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VARIABLE DEAD TIME NEUTRON COUNTER FOR TAMPER RESISTANT MEASUREMENTS OF SPONTANEOUS FISSION NEUTRONS

by

G. BIRKHOFF, L. BONDÁR and N. COPPO

1972

Joint Nuclear Research Centre
Ispra Establishment - Italy

Physics Division and Technology Division

Paper presented at the
International Meeting on Non-Destructive Measurement
and Identification Techniques in Nuclear Safeguards
Ispra (Italy) September 20-22, 1971

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It consists of a high efficiency moderating neutron detector and five neutron pulse counters with variable dead times of nominal $\tau_0 = 0.03\ \mu s$, $\tau_1 = 16\ \mu s$, $\tau_2 = 32\ \mu s$, $\tau_3 = 64\ \mu s$, $\tau_4 = 128\ \mu s$.

The neutron counting rate, C_K, of the counter with dead time τ_K is depending on the multiplicity, ν, of the fission process.

From the set of five measurements K = 0, 1, 2, 3, 4 it is possible to verify the spontaneous fission isotope and to determine its amount.

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ABSTRACT

The paper describes the principle of the measurement and the technical performance of the instrument.

It consists of a high efficiency moderating neutron detector and five neutron pulse counters with variable dead times of nominal $\tau_0 = 0.03\ \mu s$, $\tau_1 = 16\ \mu s$, $\tau_2 = 32\ \mu s$, $\tau_3 = 64\ \mu s$, $\tau_4 = 128\ \mu s$.

The neutron counting rate, C_K, of the counter with dead time τ_K is depending on the multiplicity, ν, of the fission process.

From the set of five measurements K = 0, 1, 2, 3, 4 it is possible to verify the spontaneous fission isotope and to determine its amount.

KEYWORDS

PLUTONIUM 240
PLUTONIUM
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SPONTANEOUS FISSION
NEUTRONS
NEUTRON DETECTION
HELIUM 3
CONFIGURATION
POLYETHYLENES
MODERATORS
COUNTING RATES
POISSON DISTRIBUTION
NONDESTRUCTIVE TESTING
WEIGHT
DEAD TIME
DATA ACQUISITION SYSTEMS

This is a short description of an instrument which has already been announced at the Safeguards Symposium in KARLSRUHE 1970 (1). The instrument is used for the non destructive determination of the Pu^{240} content in plutonium bearing fissile materials.
It consists of a high efficiency moderating neutron detector and five neutron pulses counters with various dead times τ_k of nominal

$$\tau_o < 0.03\,\mu s , \quad \tau_1 = 16\,\mu s , \quad \tau_2 = 32\,\mu s , \quad \tau_3 = 64\,\mu s, \quad \tau_4 = 128\,\mu s$$

A scheme of the instrument is shown in Fig. 1. The neutrons counting rate C_k of the counter with dead time, τ_k, is depending on the multiplicity of the fission process. From the set of five measurements (K = 0, 1, 2, 3, 4) it is possible to verify the spontaneous fission isotope and to determine its amount.

Method

If single neutrons are emitted, as in the (α, n)- process, the time distribution of the detector pulses obeys Poissons's law and the counting rate, C_k, of a counter with dead time, τ_k, is described by the equation

$$C_o = \frac{C_k}{1 - C_k \tau_k} \qquad (1)$$

(counting losses of C_o neglected). Fission neutrons are emitted in groups, at the average more than 2 per fission event, and the pulse distribution deviates from Poissons's law. The redundancy, R_k, of the measured distribution is

$$R_k = C_o - \frac{C_k}{1 - C_k \tau_k} \quad 0 \qquad (2)$$

R_k is a function of the average number of neutrons per fission $\bar{\nu}$, the detection efficiency ε, the mean neutron lifetime 1 of the detector assembly, the dead time τ_k and the total counting rate itself.

$$R_k = \frac{C_k}{1 - C_k \tau_k} \cdot f(\bar{\nu}, \varepsilon, 1, \tau_k, C_o) \qquad (3)$$

For $C_o < \frac{1}{\tau_k}$ we have in a good approximation

$$R_k = \frac{C_k}{1 - C_k \tau_k} \varepsilon \cdot F(\bar{\nu})(1 - e^{-\tau k/1}) \; P_k(C_o , \bar{\nu}) \qquad (3\,a)$$

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(1) G. BIRKHOFF et al. Proc. Symp. on progress in safeguards techniques 6-10 July 1970 vol. II (abstract)

(detector dead time losses neglected)

where εF is the average number of associated pulses of fission neutrons following the first pulse of the group and the factor $P_k < 1$, takes account of the fact that sometimes not the first but one of the following associated pulses may trigger the counter K. This is the case for $\exp(-\tau_k/l) > 0$ because during τ_k only a fraction of the neutron group dies away and the remaining may retrigger the counter. Essentially no associated pulse will arrive afterwards. Another possibility is that fission neutrons are born during the counter K is paralized by the dead time and after it is reopened, the surviving fraction of neutrons may retrigger it. Both cases result in a reduced number of associated counts. $p_k(C_o, \bar{\nu})$ can be calculated or determined experimentally. As an example we consider the measurement of spontaneous fission neutrons (C_k^{40}) of Pu^{240} in the presence of (α, n)-neutrons (C_k^{α}) neglecting induced fission neutrons.
The basic equations are the following:

$$C_k = C_k^{40} + C_k^{\alpha} \tag{4}$$

$$C_o^{40} = \frac{C_k^{40}}{1 - C_k \tau_k} + R_k^{40} \quad ; \quad k = 1, 2, 3, 4 \tag{5}$$

substituting C_k^{40} by the eq. (3a) we obtain

$$C_o^{40} = R_k^{40} \left(1 + \frac{1}{\varepsilon \cdot F^{40} \left(1 - e^{-\tau_k/l}\right) P_k^{40}(C_o)}\right) \tag{6}$$

if $P_k^{40}(C_o)$ is known (from calculations or calibration measurements) we may determine from the four measurements of R_k the quantities C_o^{40}, εF^{40} and l.
F^{40} serves for the identifications of the Pu^{240} isotope.

The attainable precision allows to distinguish clearly Pu^{240} from the most interesting spontaneous fission isotopes Cf^{252}, B_k^{249}, Cm^{244}. Knowing ε we may compute the Pu^{240} mass.
Of course F and l can be measured more precisely by a Rossi-α experiment, but this requires very special instrumentation.

Formula (6) is only valid for small samples of a few grams of Pu, where neutron multiplication is negligible. In cases of large samples corrections have to be applied for the multiplication of spontaneous fission and (α, n) neutrons which can be quite excessive. A check on this effect is obtained by measuring the cadmium ratio of R_k,

i.e. measurements with bare and Cd covered sample. An illustration of the Cd ratio measurements of fuel pins is given in Fig.2 . In the case of RAPSODIE fuel pins (55 g of fissile materials) the contribution of thermal neutron multiplication to R_k amounts to about + 10 % . This effect is rather high and serves for the assay of the fissile materials content of the sample. On the other side, high multiplication is conplicating considerably the analysis of the measurements. However, we dispose of a computer code which is capable of resolving the problem in a satisfactory manner. A description of it is given in the paper of G.BIRKHOFF and L.BONDÁR "Computerized system for the application of fission neutron correlation techniques in nuclear safeguards" presented at this meeting.(3)
Evidently all analysis problems are essentially simplified in the case of relative measurements utilizing calibration standards.

Performance

- Detection efficiency (ε) variable, maximum 0.35
- Neutron lifetime (l) variable between 25 µs and 60 µs
- Detector dead time θ < 0.7 µs
- Pu^{240} mass measurable between 0.03 g and 100 g
- Relative precision of ± 0.5 % attainable for small samples

Further informations can be obtained on special request.

Remarks

The method as described above has been developed during 1959 - 1962 in the CEA laboratories of Saclay by J.JACQUESSON and co-workers (2). They used one fast and one slow counter with $\tau / l >> 1$.
Our improvement consists, apart from electronics, in the simultaneous measurement with five counters of different dead times τ_k. This gives the possibility of verifying the spontaneous fission isotope and an improvement of precision and reliability of the results. Jacquesson and co-workers developed a complete theory (including neutron multiplication) of their method which is based on probability distribution generating functions, but they neglect the correction factor $P_k(C_o, \bar{\nu})$. This implies the conditions $C_o << 1/\tau$ and $\tau/l >> 1$. Our interpretation model is based on Monte Carlo simulation and has in principle no limitations.
Since 1969 several types of "neutron coincidence counters" have been brought into application. These instruments correspond in principle to the CEA instrument. The Brookhaven Coincidence Counter model 1 has been tested during 1969 in our laboratory and we found that the CEA system is superior to the Brookhaven instrument as concerns the transparency of the measuring process and the interpretation of the raw data.

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(2) J.JACQUESSON, J.Phys. 24, 1963, Suppl.6, 12A
(3) To be published as an external report (EUR)

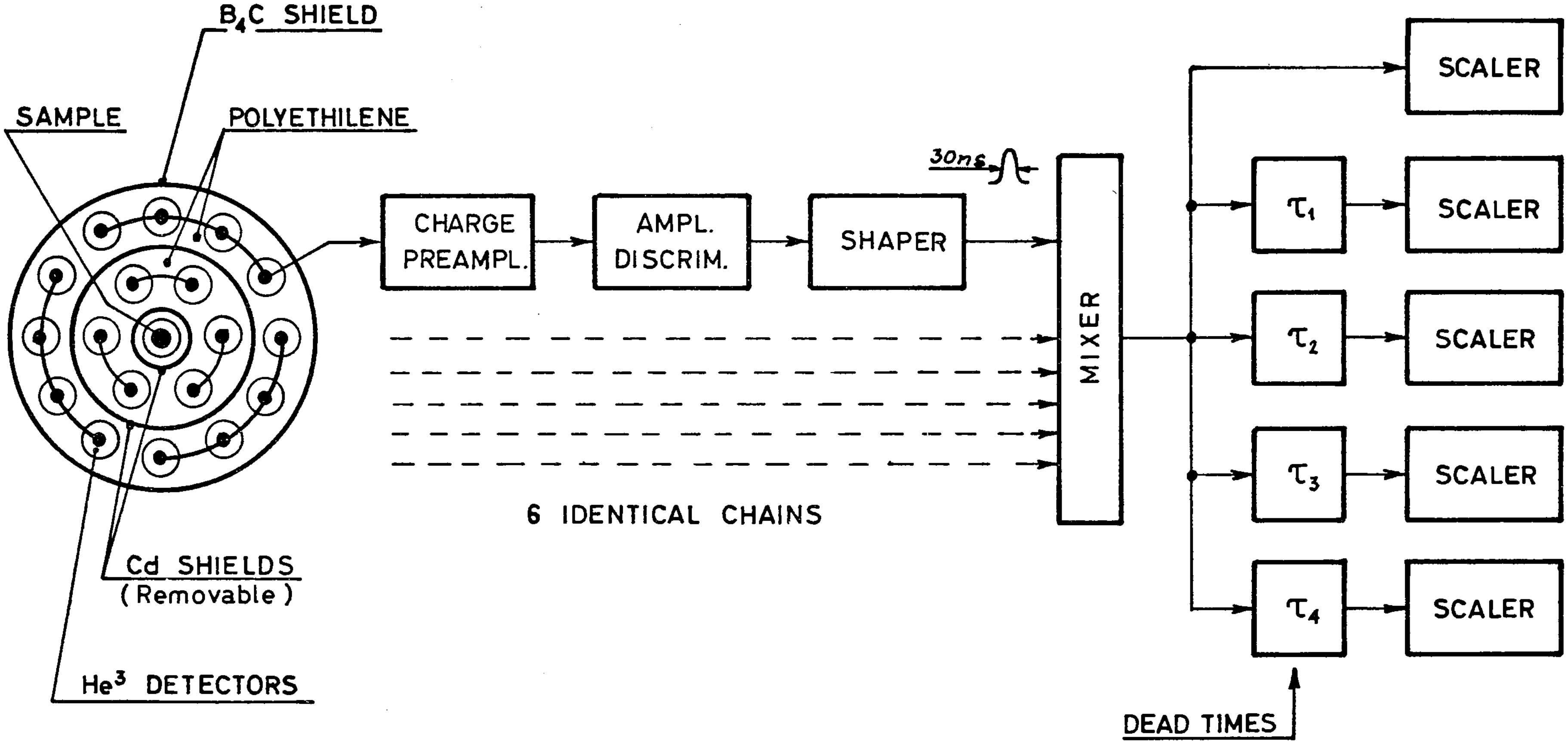
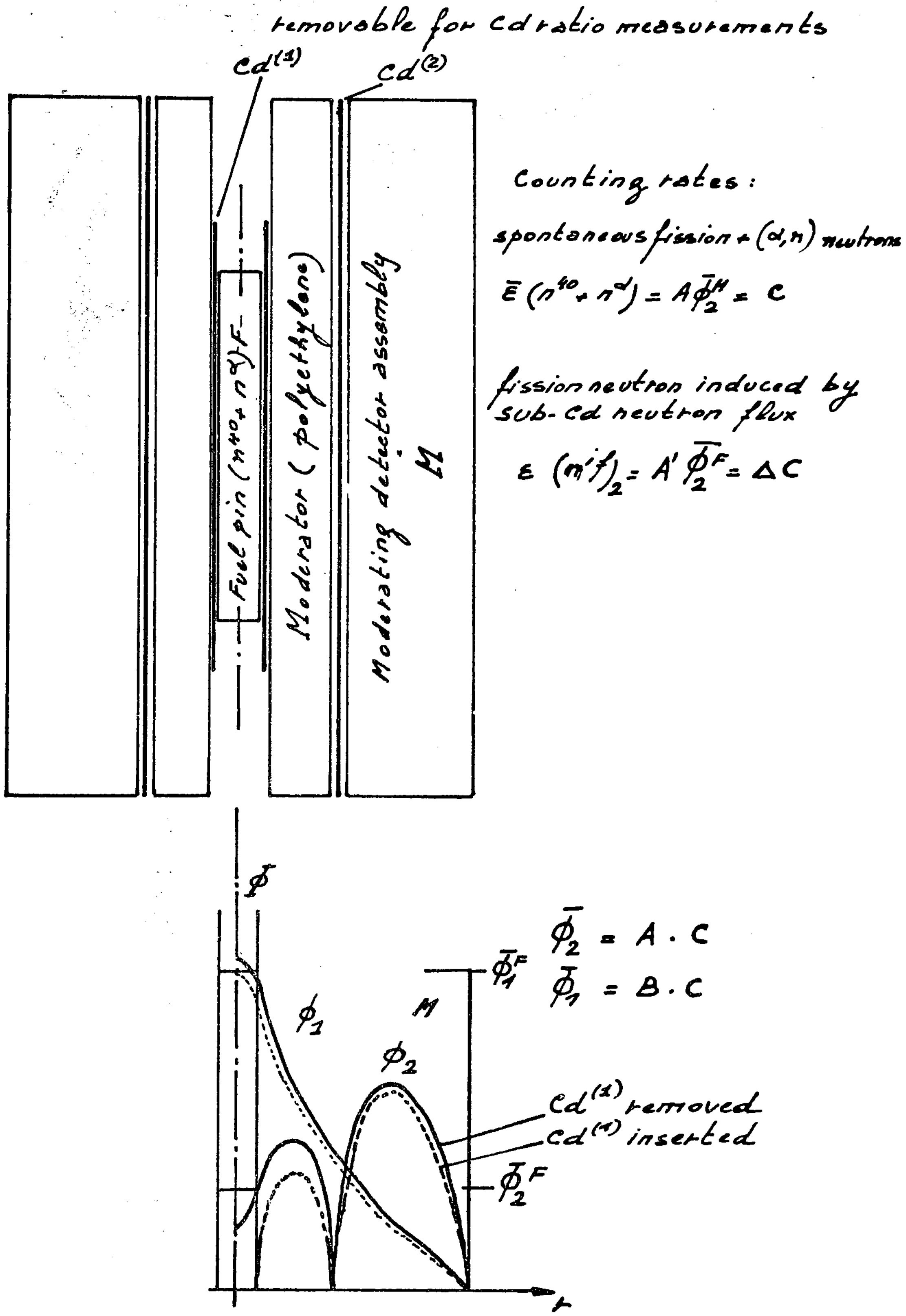

B4C SHIELD
SAMPLE
POLYETHILENE
Cd SHIELDS
(Removable)
He3 DETECTORS
CHARGE PREAMPL.
AMPL. DISCRIM.
SHAPER
30ns
MIXER
6 IDENTICAL CHAINS
SCALER
τ1
SCALER
τ2
SCALER
τ3
SCALER
τ4
SCALER
DEAD TIMES

FIG. 1

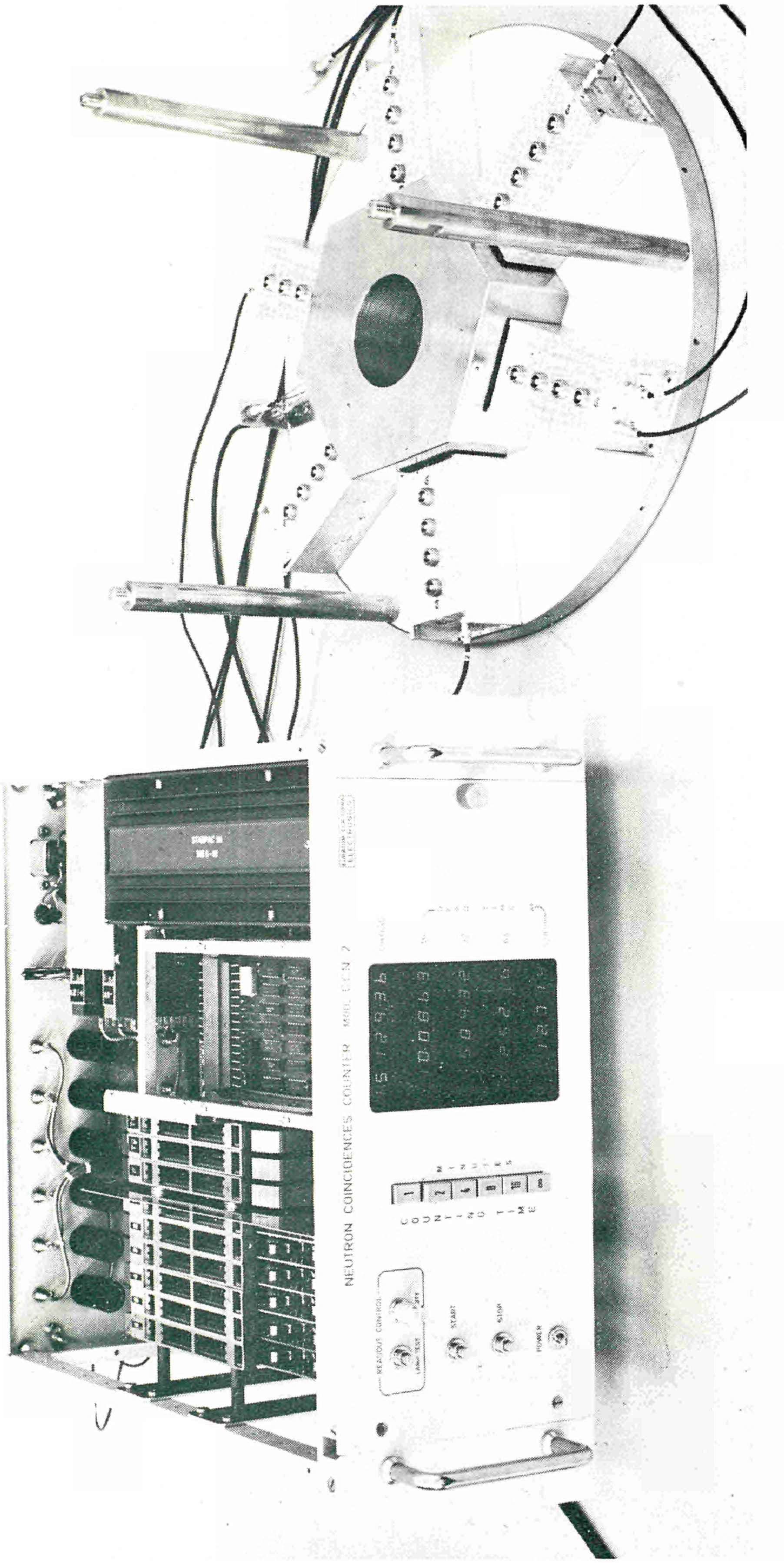


Induced fission neutrons

Epi Cadmium $\quad N_1 \cdot V \cdot (\overline{\nu\sigma_f})_1 \cdot \bar{\Phi}_1^F = B' \cdot C$

Sub Cadmium $\quad N_2 \cdot V \cdot (\overline{\nu\sigma_f})_2 \cdot \bar{\Phi}_2^F = \frac{\Delta C}{\varepsilon}$

Figure 2


NEUTRON COINCIDENCES COUNTER

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To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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