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Gamma Scanning of Industrial Column for Water Treatment Comparing Two Scintillator Detectors: CsI(Tl) and NaI(Tl)

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Abstract

A gamma ray scanning system was developed, aiming to identify process failures in industrial columns. Two scintillator detectors: CsI(Tl) and NaI(Tl) were used for comparison. This system was tested in an industrial column for water treatment (6.5 m diameter and 40 m height). The source –detector system consists of: (1) ^{60}Co radioactive sealed source in a panoramic lead irradiator, (2) a scintillator detector coupled to a ratemeter / analyzer and (3) a mobile system. A dedicated computer with software for a data processing was used for recording in appropriate intervals and a profile of the instantaneous operation state was obtained by plotting the detector response against the column elevation. Based on the gamma ray absorption behavior of the inside medium, the density profiles of the columns were obtained. The thickness and the relative tray position column could then be clearly identified. Both, the NaI(Tl) and the CsI(Tl) detectors showed good proprieties for gamma scanning applications.

1. INTRODUCTION

Gamma scanning technique is a fast, efficient and cost–effective tool for better understanding of dynamic processes taking place in industrial columns and to examine inner details of a distillation, while it is in operation. This nondestructive technique provides an accurate density profile of an on-line process, and can be applied for troubleshooting, debottlenecking, predictive maintenance and process optimization [1].

The source selection, equipment for handling radioactive source and strategy to be adopted for inspection, vary to situation to situation. Knowledge of column internals, the process taking place inside and expertise in handling radioactive sources are essential for the analysis of scan data.

A collimated sealed source of penetrating gamma rays is allowed to pass through the shell of a vessel, is modified by the vessel internals and then comes out of the other side. By measuring the transmitted radiation intensity, valuable information can be obtained about the densities of the materials present inside the vessel. The higher the density of the material, the less radiation gets through; so significantly more gamma rays are transmitted trough a vapour compared to a liquid phase [3,4].

For columns of constant diameter and constant wall thickness, the radiation that is not absorbed can be obtained from the relationship [4,5]:

$$I = Io * e^{(-\mu_{eff}\rho x)} \quad (1)$$

where Io is the initial gamma ray intensity measured at a given distance with no medium interfering with the transmission of the radiation (empty column), and I represents successive radiation measurements taken through the column material. The average density of the process material is given as □. The effective mass absorption coefficient, μ_{eff}, of the process material derived experimentally. The thickness of material (radiation path length through which radiation is transmitted) is given as x. For gamma rays of energy greater than about 200 keV, the mass absorption coefficient is approximately independent of elemental composition. The scattering effects can usually be allowed for by calibration [3].

Since μ_{eff} is essentially a constant for organic materials, and x is a constant for liquids in columns of fixed diameter, the remaining variable is □. The log of the measured radiation intensity is proportional to the process material density [4].

In this paper a gamma scanning sealed source–detector system for distillation columns was developed. Basically, the system consists of: (1) ^{60}Co radioactive sealed source in a panoramic lead irradiator, (2) a scintillator detector coupled to a ratemeter/analyzer and (3) a mobile system. The performance of the system was compared, using two types of scintillator detectors: (a) CsI (Tl) crystal of 1.0 x 1.0 x 2.5 cm^3 developed at IPEN [6] coupled to a photodiode PIN, operating at 12 and a commercial detector of NaI(Tl) 2"x2" Minekin (model 9501) coupled to a photomultiplier, which operation voltage in the range of 500 – 1200 V. Each detector had their own ratemeter (counter).

A dedicated computer with a software for data processing was used for recording the counts at appropriate intervals and, so, a profile of the instantaneous operational state was obtained plotting the detector response in function of the column elevation. The detectors were calibrated to work only in the photopic region of the ^{60}Co. The typical radioactive sealed source used for gamma ray scans of a distillation column is only approximately 1 % of the strength needed to investigate X-ray welds [2].

2. EXPERIMENTAL METHODS

The detector is calibrated using a small cesium (0.22 MBq ^{137}Cs) source, mounted on the detection assembly. This provides a known energy level (0.667 MeV), from which a spectrum stabilizer maintains a constant base voltage to energy absorbed in the detector. Drifts in the detector characteristics do not result in a drift of the pulse height of the cesium peak at the single channel analyzer. The lower window of the analyzer is set above the cesium peak and the detector counts the radiation only from the photopeak region of cobalt rays (1.33 MeV) [5].

The radioactive source was placed inside a panoramic pot container collimated with lead, which give a uniform panoramic (360 grade) beam in the horizontal plane. The activity of the ^{60}Co

sealed source (1.48TBq), was calculated using a software to simulation of the density nucleonic gauges. This software takes into account parameters like the sensitivity, the type of detector, the statistics error, the resolution of the detector answer, the efficiency and geometry issues of the measurement system; to calculate the appropriate activity that should be used for each work conditions and to improve the result quality. [3,4].

The system developed was tested in an industrial concrete column (trayed column) for water treatment (6.5 m diameter and 40 m height), which consists of 4 trays: R1-R2, R3-R4, R5-R6 and R7-ground, as shown in Fig. 1.

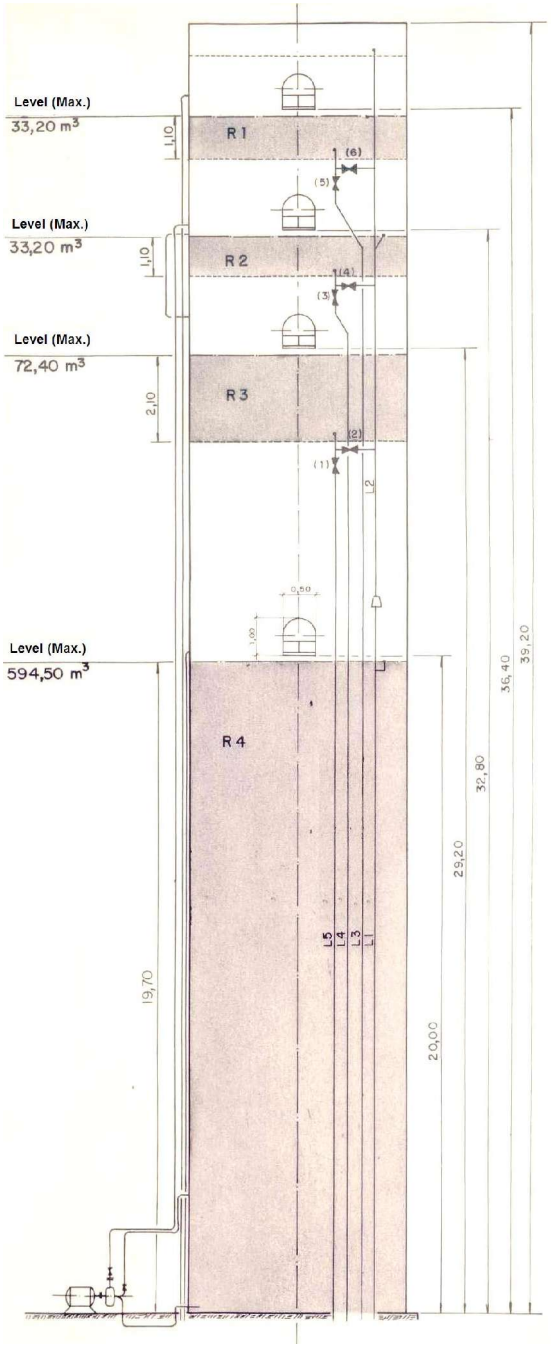

Figure 1. Water treatment industrial column

Fig. 2 illustrated the procedure scheme of the gamma scanning in the industrial column. The panoramic scanning container as well the detectors experimentally positioned to the column, on opposite sides, were moved concurrently in small increments. Both devices were moved along the column, and the radiation intensity values were measured in intervals varying between 10 to 100 cm. The counter times were fixed to thirty (30) flat seconds [2]. All data were evaluated statistically with a 95% confidence level.

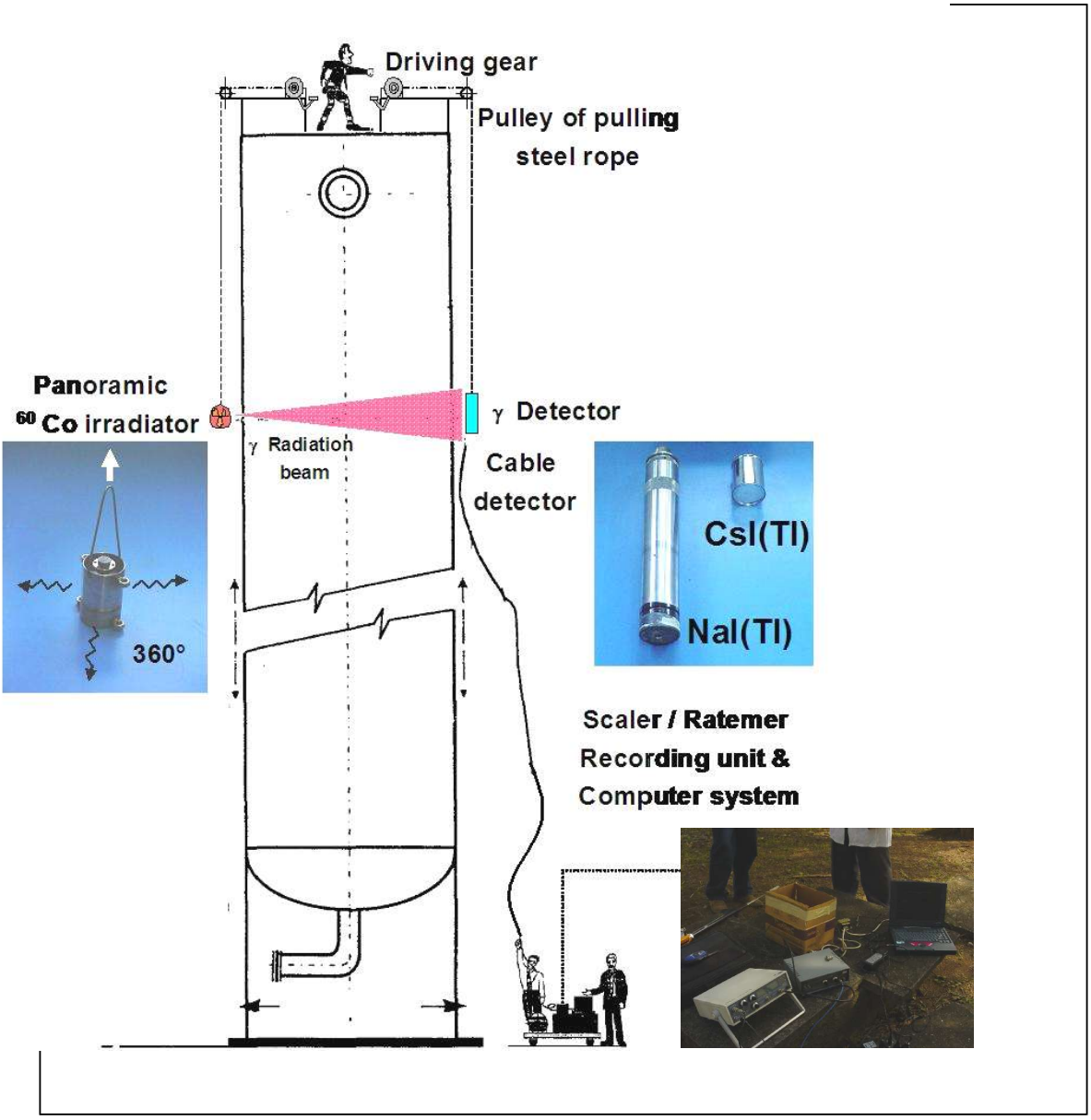

Figure 2. Scheme to execution of the gamma scanning

The relatives densities profile was obtained, by plotting the graph as: ln(I) vs. column height.

$$\ln(I) = \ln(Io) - \mu_{eff}\rho x \tag{2}$$

The thickness of a tray can be defined as "the increased gamma absorption to gamma absorption decay to clear vapour absorption between trays". The deviation from achieving clear vapour absorption between trays at industrial column indicates the extent of tray-to-tray entrainment and another hydraulic parameters (Fig. 3). Both, the width and the height of the attenuation peaks at tray position are a measure of the tray thickness.

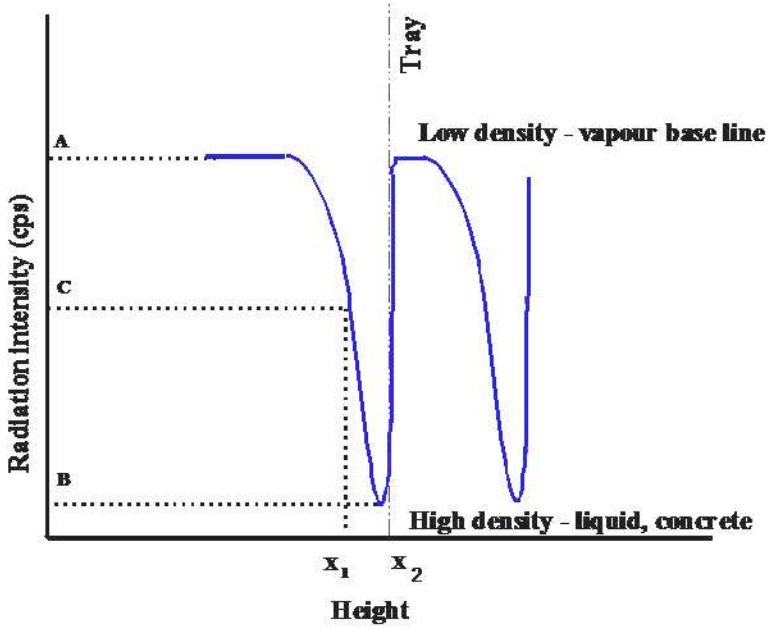

Figure 3. Method to determinate the thickness of a tray by: X_2 - X_1. Mid-way from maximum and minimum count rate that is (maximum + minimum)/2

The scans as already mentioned can be normalized by dividing all the scan values obtained by a reference relation (I_o). The normal equation (1) can be rewritten as:

$$\frac{I}{Io} = e^{\left(-\mu_{eff}\rho x\right)} \tag{3}$$

In this way, the scan profile is no dependent on the actual radiation level and the changes in the instrument settings or sensitivity of detector), since any effect on the intensity level is compensated for in this way. It is only dependent of μ_{eff} , □ and x functions (column and its

internals). In the practice, the value of I_o was obtained by measuring the radiation level through the column empty at a known source/detector distance. It is important to record this distance, since all future Io values have to be measured with the source and detector at the same distance [7].

3. RESULTS AND DISCUSSION

Fig. 4 shows the density profiles obtained with the gamma scanning technique, using CsI(Tl) and the NaI(Tl) detectors and ^{60}Co source. As it can be observed, both detectors were able to determine the trays positions (R4, R5, R6 and R7), which are identified by the attenuation "peaks" obtained during the time of the scan.

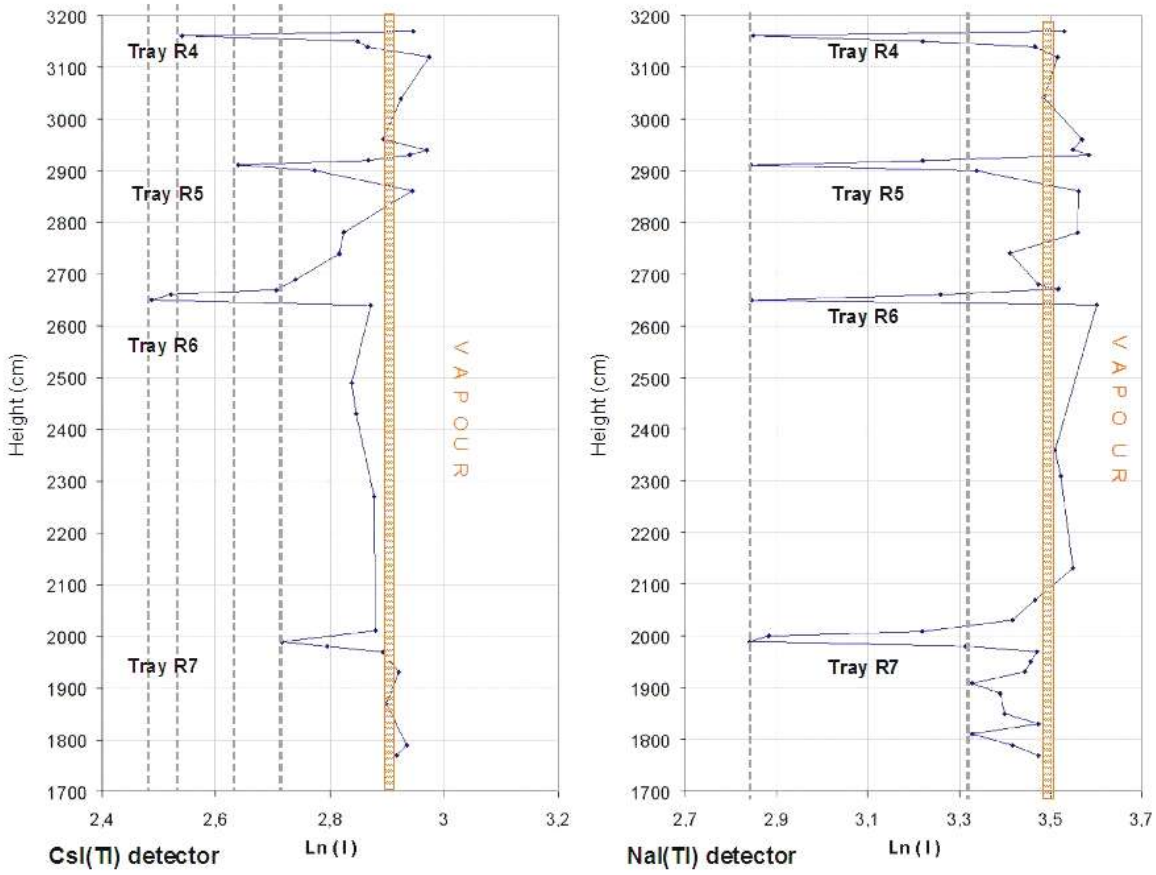

Figure 4. Gamma scan profiles with the CsI(Tl) and NaI(Tl) detectors

Table I summarize the critical limits (LC) and the detection limits (LD) and statistic errors of counting for the CsI(Tl) and NaI(Tl) detectors. LC is the limit value of the rate counting net (R_S), where above this counting value, the R_S is over zero (0) with 95% confidence level and LD is the

value limit that must be accumulated in the counting, in order to this value to be on LC region, discounting the background radiation.

Table I. Results of the gamma scanning proves with CsI(Tl) y NaI(Tl) detectors

	CsI(Tl) detector LC=0.08 cps / LD=0.15 cps		NaI(Tl) detector LC=0.17 cps / LD=0.35 cps	
	Mean Value (cps)	Statistic error (%)	Mean Value (cps)	Statistic error (%)
Io	18.17±1.54	8.56	32.30±2.05	6.41
I	12.00±1.24* 19.50±1.58**	8.26* 10.53**	16.97±1.49* 36.5±2.17**	6.03* 8.82**

*Minimal Values
**Maximal values

For both detectors, the Io and I values is higher than the LC and LD values. However, high statistical errors were obtained for the measurements, being higher for that the CsI(Tl) compared to the NaI(Tl) detector. This can be attributed to NaI(Tl) detector used to have efficiency (30%) higher than that of the CsI(Tl) detector (3%). The signal intensities recorded through the vapor spaces between the trays show statistics fluctuations, 17±0.8 cps (5.6% error) to the CsI(Tl) and 32.5±2.4 cps (15% error) NaI(Tl) detector. The statistical fluctuations could be improved, using a radioactive source higher and a guided system to vertical displacement of the source and detector, which minimize the source or/and detector drift.

The two detectors were able to identify the trays thickness and tray positions, inside de column, as shown in Table II. Both detectors determined the relative tray position with good precision, with errors of < around 1%. Nevertheless, for the tray thickness determination, the errors were high. Further experiments with radioactive source activity higher should be performed.

Table II. Tray thickness and relative position trays determinates from gamma scanning with CsI(Tl) y NaI(Tl) detectors

		Tray thickness				Relative position*				
Tray	Real value	CsI(Tl) detector		NaI(Tl) Detector		Real value	CsI(Tl) detector		NaI(Tl) detector	
		Exp.	Error	Exp.	Error		Exp.	Error	Exp.	Error
	(cm)	(cm)	%	(cm)	%	(cm)	(cm)	%	(cm)	%
R7	30	43.5	45.0	37.0	23.3	1970	1968	0.10	1980	0.51
R6	30	41.5	38.3	26.0	13.3	2650	2638	0.45	2642	0.30
R5	30	52.0	73.3	30.5	1.7	2890	2870	0.69	2887	0.10
R4	30	36.0	20.0	26.0	13.3	3140	3133	0.22	3143	0.10

*Lower tray level.

At the Fig. 5 it is showed a comparison of the normalized gamma profiles obtained for both detectors. The best results were found using the NaI(Tl) detector, because it presents, same values to the lower value by the attenuation "peaks". The method adopted by the determination of the thickness and the position tray is very related with the regular shape to the attenuation peaks.

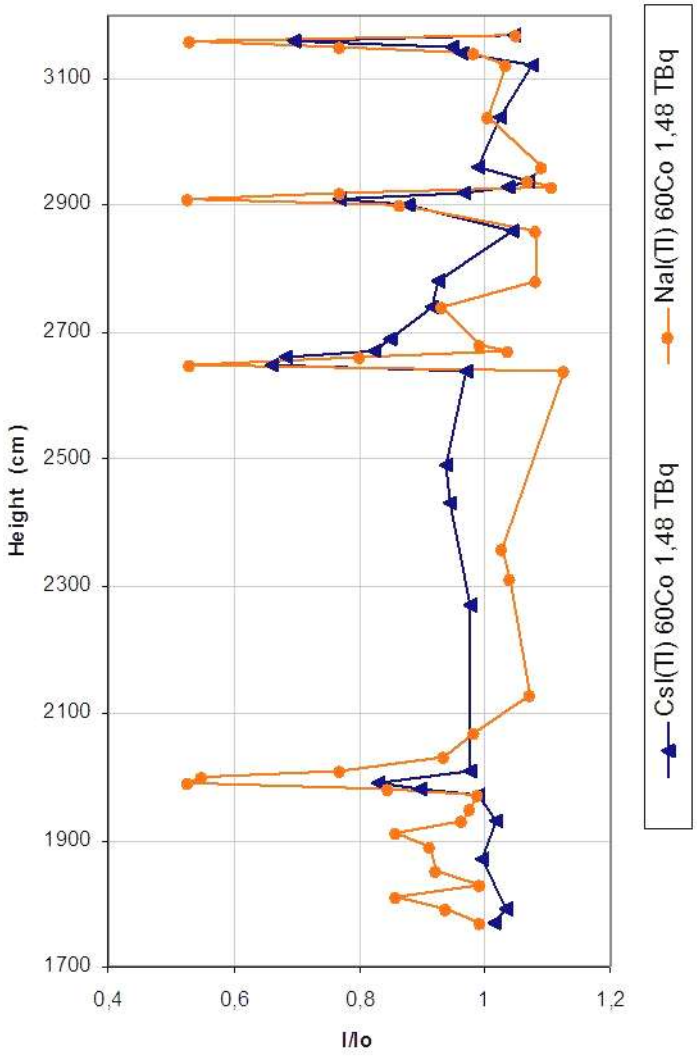

Figure 5. Comparison of the normalizations gamma scanning with the CsI(Tl) y NaI(Tl) detectors

The NaI(Tl) used in this work presented the statistical errors lower than CsI(Tl) probably due to its higher efficiency. However, in the practice, both detectors shown suitable to be used in the gamma scanning of industrial column. On the other hand , the CsI(Tl) crystal coupled to a PIN

photodiode has the advantage of being rigid, compact, having high mechanical and thermal resistance, operating at low tension (12V), while the NaI(Tl) detector operates at high tension, around 1 000V. For industrial application, as in the gamma scanning, where it is necessary to work in adverse situations, these factors are very important. Besides, thee cost of the CsI(Tl) detector is ten times most economic to the NaI(Tl) detector system.

4. CONCLUSIONS

The NaI(Tl) and the CsI(Tl) detectors showed good proprieties for gamma scanning applications, determining the thickness, position and presence or absence of trays. The results of gamma scanning were able to evaluate the functioning of the water treatment column and the applying of the these technique reveal the real advantages. The technique shows to be straight- forward, quick, sensitive and safe for the determination of the hydraulic parameters. The ^{60}Co activity depends of the goal of the work, because low activities can evaluate the great error problems, but if the goal is the determination of the densities of liquids and vapours moderate activities can be used. Consequently, it can help improve the efficiency of a process and its quality control, thus yielding large savings through the avoidance of loss of production and wasted maintenance effort.

4. FURTHER WORK

The system test under a distillation industrial column of a petrochemical plant will be carried out with ^{60}Co panoramic irradiator, with the same detectors.

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