected. The second is an energy loss which could be parameterized by the relation used by Sternheimer [12]:

$$R = a \cdot (Eo)^n \qquad (1)$$

where R, in mg/cm2, is the amount of matter crossed by electrons and necessary to absorb the energy equal to Eo. Eo is the kinetic energy.

$$n = b - c \cdot \ln Eo \qquad (2)$$

Constant a is adjusted according to the atomic number of the traversed matter. Constants b and c are determined for each material following the atomic and nuclear properties of the material [13]. Energy Eo is in MeV.

The initial distribution in momentum of the electrons (before interaction) could be represented by a triangle (which was generated by the sum of three random numbers). Maximum momentum will be 2.748 MeV/c (for Sr90 electrons). A model based on Montecarlo method has been carried out to verify the potential sensitivity of this principle. The source emits N electrons per event with a triangular distribution in momentum between 0 and 2.748 Mev/c. The matter to be crossed consists of two sheets of stainless steel (2 x 0.25 mm thick) surrounding a variable thicknesses of LHe and GHe between 0 and 10 mm (sum of both always equal to 10mm). A 11 mm diameter Ge detector, 5 mm deep is located 12 mm from the Beta source (solid angle ≈ 5.5 %). Figure 1 represents the calculated behavior of such a system in energy and in counting results for 100000 electrons per run. Model finally shows that energy loss is quasi independent of the position of gas in the liquid (linear behavior of ΔE versus gas/liquid proportion). Void fraction α could be then estimated by relation :

$$\alpha = \frac{\overline{E}_{tp} - \overline{E}_l}{\overline{E}_g - \overline{E}_l} \qquad (3)$$

where E_{tp} is the average energy of the electrons received by the detector during a run of N particles, indices l for pure liquid, g for pure gaz , tp for two-phase mixture and $\alpha_l=0$ and $\alpha_g=1$

During a measurement, fluctuation of particles involved in the interaction leads to an error attached to this measurement and that could be considered like a noise (standard deviation). A part of this statistics error is due to energy distribution of electrons. Another part is due to electron number fluctuation in time. The second one is generally much larger than the first one (except for small counts, N<100). As statistics errors on E_g and E_l can be neglected , final statistics error on void fraction measurement will be :

$$\frac{\Delta\alpha}{\alpha} = \frac{\Delta\overline{E}_{tp}}{(\overline{E}_{tp} - \overline{E}_l)} \qquad (4)$$

Always using a Montecarlo calculation, we have estimated the void fraction error and figure 2 shows theoretical standard deviation for energy measurement.

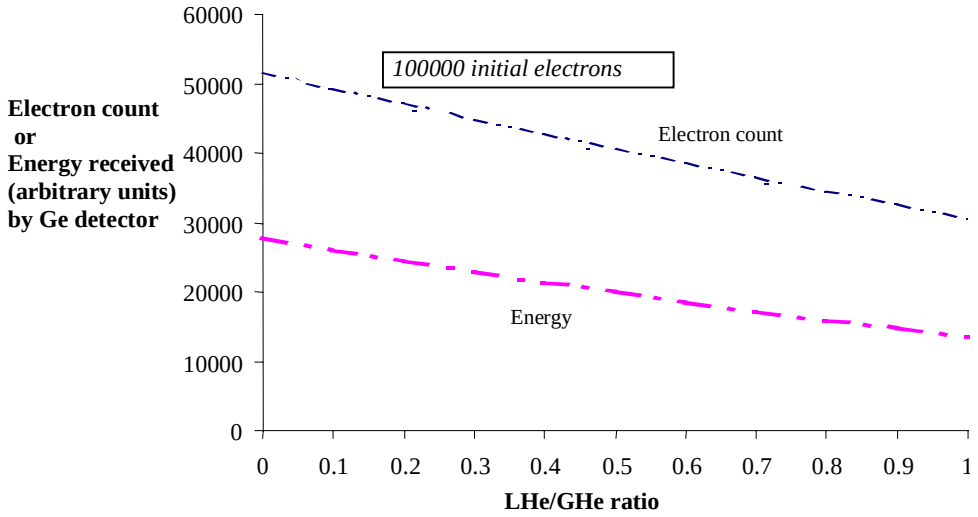

FIGURE 1. Montecarlo simulation results for electrons from Sr source with absorption by a stainless steel tube 0.25 mm thick , filled with mixture of He Liquid and gas.

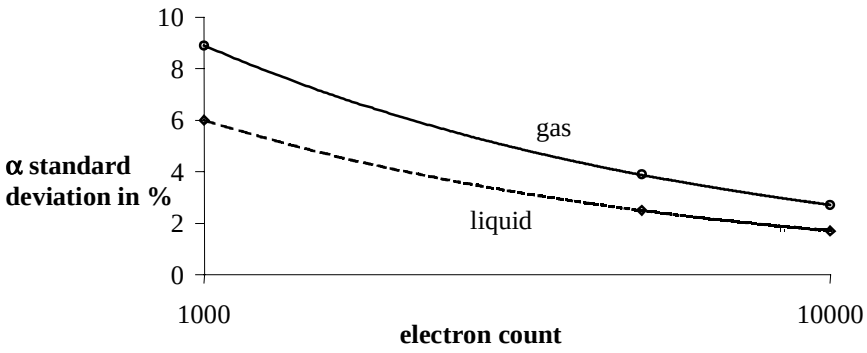

FIGURE 2. Standard deviation in energy function of counts.

Statistics errors are less than 3% for events with more than 10000 counts. Our Beta source (Sr90) is a 6mC source i.e 2.22E8 desintegrations/s in 4π direction . In the solid angle of our assembly , we have a maximum count of 1.11E7/s which permits good statistics even with a short duration (less than one second).

DESCRIPTION OF THE SET-UP

Commercial products have been used for the source and the Germanium detector [14-15]. The germanium detector is a planar detector for charged particles, mounted in aluminium support, which can be fixed on a cold plate of a cryostat, to allow cooling to liquid nitrogen temperature. Manufactured with high purity germanium covered with a thin aluminium film, this type of detector allows shipment and storage at room temperature. The cooled part of the preamplifier (FET) is attached with the aluminium support. High voltage polarization of semiconductor is 1500 V. An associated charge preamplifier is located at room temperature outside the cryostat.

Amplification and conversion systems have been built, from recovered equipment, to obtain particle counting and integrated energy . Integration time can be less than 10 ms but electronic noise requires to acquire energy and counting average values (around 1s).

Figures 3-a/b/c show a general description of the measurement chain.

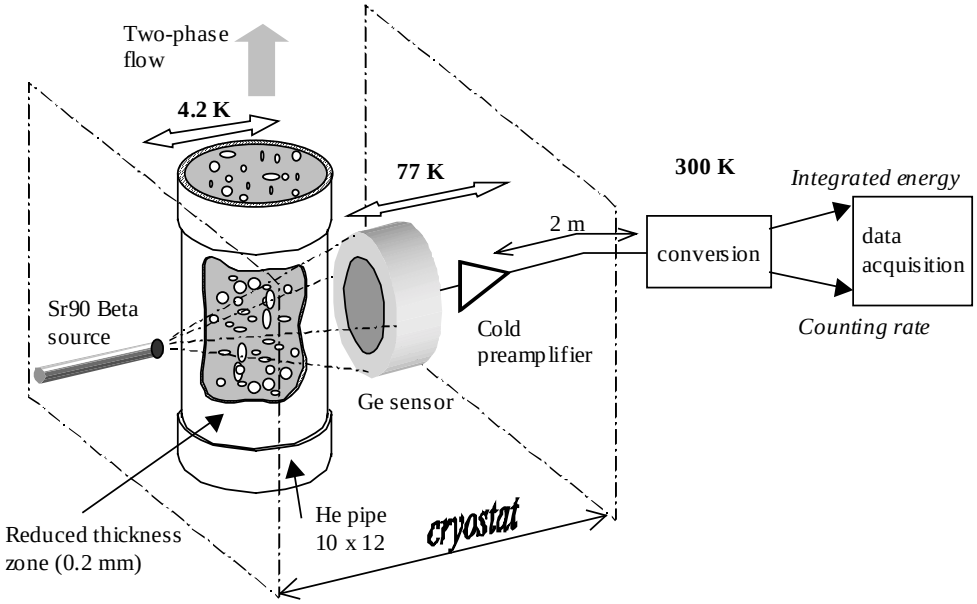

FIGURE 3a. General layout of the sensor

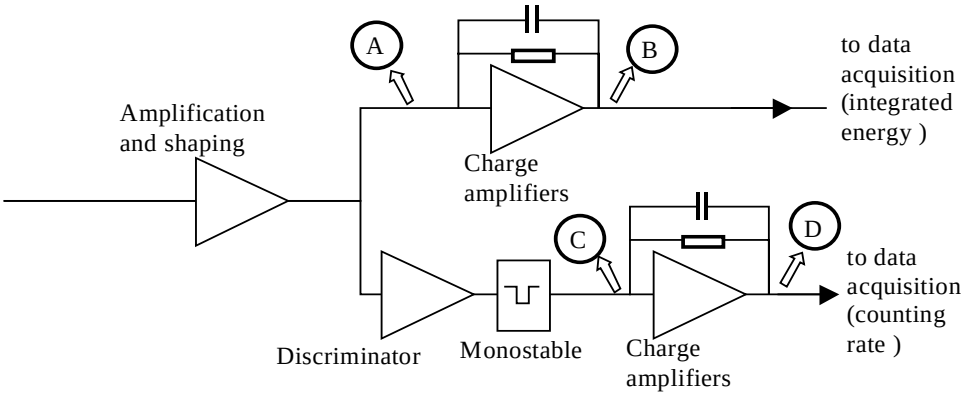

FIGURE 3b. Principle of measurement line.

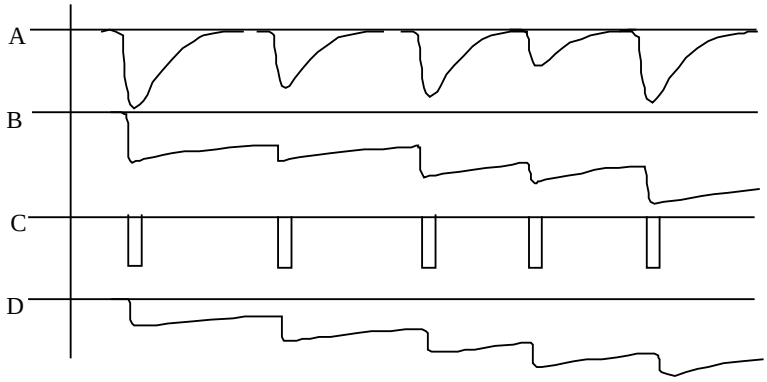

FIGURE 3c. Signal time diagram

MEASUREMENTS ON LN2/GN2 TWO-PHASE FLOW

The first tests to valid our sensor have been carried out in a specific test box where the detector was directly cooled by the fluid to be measured i.e LN2. The Beta source was located in a retractable support to avoid a long time exposure on the Ge crystal. High voltage polarization was 1600 V.

The vertical pipe was filled with LN2, then gas production was made by an electrical heater located below the detection zone. Finally, the pipe was quickly liquid purged. Temperature detector was around 77 K. Typical signal variations for energy and counting are represented in figure 4. During these nitrogen tests, we measured between 21000 and 25000 shots/s for pure LN2 (included stainless steel thickness) and more than 600000 shots/s in GN2 at 77 K. Total variation of energy signal has been slightly less than counting rate.

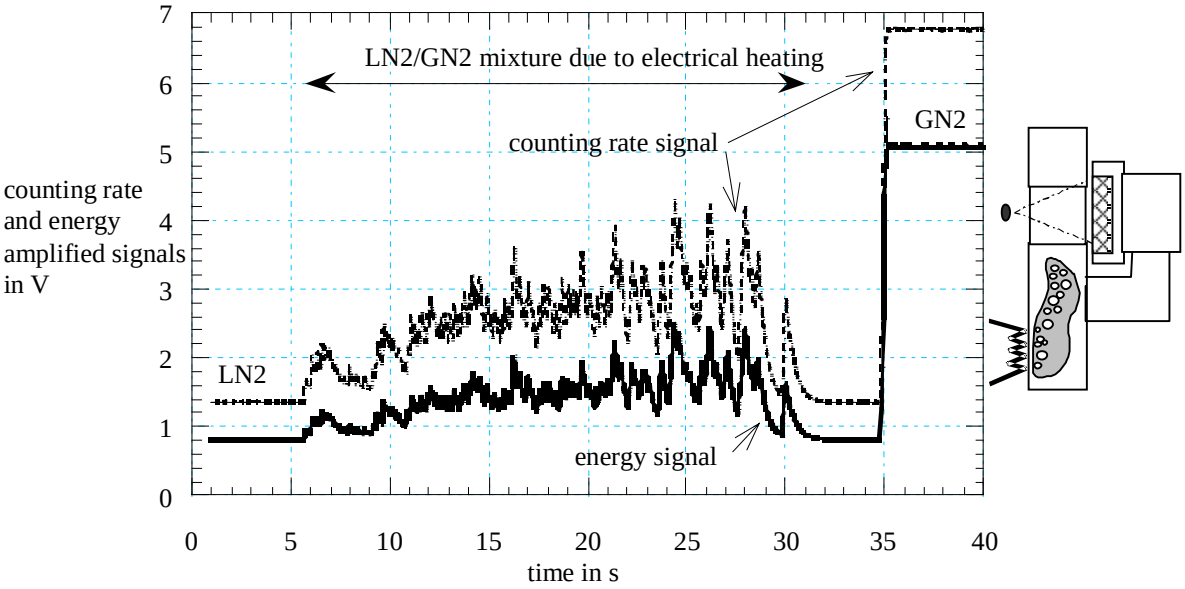

FIGURE 4. Signal measurements during 77 K nitrogen tests (gas volumetric quantity unknown).

MEASUREMENTS ON GHE/LHE TWO-PHASE FLOW

In the same configuration (test box), we used LHe/GHe to evaluate the sensitivity of our system. The temperature of Ge sensor was regulated by local heating and controlled by a Pt100 sensor. The temperature set-point was fixed at 83 K. Unfortunately by conception, it was then impossible to obtain , in this test case, a pure liquid helium medium(500 mW produced by regulation electrical heater). Typical signal variations for energy and counting are represented in figure 5. During these helium tests, we measured between 640000 shots/s for pure LHe (included stainless steel thickness) and more than 850000 shots/s in GHe around 4.2 K. Energy signal variation is larger than counting rate variation.

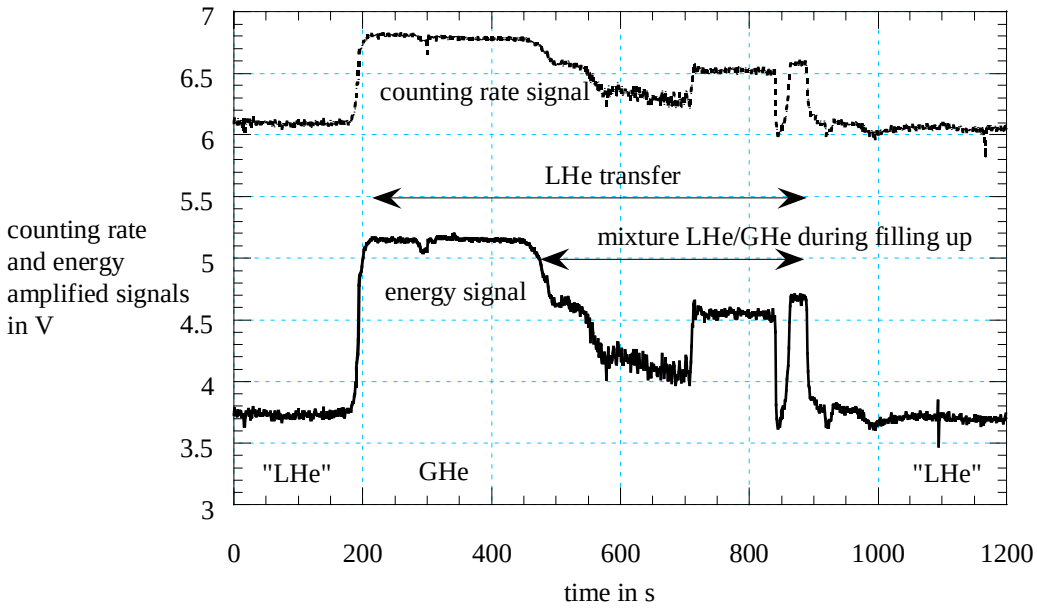

FIGURE 5. Signals variation during LHe/GHe at 4.2 K (gas volumetric part unknown)

MEASUREMENTS ON VERTICAL TWO-PHASE FLOW HE LOOP

In the study of vertical LHe/GHe flow, our laboratory has produced a specific vertical cryostat to generate vertical flow in a 10mm diameter pipe and to observe flow pattern modifications with mass flow rate and quality [11]. During these works , we implemented our sensor on the experimental loop, in addition with an already existing intrusive capacitance probe (coaxial capacitance). A Ge detector was fixed on a nitrogen thermal shields (80 K) and a source was located in an anti-cryostat tube to permit temporary positioning of the source during tests. We only used the energy signal for these tests. Figure 6 shows a scheme and a picture of the detector location.

The calibration of detector chain was made in-situ with a sub-cooled LHe flow (0.1 K below saturation) for the 0% gas and with gas vaporized for 100% gas (gas vaporization from a very close LHe interface to insure the 4.2 K temperature). Figure 7 gives typical results obtained in our vertical loop. During this test, instabilities in mass flow rate (+/- 10% of 0.9 g/s) lead to a significant scattering in quality values and void fraction measurements with capacitance probe. Nevertheless, the signal issued from our beta detector is well correlated with the capacitor probe. Others mass flow rates have been tested (0.4 and 0.6 g/s) and gives very similar behavior. During each test, initial and final values have been reproducible within 3 %. Counting rate was around 500000 shots/s in

pure gas at 4.2 K and 100000 shots/s in pure liquid. The difference with preliminary He tests is due to a larger thickness of the vertical pipe (e ≈ 0.30 mm for the final setup) and to the additional window to insulate source from the cryostat vacuum.

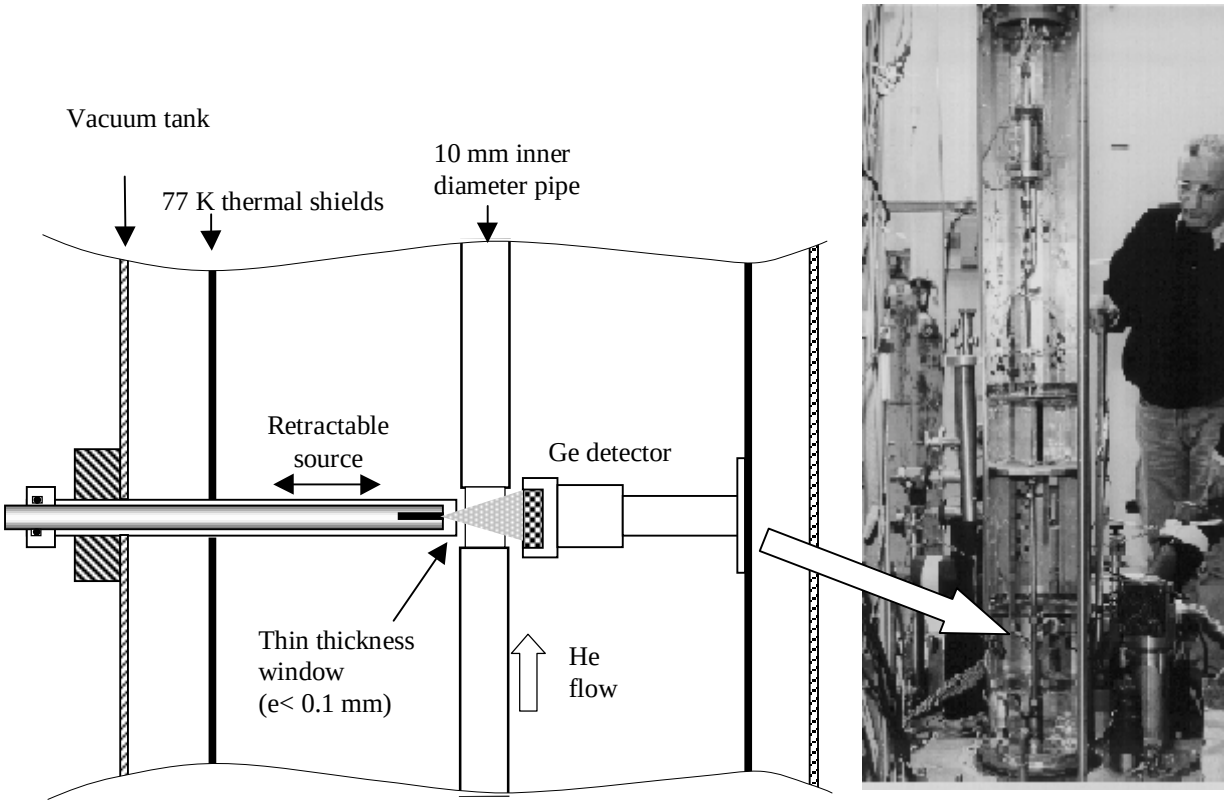

FIGURE 6. Schematic view of detector set-up with picture of vertical loop (without half of thermal shields and cryostat)

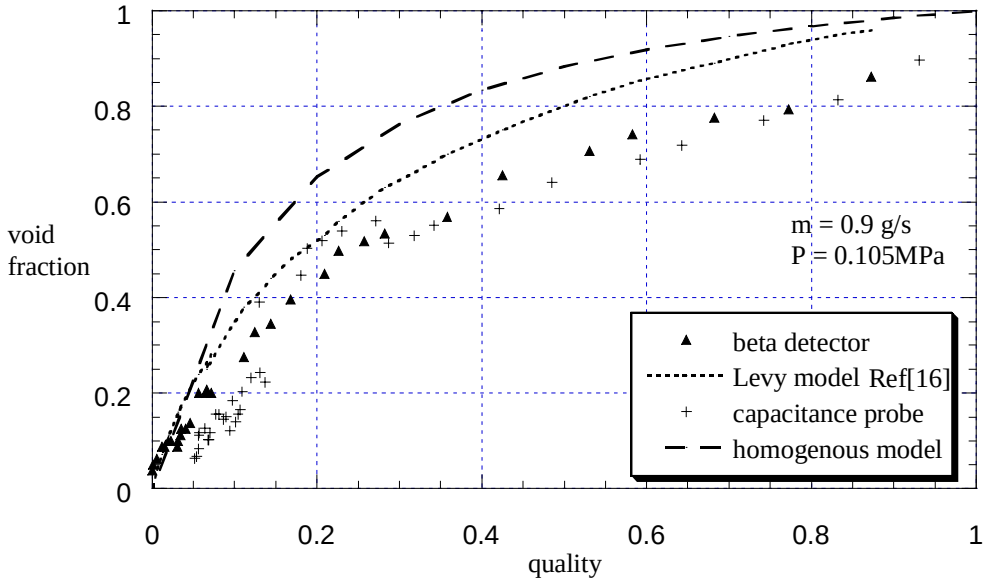

FIGURE 7. Void fraction measurements in vertical upwards two-phase LHe/GHe at 4.2 K

CONCLUSION

Void fraction measurement by attenuation technique with Beta source Sr90 and commercial semiconductor detector has been successfully tested on cryogenic fluids. Sensitivity of such method is demonstrated even in He two-phase flow.

The next step, started in our laboratory, will be to develop a dedicated electronic device able to measure void fraction with short time constant in order to access void fraction fluctuations ($\tau \approx 10$ ms) in LHe/GHe thermosiphon behavior.

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