PROMPT GAMMA-RAY NEUTRON ACTIVATION ANALYSIS FOR FLUIDS

Ilker Meric, Jiaxin Wang, and Robin Gardner

TOPICS

- How Started
  + IAEA CRP and Prof. Johansen
- References
- CEAR Research
- University of Bergen Research
- Possible Saudi Aramco Project

REFERENCES

- A.M. Mutiso, G.A. Johansen, and R.P. Gardner, "Investigation of Prompt Gamma-Ray Neutron Activation Analysis for Determining Phase Amounts in Multiphase Flow", CD ROM Proceedings of 5th World Congress on Industrial Process Tomography, pp. 979-985, (2007).
- Jiaxin Wang, Fusheng Li, and Robin P. Gardner, "On the use of prompt gamma-ray neutron activation analysis for determining phase amounts in multiphase flow", Measurement Science and Technology, 19, pp. 1-6, (2008).
- Ilker Meric, Geir A. Johansen, Marie B. Holstad, Jiaxin Wang, and Robin P. Gardner, "Produced Water Characterization by Prompt Gamma –Ray Neutron Activation Analysis", submitted to Nuclear Instruments and Methods A.

REFERENCES, 2

- Athanas Mutiso, "Investigation of Prompt Gamma-Ray Neutron Activation Analysis for Determining Phase Amounts in Multiphase Flow", MS Thesis, NCSU, 2007.
- Vincent DiNova, "Automated Spectrum Stripping of Photon Spectra", MS Thesis, NCSU, 2011.
- Xiaogang Han, Robin P. Gardner, and W.A. Metwally "CEARCPG: A Monte Carlo Simulation Code for Normal and Coincidence Prompt Gamma-ray Neutron Activation Analysis (PGNAA)", Nuclear Science and Engineering, 155 (1), pp. 143-153 (2007).
- Salahuddin Sheikh and Albert P. Richter, "Nuclear Salt-in-Crude Monitor", Society of Petroleum Engineers of AIME, pp. 1009-1016, May, 1983.

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Table 2. The assumed elemental composition for oil, water and gas samples as used for CEARCPG simulation with densities of $0.8\ g\ cm^{-3}$ for oil, $1.025\ g\ cm^{-3}$ water and $0.031\ g\ cm^{-3}$ for gas.

Sample	Element	Weight fraction
Oil	Hydrogen	0.15
	Carbon	0.85
Pure water	Hydrogen	0.1111
	Oxygen	0.8889
Salt	Sodium	0.3934
	Chlorine	0.6066
Gas	Carbon	0.75
	Hydrogen	0.25

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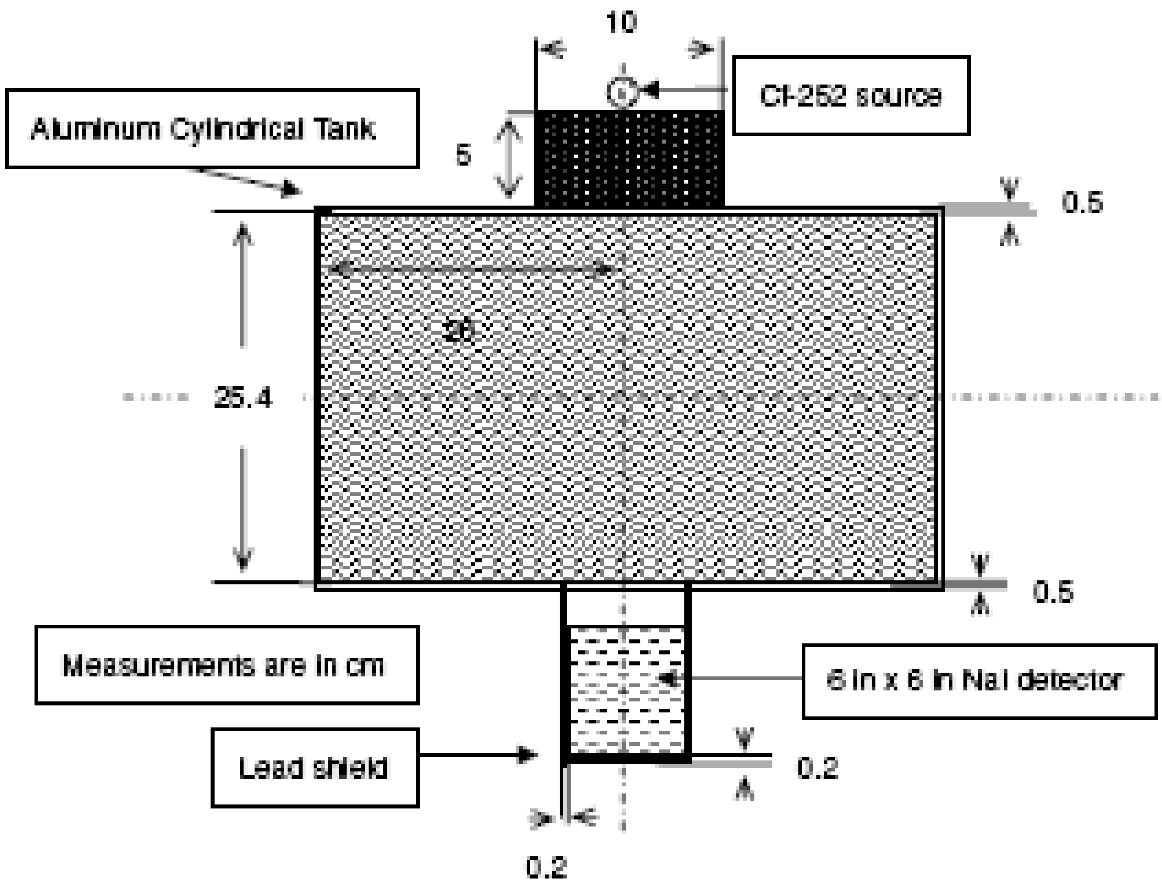

Figure 1. Schematic design and dimensions of the multiphase flow measurement system (unit: cm).

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Table 3. The assumed elemental composition for the eight elements in the sample used for CEARCPG simulation with a density of 0.92 g cm^{-3}.

Element	Weight fraction
Hydrogen	0.127 563
Carbon	0.375 781
Oxygen	0.478 055
Sodium	0.006 015
Chlorine	0.010 804
Potassium	0.000 223
Calcium	0.000 223
Magnesium	0.000 72

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relationship between weight percentage (W) of salt (NaCl) and solution density (ρ) in g cm^{-3} is taken here as

$$\rho = 0.007\,595\ W + 1.000\,00.$$

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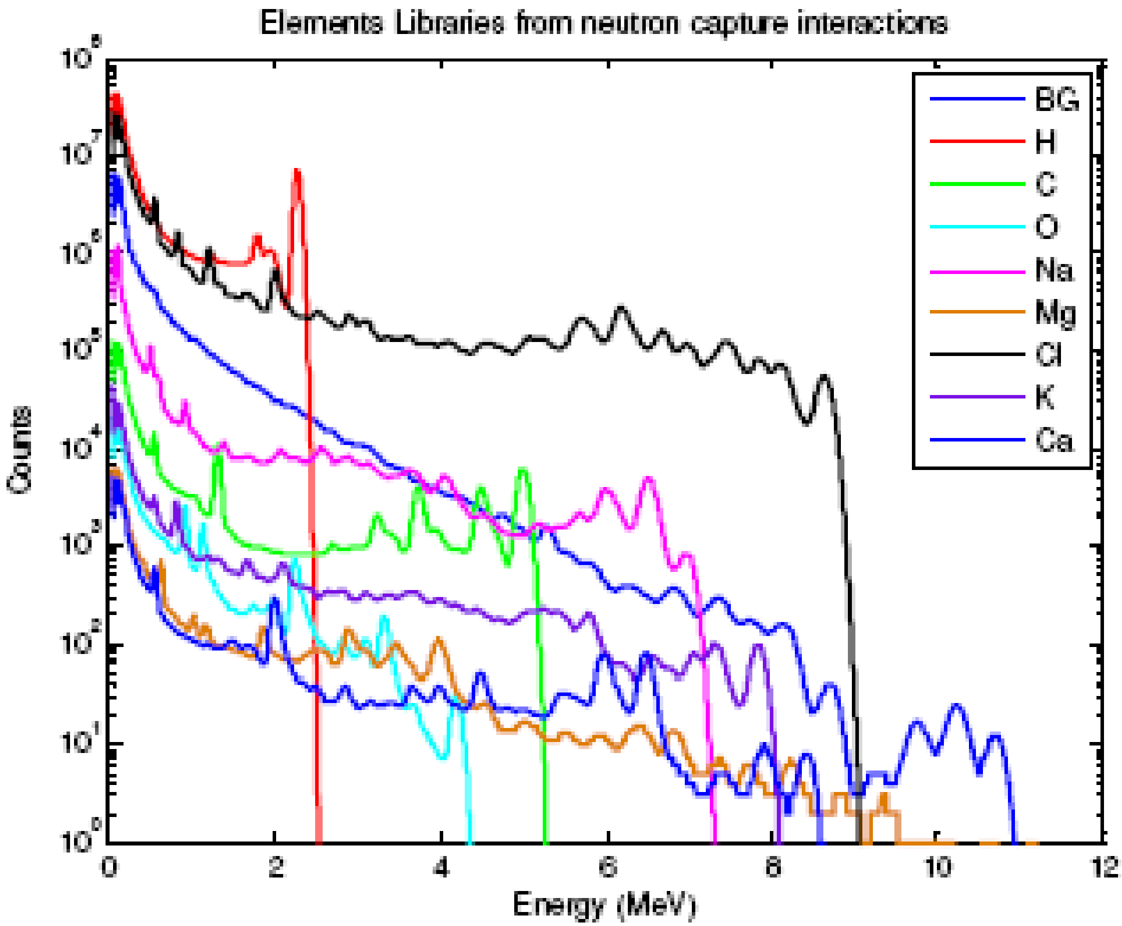

Figure 2. Elemental libraries from neutron radioactive capture interactions.

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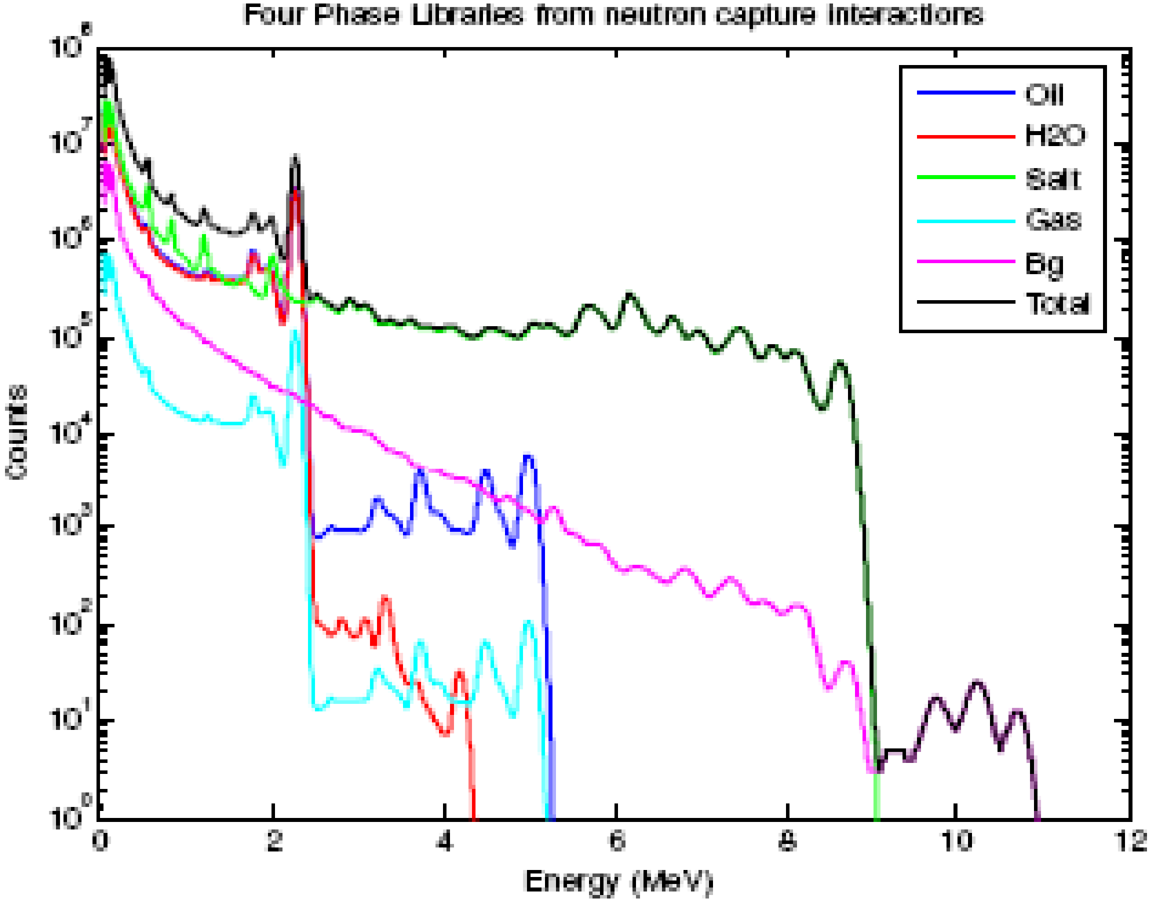

Figure 3. Phase libraries from neutron radioactive capture interactions.

CEAR RESEARCH, 7

Table 4. Simulated sensitivities for the assumed oil–seawater–gas sample analysis for three different background levels for all three phases and background.

	True weight fraction[a]	Fitted weight fraction[a]	σ (%)	Spectral area (%)
H_2O	53.88%	53.88%	3.71	25.89
Salt	1.69%	1.69%	0.04	38.23
Gas+oil	44.44%	44.44%	3.35	29.06
Background	100%	100.003%	0.91	6.83
H_2O	53.88%	53.89%	4.30	16.04
Salt	1.69%	1.69%	0.04	23.68
Gas+oil	44.44%	44.43%	3.88	17.99
Background	100%	1000.05%	0.14	42.29
H_2O	53.88%	53.96%	9.32	3.34
Salt	1.69%	1.69%	0.05	4.93
Gas+oil	44.44%	44.38%	8.43	3.74
Background	100%	10000.3%	0.05	87.99

[a] Background is a relative value only.

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Table 5. Calculated weight fractions of salt and gas plus oil in unknown samples.

	Phase	Real WF	Fit WF	Error
20% less salt	Salt	1.35%	1.36%	0.58%
	Water	54.06%	52.21%	3.41%
	CH	44.59%	46.42%	4.12%
20% more salt	Salt	2.02%	2.01%	0.49%
	Water	53.70%	56.07%	4.41%
	CH	44.29%	41.93%	5.33%

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To extract the gas volume fraction one can use a traditional gamma-ray densitometer using a Cs-137 source, which has a single energy of 0.662 MeV and a half-life of about 30 years (Johansen and Jackson 2004). In fact, one could use this radioisotope gamma-ray source simultaneously with the Cf-252 source while using the same NaI detector as used for the prompt gamma rays, since the gamma-ray energy of the Cs-137 is in a region of the prompt gamma-ray spectrum that does not interfere with determining the prompt gamma rays.

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water. Assuming that the response to the Cs-137 gamma ray intensity is essentially an exponential, an analysis using the relationships

$$\sigma(\rho) = (\mathrm{d}\rho/\mathrm{d}R)\sigma(R)$$

and

$$R(\rho) = R(0)\exp[-(\mu/\rho)\rho t] + b,$$

where R is the total counting rate response to the Cs-137 gamma rays, t is the cylinder diameter (25.4 cm) and b is the gamma-ray gauge background response. Indications are that a 1% variation in ρ (which is equivalent to a 1% variation in R) would be easy to obtain.

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- DiNova also used the same Monte Carlo simulated data that was generated by Wang et al with his spectrum stripping approach.

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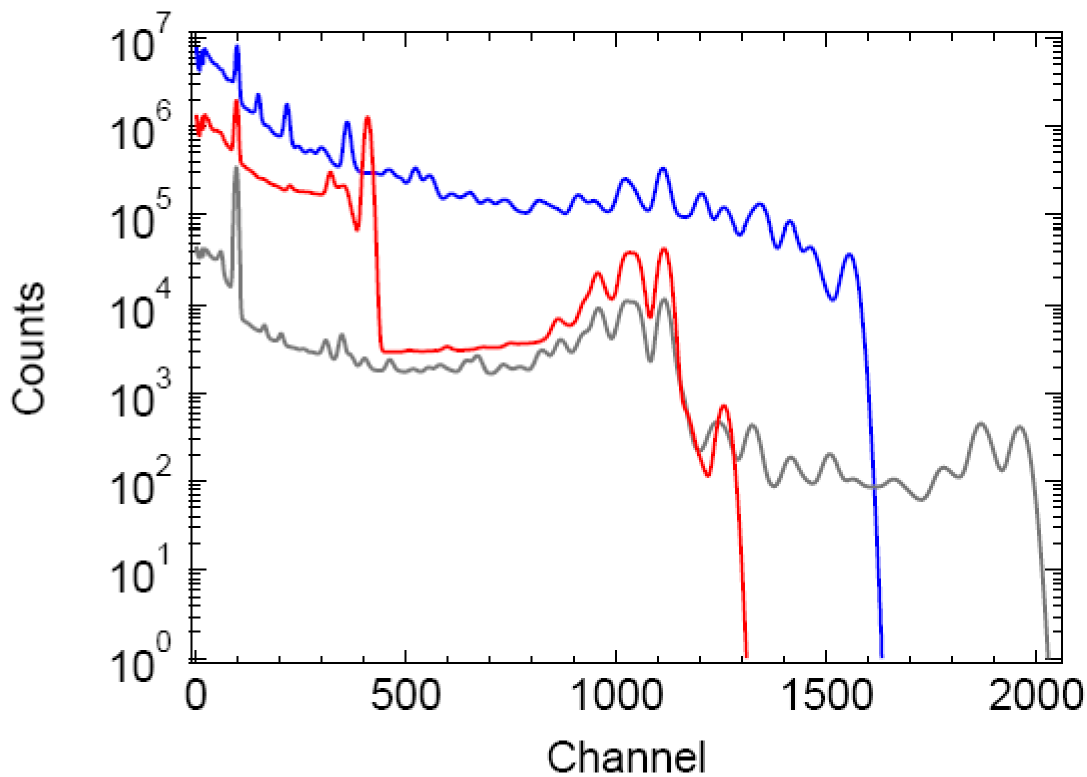

Figure 24: Library Contribution to Experimental Spectrum

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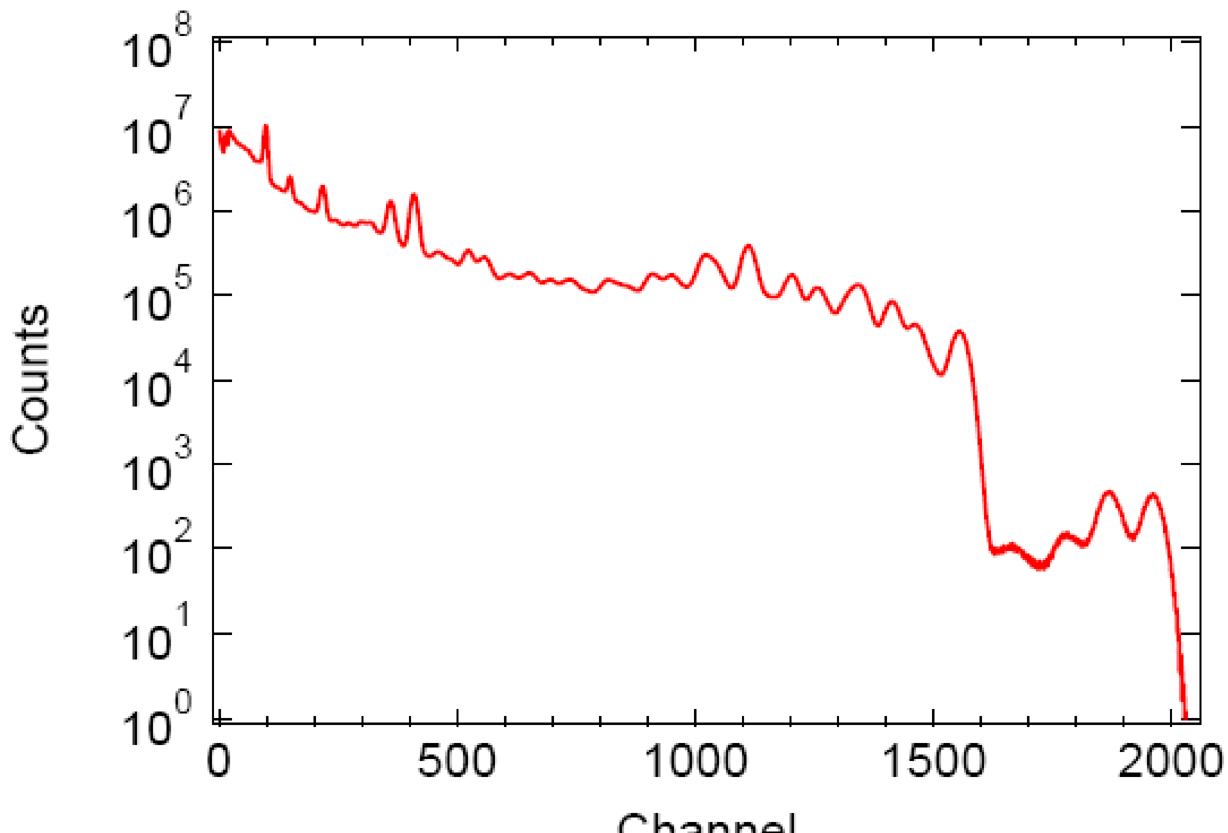

Figure 25: Experimental Spectrum

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Table 6: Comparison between Calculated and Known Amounts

Library	Known Coefficient	Calculated Coefficient	Relative Error
Air	1.00E+14	9.990E+13	0.10%
Salt	1.00E+14	1.000E+14	0.00%
Water	1.00E+14	9.924E+13	0.76%

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composition and density of the produced water sample

Elements	Weight fractions	Density of solution g/cm^3
Hydrogen	0.107 367	
Oxygen	0.852 122	
Sodium	0.015 641	1.0224
Chlorine	0.024 455	
Strontium	0.000 414	

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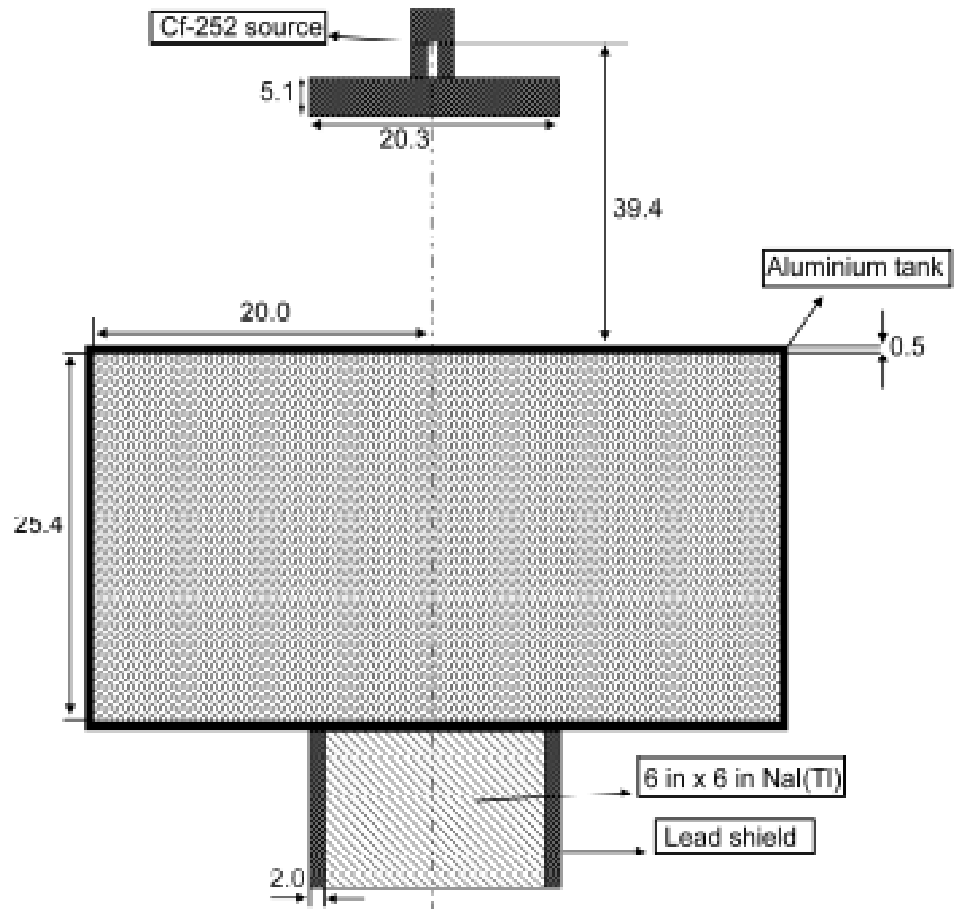

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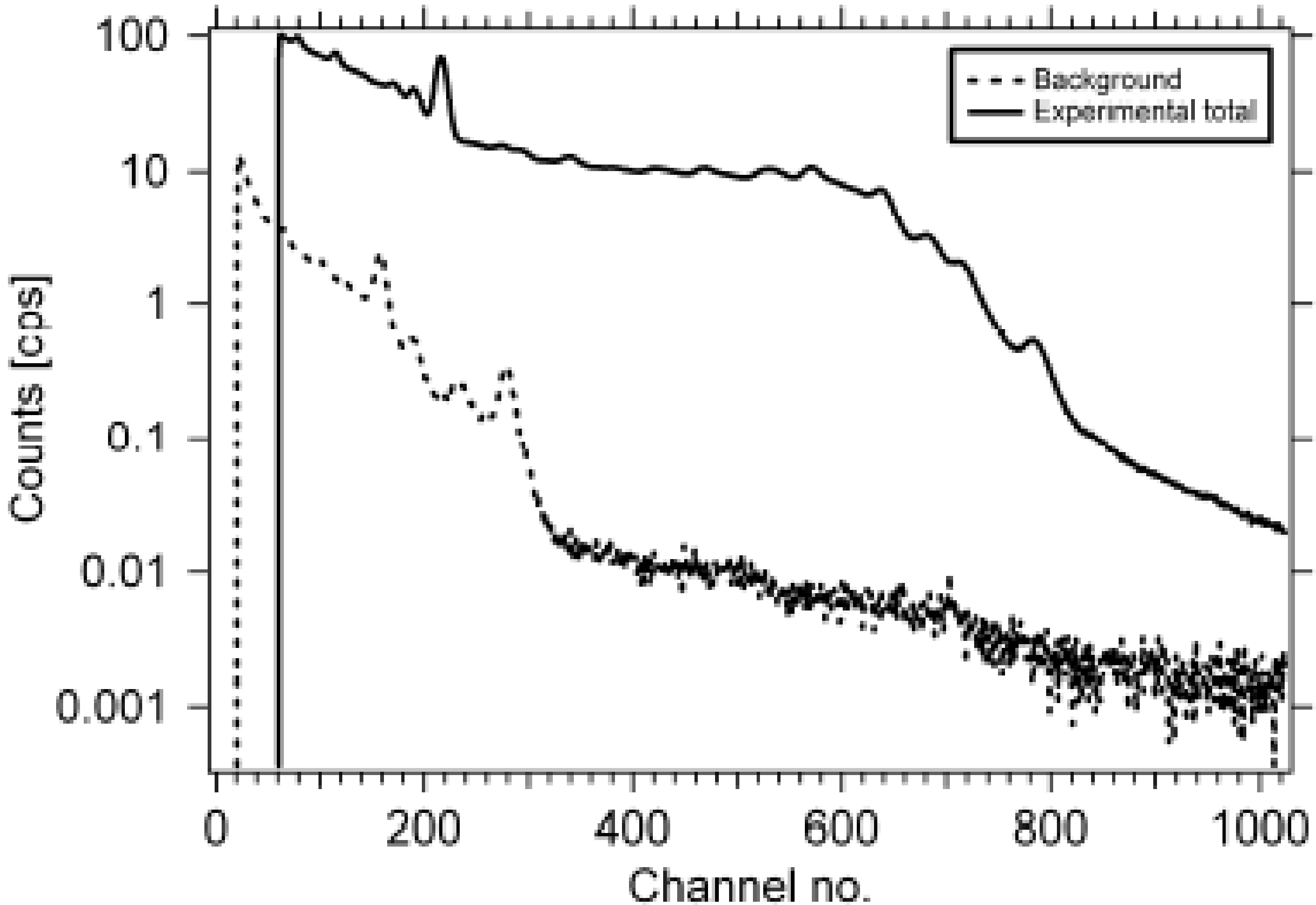

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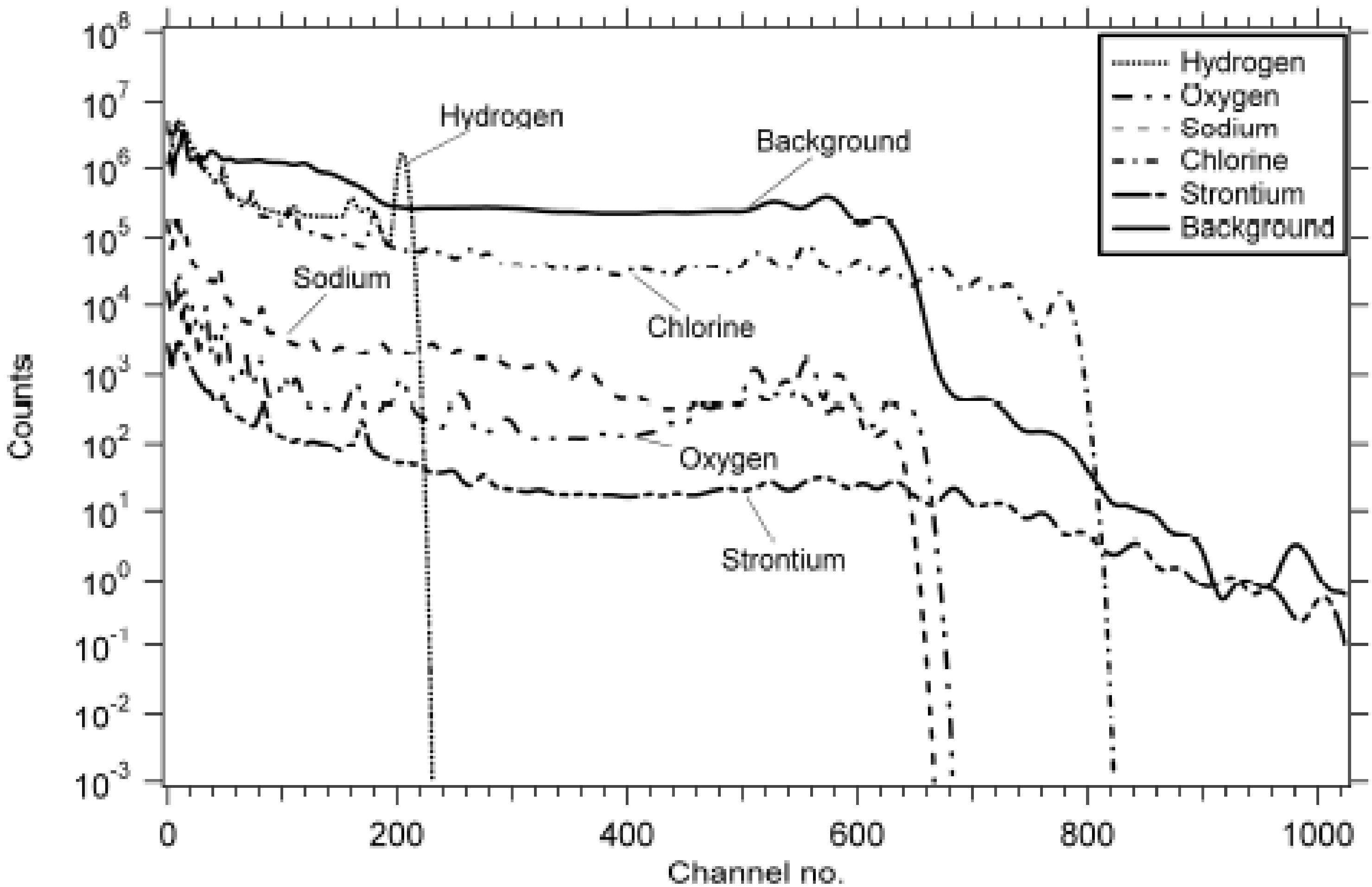

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Table 5. MCLLS calculated and real weight fractions of the elements in the produced water sample. Also given are the errors in the estimates.

Element	Real weight fraction	Calculated weight fraction	Error [%]
Hydrogen	0.107 367	0.004 2	96.1
Oxygen	0.852 122	-0.98	215.01
Sodium	0.015 641	0.014 3	8.6
Chlorine	0.024 455	0.000 7	97.14
Strontium	0.000 414	0.000 8	92.24

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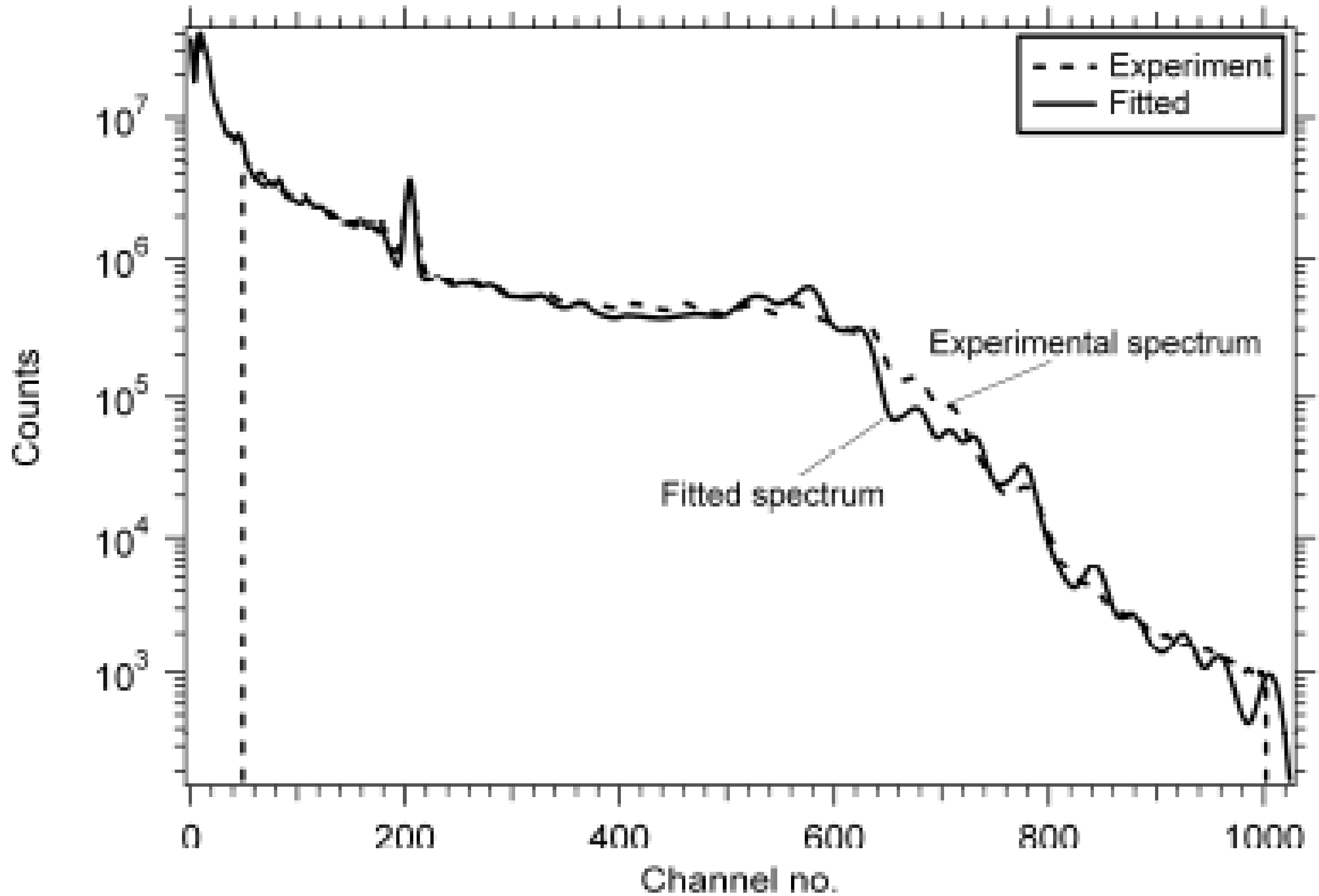

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Element	Real weight fraction	Calculated weight fraction	Error [%]
Hydrogen + Oxygen	0. 959 489	0.960 046	0.06
Sodium	0.015 641	0.0152	2.82
Chlorine	0.024 455	0.0241	1.45
Strontium	0.000 414	0.000654	57.8

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- The results indicate that all the components except strontium give good measured amounts. This is to be expected in that Sr is present in a very small amount.
- There is an indication that pulse pile-up is a problem at the higher energies. This could be eliminated by first correcting the experimental spectrum for pulse pile-up distortion.

POSSIBLE SAUDI ARAMCO PROJECT

- **Saudi Aramco has asked me to look at a new design for measuring Cl and S in flowing oil by PGNAA.**
- **The paper describes a device that consists of a 24-inch diameter pipe that is 48 inches long that has two cross flow pipes – one is about 3 and the other 6 inches in diameter. They house the Am-B source and NaI detector, respectively.**
- **Measurements with this PGNAA device are desired for Cl and S in a flowing oil mixture.**
- **The source is an Am-B source emitting about $1.X10^7$ neutrons per second.**
- **The detector is a NaI crystal of unknown size – could be up to a diameter of six inches and more than six inches in length, but appears to be 5 inches long by 3 inches in diameter.**
- **Three windows on the spectrum are used of about 2.0 to 2.4, 5.0 to 5.6, and 5.6 to 8.0 MeV for H, S, and Cl, respectively.**

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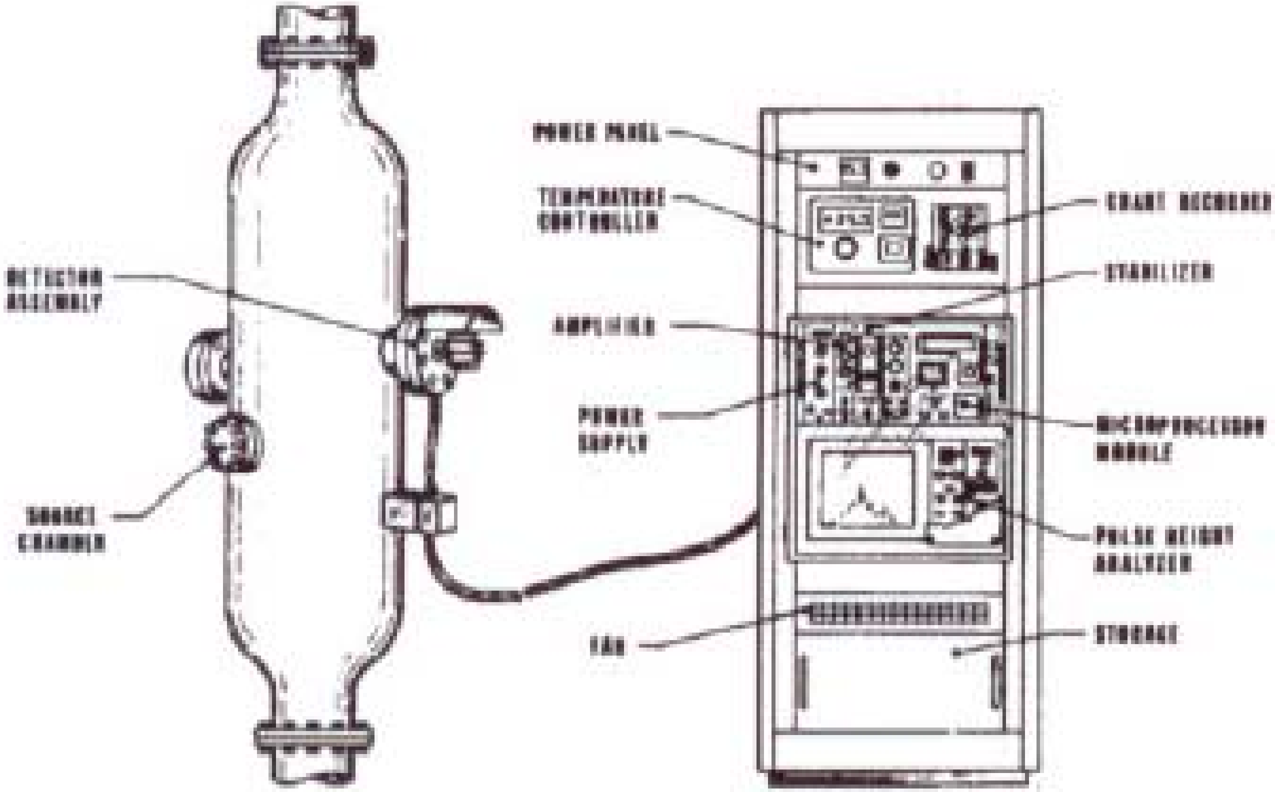

Fig. 1—Salt-in-crude monitor system.

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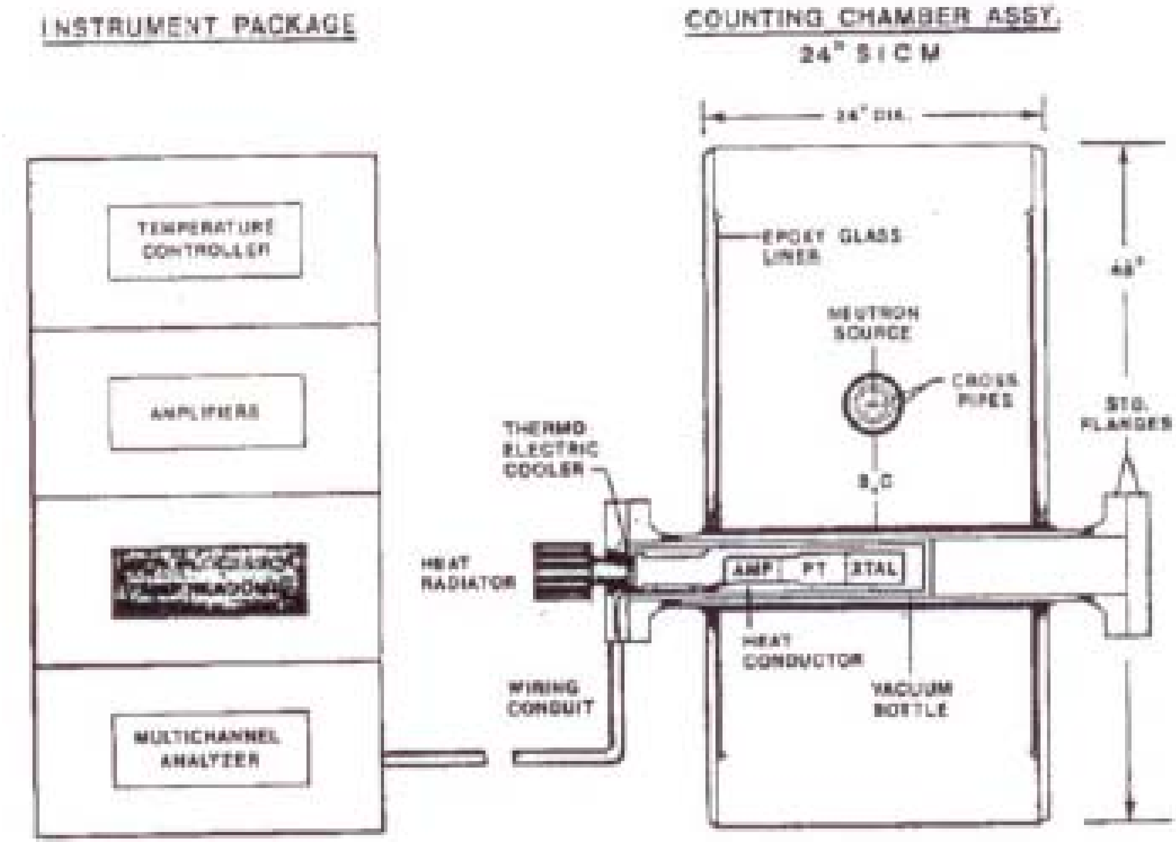

Fig. 4—System cross section.

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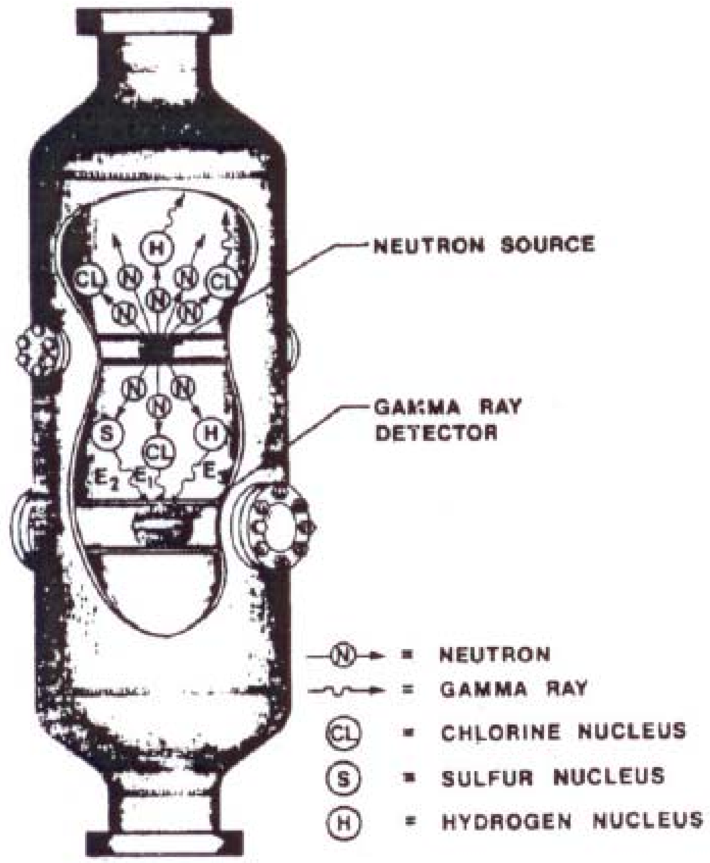

Fig. 2—Chamber cutaway.

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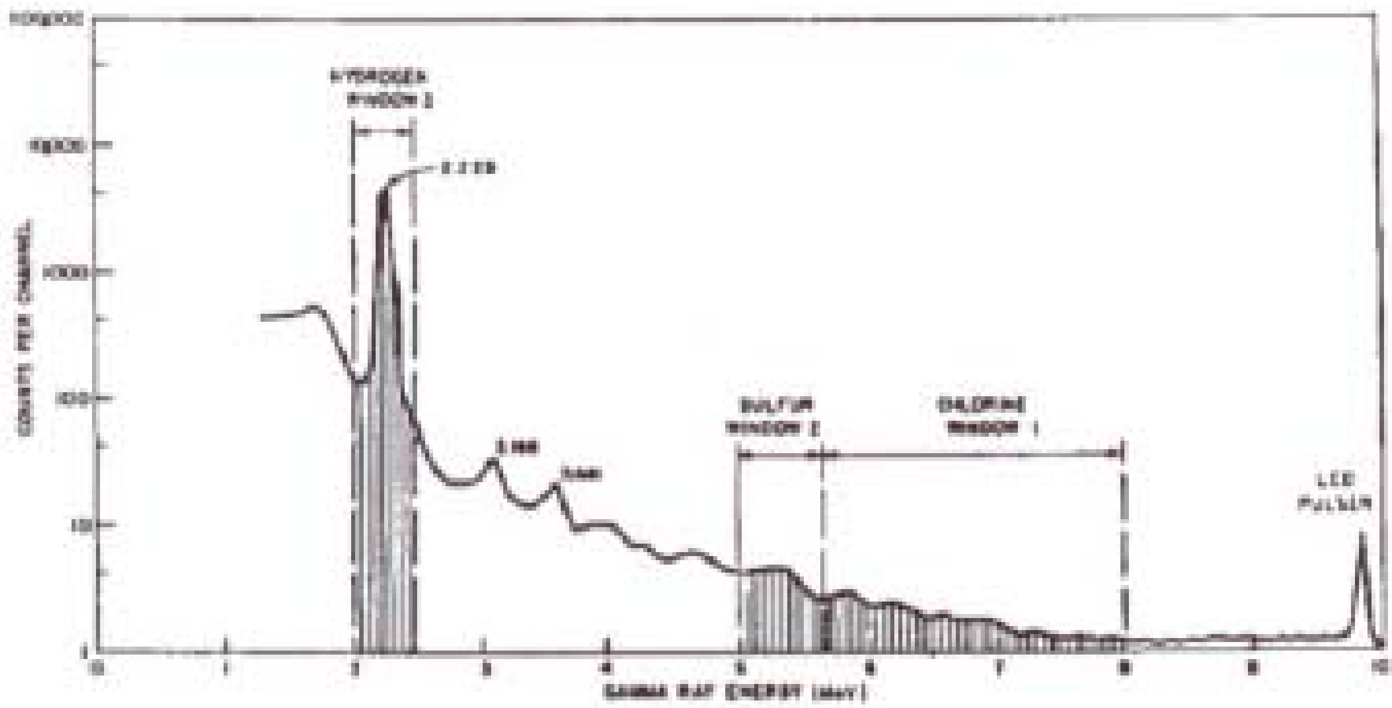

Fig. 3—Typical gamma ray spectrum.

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- The inverse analysis described in the paper consists of the two equations: Salt=$K_1+K_2F_{Cl}+K_3F_S$ and Sulfur=$K_4+K_5F_S+K_6F_{Cl}$ where the F_{Cl} and F_S are ratios of the Cl and S counts to the H counts, respectively.
- This device reminds me of the first (SAIC) PGNAA device for measuring the elemental analysis of coal on a conveyor belt. It had "Cadillac" hardware and "Model T" software.
- A range of improvements can be made in a new design for this device. Hardware improvements might be: (1) an Am-Be neutron source, (2) a neutron accelerator source, and (3) installation of the detector(s) and/or the source outside of the main pipe. Software improvements might be (1) the use of the Monte Carlo – Library Least-Squares (MCLLS) approach that uses the entire experimental spectrum and generates library spectra for all components by Monte Carlo simulation or (2) use of coincidence counting which would decrease the background considerably.
- It is a very interesting problem.