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METHOD OF CLADDING RUPTURE LOCALIZATION BY TRACER GASES - EXPERIENCE ACQUIRED AT CEA

(Methode de localisation des ruptures de gaine par gaz traceurs - experience acquise au cea)

By

Boyer, Chantoin, Jarretou and Pages

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June 10-15, 1974

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By

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I. Introduction

One method of cladding rupture localization (CRL) consists of introducing a certain volume of "tracer" gas (or "label") into all pins of one assembly. The selected gases which must differ from fission gases are kryptons and xenons of specific isotope composition with light-isotope enrichment (Kr-78, Xe-124, Xe-126, Xe-128). In the case of cladding rupture, this tracer gas is transferred into the blanket argon. An activated carbon trapping device and mass spectrometry then allow a measurement of the isotope ratio (Kr-82/Kr-78, Xe-129/Xe-124 or Xe-129/Xe-126) identifying the tracer.

In RAPSODIE, this labeling is done routinely except in a particular category of capsule assemblies (about 1/4 of the core). It has been in effect since the first quarter of 1973 for the experimental assemblies and since mid-1974 for the seed core. At the present time, only xenon is utilized with significant ratios of Xe-129/Xe-124 with a 20% difference; the use of krypton is planned; more than half of the assemblies irradiated in the core are labeled.

For PHENIX, labeling with krypton and xenon has been investigated and the instrumentation installed. In mid-1973 it was decided to label the experimental assemblies and the subsequent possibility of labeling the entire core is under consideration.

For SUPER-PHENIX, design studies are giving consideration to xenon and krypton labeling as an option.

II. Labeled Assembly Fabrication Experience

II.1 Tracer gas supply. Krypton and xenon with light isotope enrichment are produced by thermal diffusion. Two installations designed and constructed by CEA are operational at CEN/SACLAY with performance data conforming to the design calculations. They are capable of supplying 6 l/year of krypton enriched with 6% Kr-78 and 2.7 l/year of xenon enriched with 10% Xe-124; this production covers the complete labeling of RAPSODIE and PHENIX.

II.2 Tracer gas capsules. The tracer gas is introduced by means of a capsule placed into the plenum chamber of the pin and losing its seal at elevated temperature. The stainless steel capsule (Fig. 1) has a tin solder joint and a porous plug to prevent spattering of tin toward the cladding. It contains the tracer gas under pressure (10 bars). The quality test after filling is performed by adding a small amount of krypton-85 ($\sim 3\ \mu$ Ci) to the tracer gas and controlling its activity with an automatic β,γ-counting system (Fig. 2).

An automatic capsule filling installation (Fig. 3) has been operating since early 1973 at a private industry (Société Industrielle de Combustible Nucléaire); it is connected with an automatic Kr-85 detection system developed at CEA. The installation was designed for an output of 30,000 capsules/year for PHENIX labeling. In fact, the present output is only about 5,000 capsules/year. After about 1 year of improvements (gas leaks, defective solder, etc.), satisfactory operation was obtained (reject rate lower than 15%).

A study of the labeled precursor assemblies for the Fortissimo pins demonstrated the following:

The tin is confined within the capsule with no risk of attack on the cladding.

The mixture of helium-tracer gas ($\leqslant$ 15%) proved to be compatible in terms of heat transfer at the start of irradiation.

The tracer gas capsule involves a loss of the available free space for fission gases. This loss is negligible in the case of PHENIX or the reactor; for Fortissimo, with its small expansion chamber (2.4 cm^3), it amounts to an approximately 9% loss in operating burnup for the fuel element.

II.3 Influence of labeling on cladding operations. Because of labeling, the fuel pins are no longer randomized; this leads to the following conditions during cladding:

A coding method (with an electric marker pen) and very strict accountability.

Organization of the fabrication program to avoid immobilization of fissile material to a maximum.

After three years of experience in the Cadarache cladding plant, no notable technical problems have occurred; labeling involves a few additional operations (storage or decladding of pins, controls, etc.).

III. Labeling Experience in RAPSODIE

III.1 Operation of measuring equipment. The measuring system shown in Fig. 1 as a diagram essentially consists of the following:

An enrichment line consisting of activated carbon cooled to -40°C.

A quadripolar mass spectrometer of low resolving power (400 at 10% of the peak height for mass 300) constructed by Riber Company.

The system is connected to a sampling station of the core blanket and on instruction of the operator, performs a cyclic analysis (1 test point/h).

It has been installed since 1970 and after a startup period of about 1 year, has proved its good operation. It permits the precise detection of a xenon isotope present in a concentration of at least 10^{-11} (with a relative error of ± 3%).

III.2 Background determinations. The explored peak spectrum contains two sources for background: hydrocarbons and natural xenon resulting from air entry into the blanket.

It has been estimated that the concentration of air necessary for a maximum variation of 1% of the significant isotope ratio of the tracer Xe-129/Xe-124 is 300 vpm. This influence of natural xenon is minimized by a calculating program making an automatic correction.

In steady state, the air concentration measured in RAPSODIE is less than 2000 vpm and an average of 800 vpm (Fig. 5). It increases after a handling procedure and an operating instruction then provides for a sweep of the core blanket until the concentration is reduced to 1500 vpm before a power rise begins.

The presence of hydrocarbons has been observed occasionally (Fig. 5) primarily following injections of helium around the reactor plugs. In order to remedy this disadvantage, the addition

of a system to eliminate the hydrocarbons (by cracking and a getter pump) to the measuring equipment is under study.

III.3 Tracer gas release tests. Two tests were performed in order to reproduce the release of tracer gases contained in a pin and their transfer through the sodium until reaching the argon and the measuring system.

In each of these tests, the investigated gas mixture (xenon, krypton, etc.) was stabilized under pressure (15 bar at NTP) in a non-fueled cladding with a fusible joint at the lower plug (AU-Si solder, $T°_M = 370°C$).

The pins were placed into the core in the interior of a diluting assembly and their leakage occurred while the reactor operated at approximately nominal conditions.

The main conclusions of these tests which apply to "patent" cladding ruptures, are the following:

Direct and rapid transfer of a large fraction of the tracer (at least 40%) into the upper zone of the reactor; the significant isotope ratio (Fig. 5) is then measured with high accuracy (± 3%).

Another fraction of tracer is entrained by sodium with progressive degassing in less than 3 h.

Restoration of the core blanket by an exponential time law (≃ 4 h) is coherent with the volume of the blanket and the restoration rate.

III.4 Cladding ruptures in labeled fuel elements. Two cladding ruptures were observed in labeled fuel pins.

The first occurred in a fuel element with low burnup during the period when the measuring system was being improved. In spite of these unfavorable conditions, the tracer was identified (Fig. 5) permitting localization and unloading of the defective assembly. The transfer coefficient in the blanket was estimated to be 3%.

The second cladding rupture was induced intentionally in an experiment involving study of the early-life rupture development. The labeled pin had a fusible joint (zinc solder) which induced release of the tracer at the end of the power rise while the internal pressure in the cladding was barely higher than the external pressure at the rupture site. The tracer could be detected but in too small quantity to allow accurate identification of the significant isotope ratio and of the transfer coefficient in the blanket.

IV. Labeling Experiment in PHENIX

IV.1 Development of instrumentation. The instrumentation designed for PHENIX (Fig. 6) operates by the same principle as that of RAPSODIE but is more advanced.

As a result of a three-stage enrichment line, its sensitivity is better with an accuracy of better than ± 7.5% for the Xe-129/Xe-126 ratio with a natural xenon concentration of 7.10^{-9} in the core blanket.

A specific computer provides for completely automatic continuous in-line operation.

Thus far, this equipment has been constructed, assembled and then subjected to endurance tests for 2 months in the CEA laboratories at CEN/SACLAY. After this fully satisfactory test, the assembly has been installed in PHENIX and on-site adjustment tests are in progress.

IV.2 Study of tracer degradation under irradiation. Two capsules containing a mixture of tracer gases (krypton and xenon) are presently being irradiated in PHENIX for 1 cycle and 3 cycles, respectively. Post-irradiation analysis will allow us to determine the degree of tracer isotope degradation by neutron capture.

Provisional calculations have led to the abandonment of Xe-124 as a significant isotope; its rate of loss was evaluated at 2.6% per month of irradiation. On the basis of these calculations, the isotope ratios Xe-129/Xe-126 and Kr-82/Kr-78 were selected as references.

V. Conclusion

The experience acquired at CEA in the past 4 years allowed us to explore different areas of the CLR method with tracer gases: gas feed, influence on cladding, data transfer, instrumentation, etc.

Application of the method to RAPSODIE is promising: expansion of the labeling method to the complete core which is in progress should confirm its efficiency.

As a supplement to this statistical experiment, it seems necessary to test labeling in a complete PHENIX core in order to evaluate the competitiveness of tracers in reactors of industrial size.

FIG. 1

TRACER GAS CAPSULE

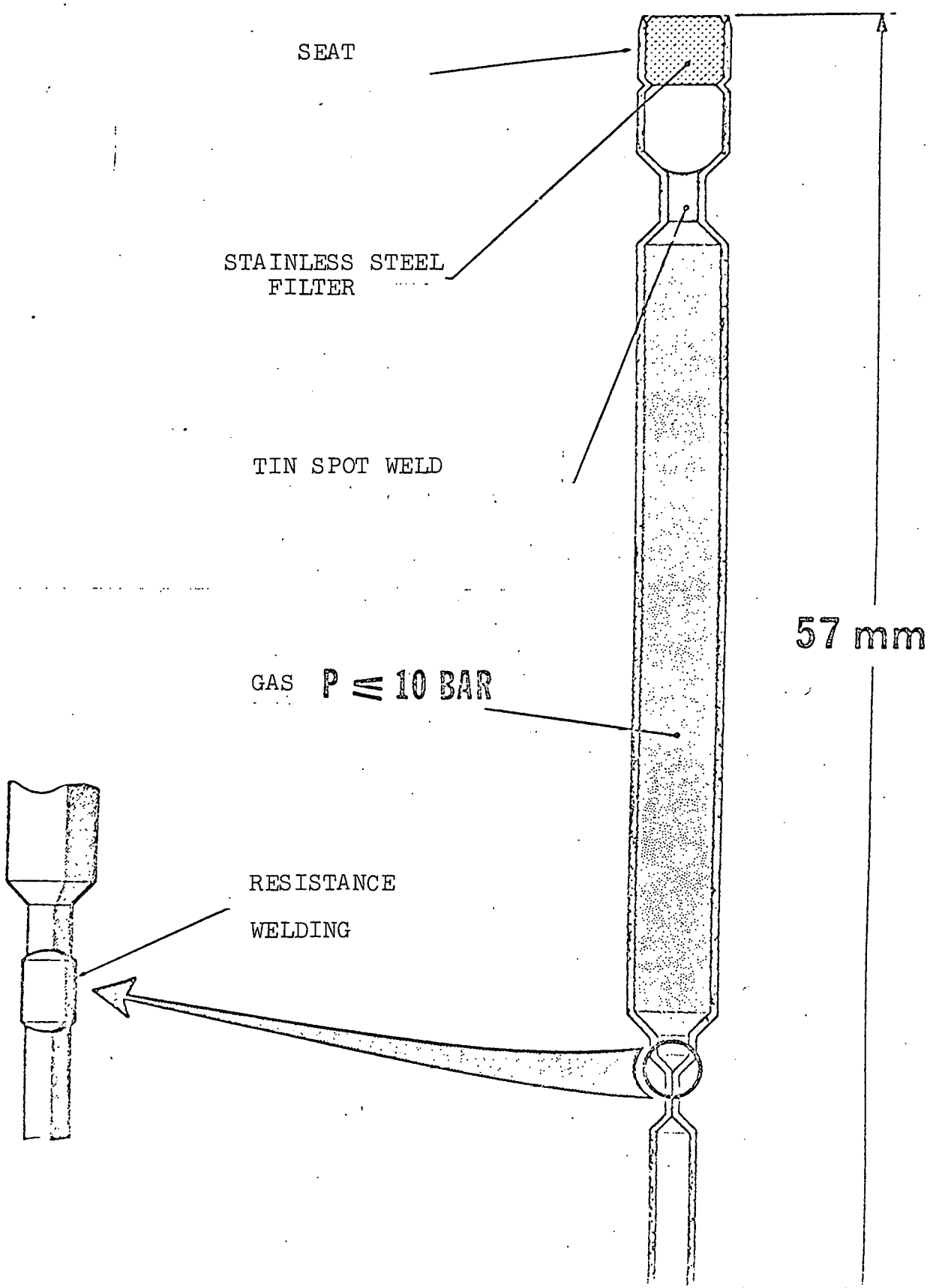
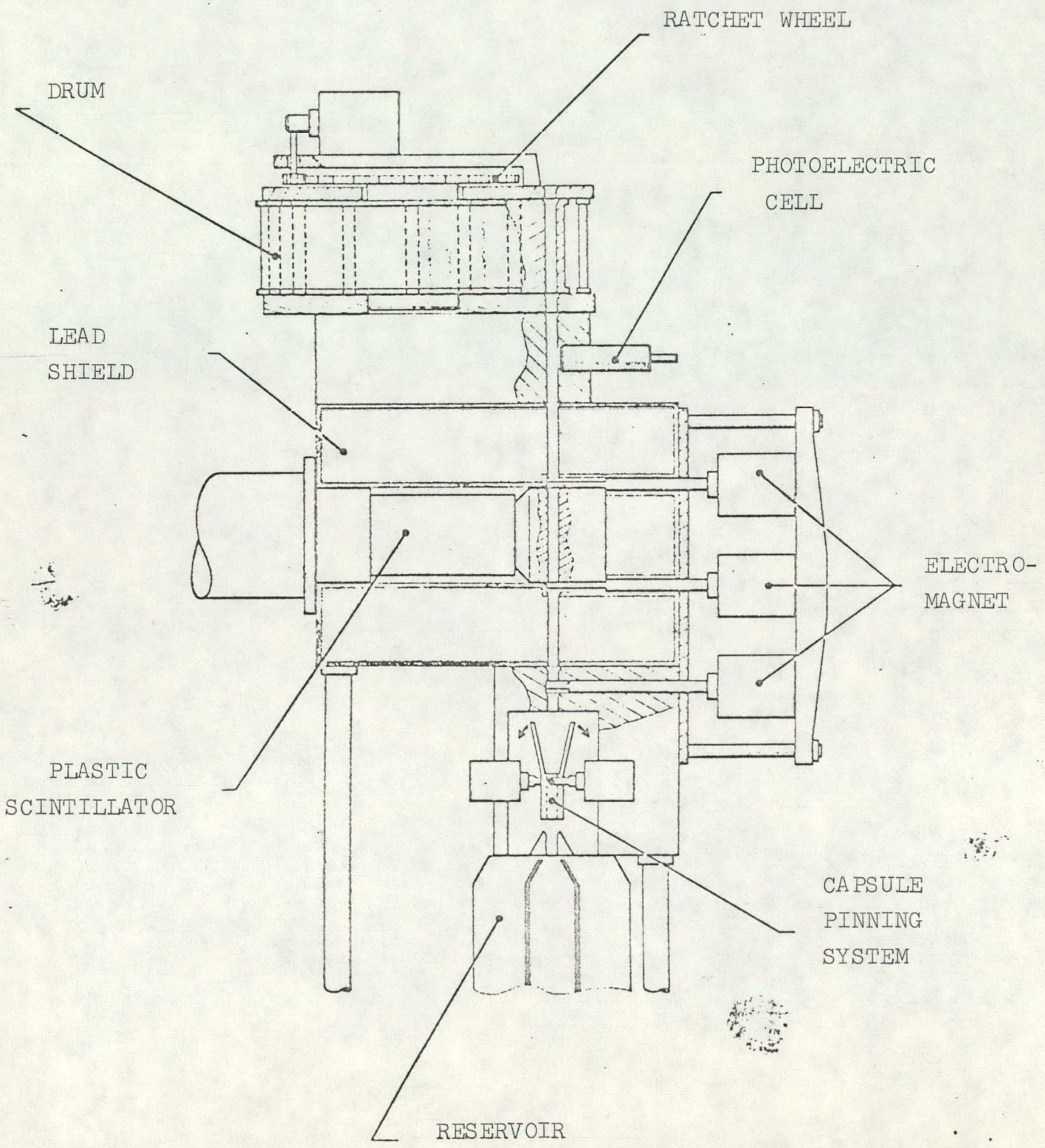


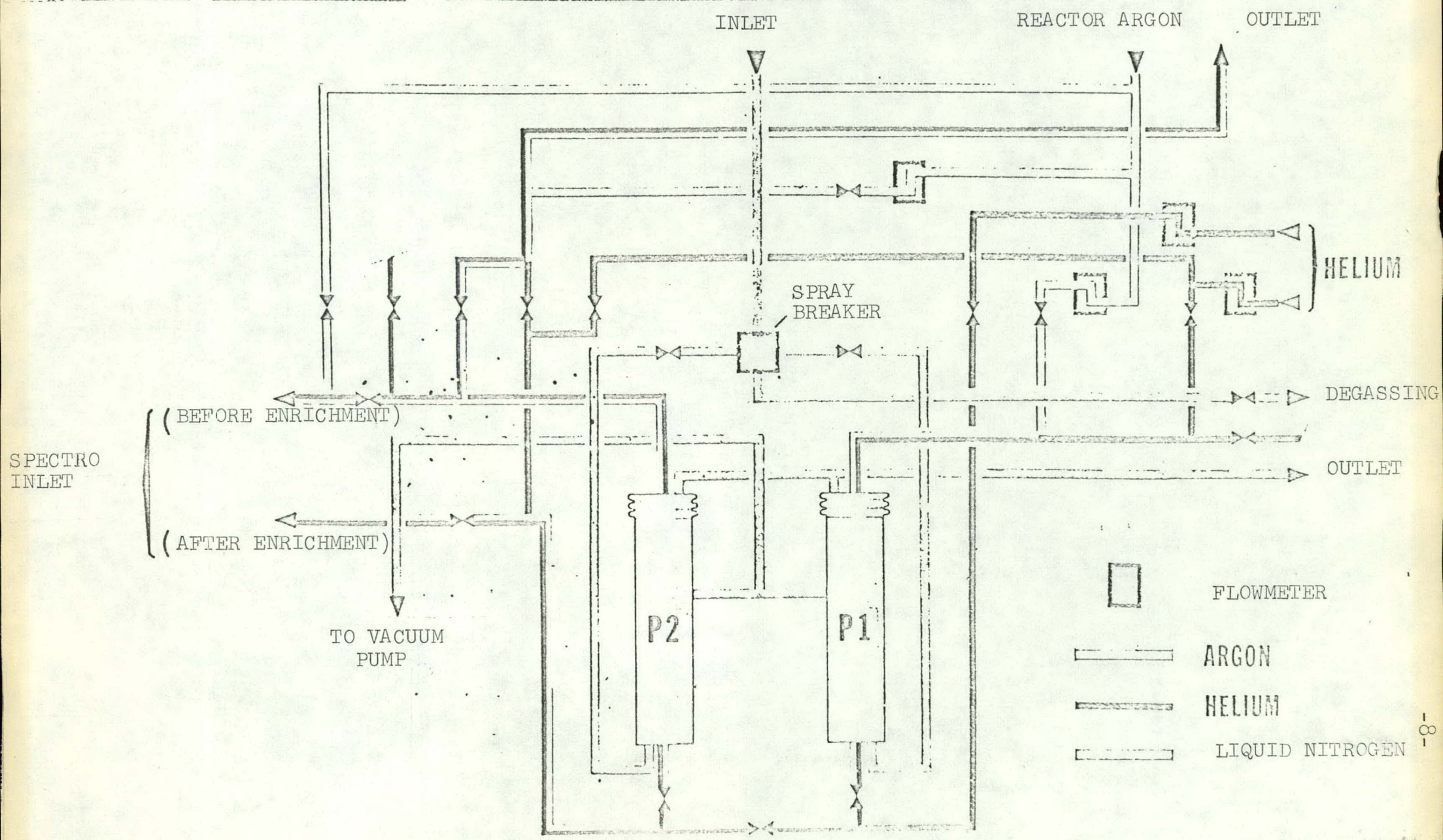
FIG. 2 PHAIGUINIX

CONTROL EQUIPMENT FOR THE RADIOACTIVE TRACER GAS FILLING OF CAPSULES



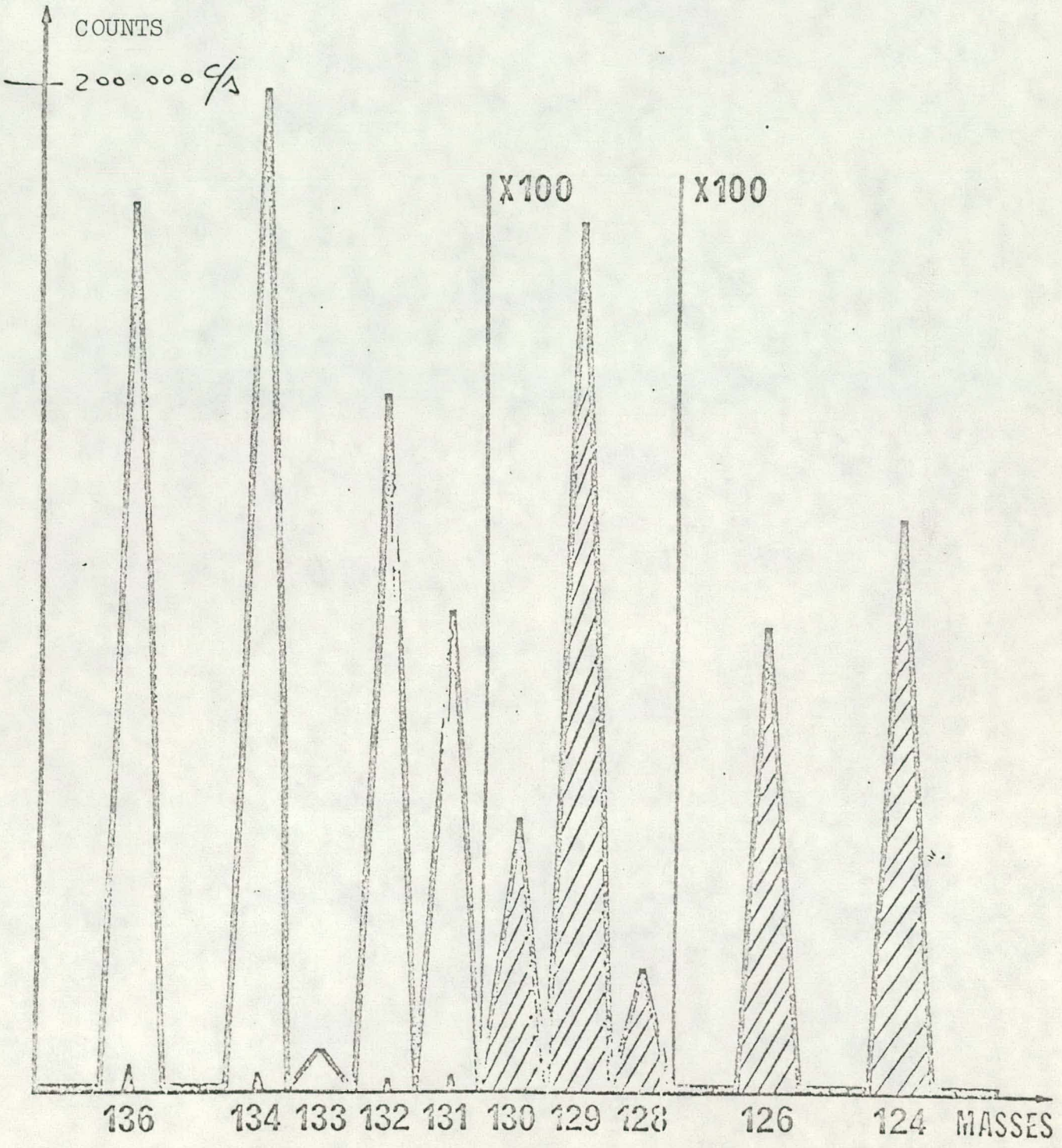
ENRICHER CIRCUIT

FIG. 3



RAPSODIE

FIG.4 MASS SPECTRUM OF FISSION AND TRACER Xe



PHENIX

EMRICHER, MASS SPECTROMETER

FIG.5

DIAGRAM OF ENRICHMENT LINE

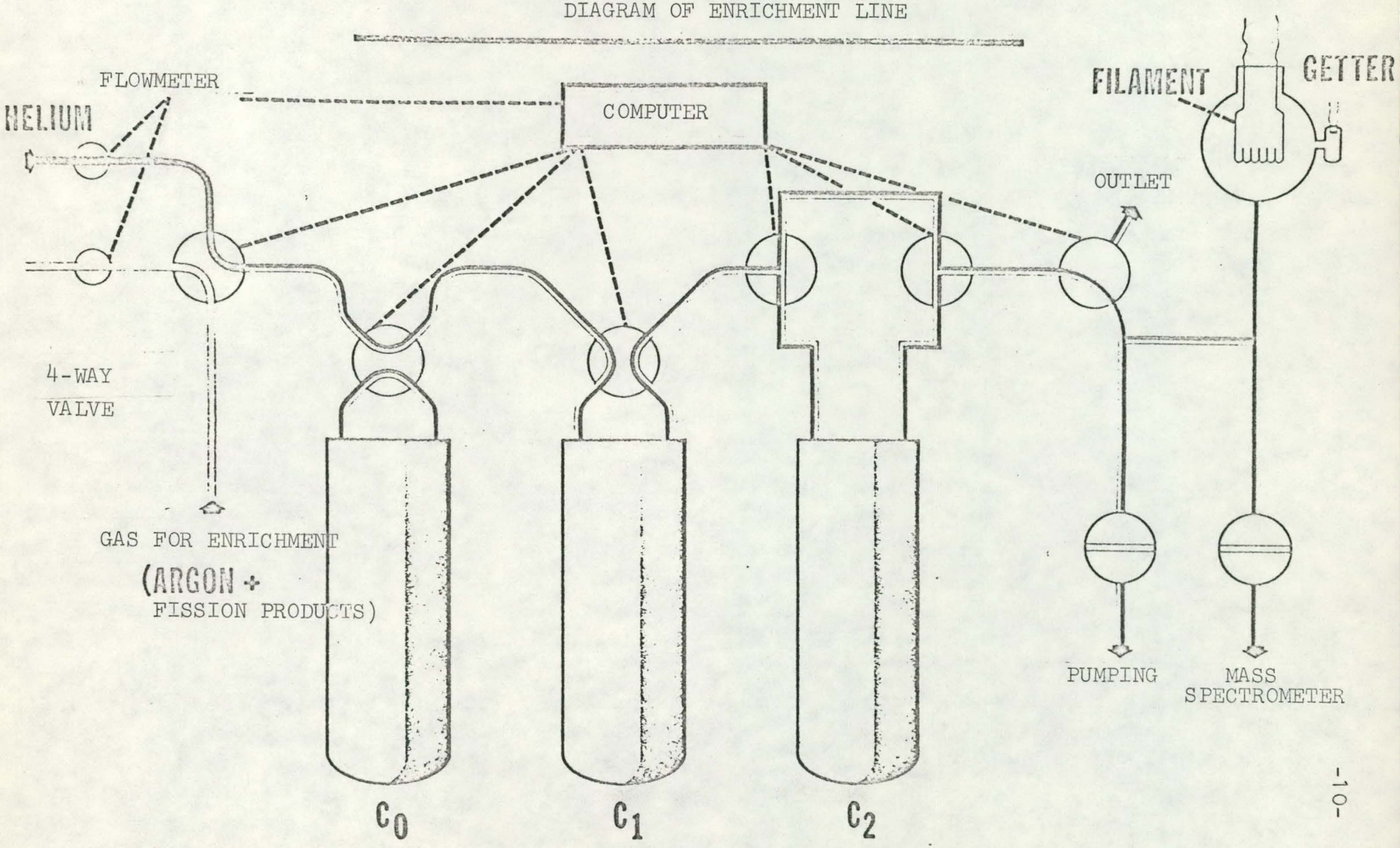


Fig. 6. Capsule Filling Device.