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THE TISSUE EQUIVALENT PROPORTIONAL COUNTER
"REAL TIME" NEUTRON MONITOR

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THE TISSUE EQUIVALENT PROPORTIONAL COUNTER RADIOACTIVE WASTES

by

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Abstract

The Tissue Equivalent Proportional Counter (TEPC) has been developed to monitor low level neutron exposure rates at working stations in a nuclear fuel fabrication facility. It has proven capable of accurately measuring neutron dose rates at levels from 0.1 to 0.2 mrem/hr. It also calculates the Quality Factor which is of importance in locations where the neutron to gamma ratio may vary significantly and irregularily. The system described is computerized to monitor 100 work locations simultaneously and can be expanded to monitor 384 locations. Neutron dose is accumulated on a real time basis and after the proton drop point is established, dose rate can be read out at any time for the dose accumulated over a specified period of time.

The current development program which provides reduced system maintenance, lower detection limits and improved accuracy is discussed along with examples of measurement data and work experience with the current system.

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TISSUE EQUIVALENT PROPORTIONAL COUNTER
THE TEPC REAL TIME NEUTRON MONITOR

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Introduction

Assessing personnel neutron dose for occupational workers in a fuel fabrication plant presents one of the most difficult personnel exposure measurement problems in the nuclear industry. A major difficulty lies in the constantly shifting and potentially large changes in the neutron to gamma ratio encountered at the work location. While the gamma dose rate is relatively constant at a given work station, for a particular fuel type, the neutron dose rate is a varying function of the fuel quantity and geometry. It is subject to both routinely changing fuel movement and flow through the process, and irratic but not infrequent large mass variations due to fuel hold-up in the process caused by temporary process variations, quality assurance and various other fuel movement delays.

This varying neutron source situation coupled with design criteria for new facility dose rate control levels that are below the current limits of detection for most personnel neutron badges (in a monthly badge change interval) has necessitated the development of new neutron monitoring instrumentation. At the Hanford Engineering Development Laboratory (HEDL), the Tissue Equivalent Proportional Counter (TEPC) is being developed for more accurate monitoring of low level neutron fields on a real time basis.

The TEPC Detector

The TEPC detector has been used for years in a few laboratories and is described in detail in the literature;[1, 2, 3] it is therefore only briefly described here. The detector is composed of a hollow sphere of tissue equivalent (TE) plastic filled with a methane compounded TE gas. Details of the plastic and gas composition may be found in ICRU Report 26[4]. The general design of the detector, called the Rossi Counter, is shown in Figure 1. The plastic sphere is contained in a pressure vessel with a valve for admitting TE gas. Within the sphere the central anode is surrounded by a helical grid to maintain uniform gas multiplication along the length of the anode wire. The gas pressure is kept at a very low value (about 25 torr in these units) so the charged particles crossing the cavity lose very little

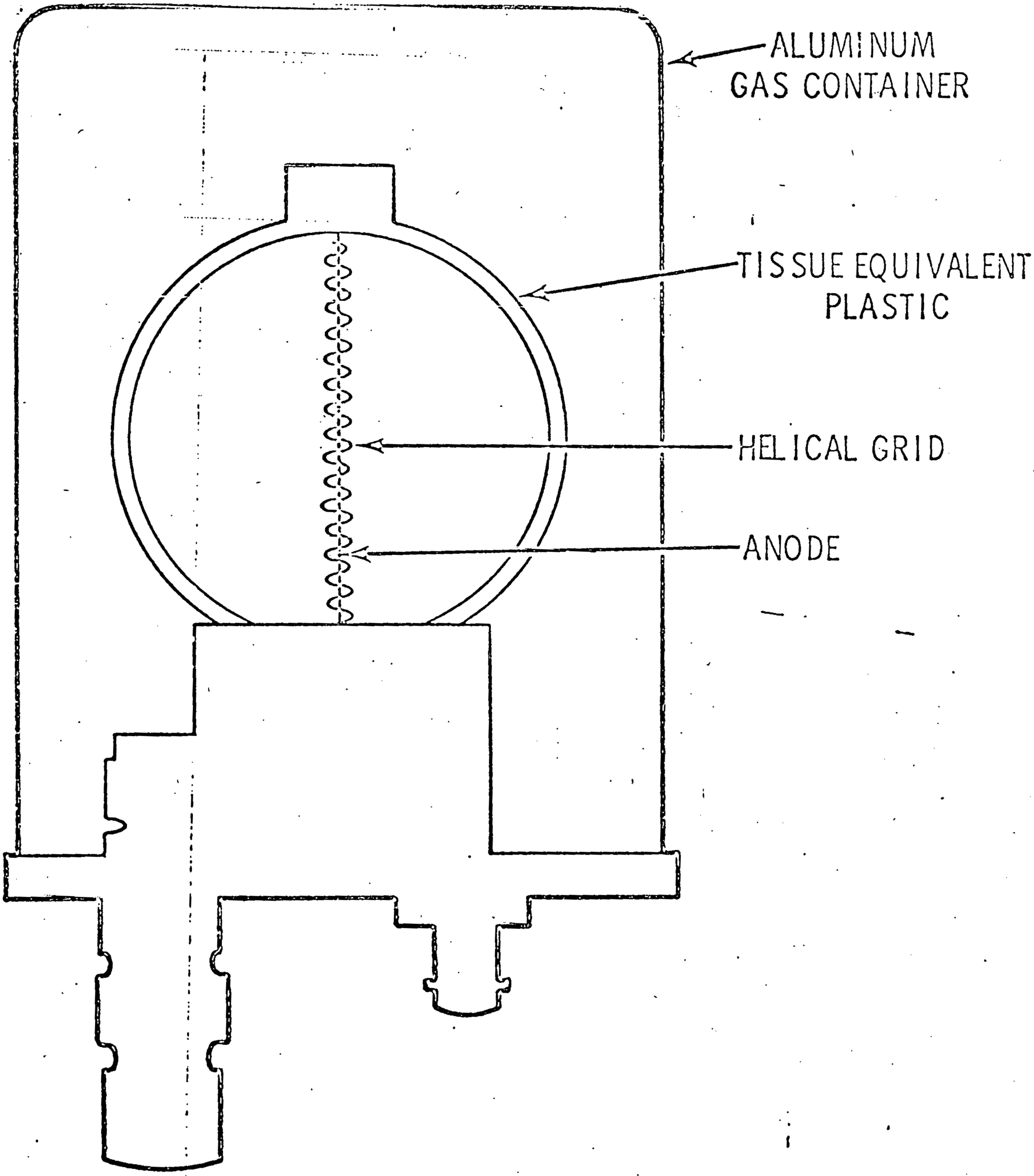

FIGURE 1. Cross-Sectional View of a Tissue Equivalent Proportional Counter

energy and the energy deposited within the cavity is equal to the linear energy transfer of the particle times the path length. The gas pressure is adjusted in the gas filled cavity so that it has the same mass stopping power as a sphere of human tissue of about two micrometers. This gives the detector an equivalent diameter of two micrometers which assists in simple mathematical translation of dose.

Figure 2 shows a typical pulse height spectrum derived from a Rossi-type TEPC. Curve B represents the data from the TEPC detector exposed to 1.4 MeV neutrons. Curve C is derived by multiplying the counts per channel from a multichannel analyzer times the channel number and is proportional to the energy deposited or the dose. Curve A represents the data from ^{60}Co gamma rays. Neutron and gamma induced events can be separated on the basis of event size. Thus the minimum point 1 is selected as the lower limit of neutron events. This works well unless the photon rate is sufficient to produce pulse pile-up. Several rads/hr of gamma are required to produce pulse pile-up.

Point 2, the point of inflection on curve C is defined as the proton drop point. This corresponds to a slow proton recoil having the highest linear energy transfer, or stopping power, traversing the diameter of the spherical cavity. The proton drop point is independent of the initial energy of the neutron producing the events. This occurs at about 98 keV/μm and is a very slowly varying function of the TE gas pressure.

Multiplying the number of events of a given size by the energy gives the absorbed energy distribution in the TE gas, which is a direct measure of the absorbed dose. Following the nomenclature in ICRU-26[1], this may be stated mathematically as:

$$\frac{D}{\text{rad}} = \frac{100D}{\text{Gy}} = 1.602 \times 10^{-8} \sum_{h_1}^{h_2} \left(\frac{c \cdot hN(h)}{\text{MeV}}\right) \left(\frac{\rho}{\text{gcm}^{-3}}\right)^{-1} \left(\frac{V}{\text{cm}^3}\right)^{-1}$$

where h is the measured pulse height exposed as channel number, N(h) is the number of pulses accumulated in channel h, h_1 and h_2 are the limits in pulse height between which the absorbed dose is determined, ρ is the gas density, V is the sensitive volume of the cavity, and c is the calibration relating energy to channel number, determined from the proton drop point.

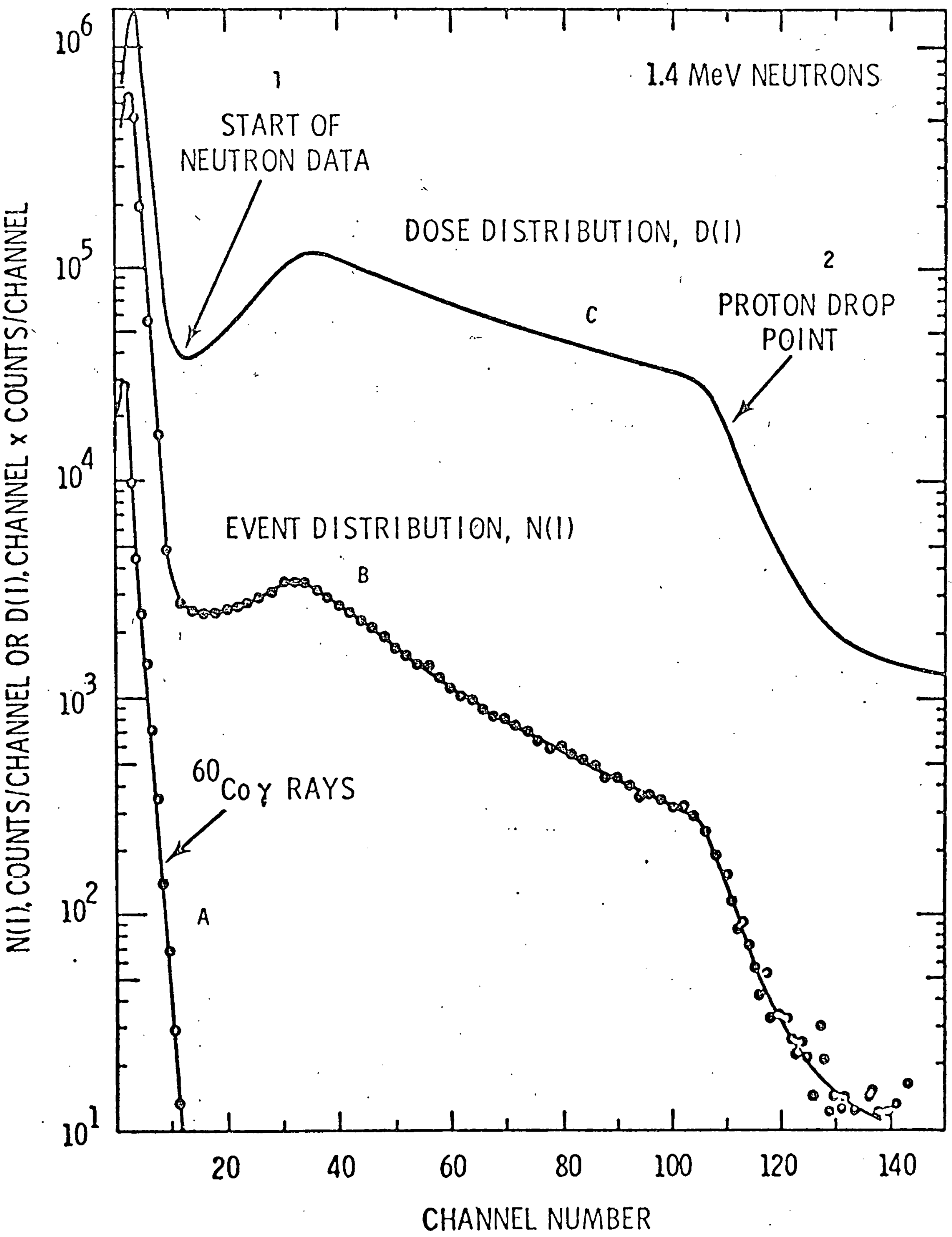

FIGURE 2. Pulse Height Spectra from a Tissue Equivalent Proportional Counter Exposed to 1.4 MeV Protons

The TEPC System

The particular system now being utilized at HEDL uses a Nuclear Data 6600 data handling system to compile, store, analyze and display the neutron information from the TE detectors. It is a computerized pulse height analysis system capable of determining absolute neutron absorbed dose and quality factors from a number of locations simultaneously. The present system is designed for use on the HEDL fuel fabrication line and for the High Performance Fuel Laboratory being designed at HEDL.

Briefly, the following sequence occurs in the Tissue Equivalent Proportional Counter system: 1) The TE detector measures the energy released by neutron secondaries which are produced when a neutron traverses the TE material within the detector. 2) A preamplifier, amplifier and discriminator are used to amplify and shape the output from the detector. 3) A mixer/rejector/router network, called a gated analog router (GAR), routes the signal to the proper memory locations in a mini-computer, allowing simultaneous data acquisition from several detectors. 4) Using the Rossi model for linear energy transfer (LET) distributions, the absolute neutron absorbed dose rate and quality factor are calculated for each detector. A simple wiring schematic for this sequence of events is shown in Figure 3. Four detectors may be handled by one GAR and four GARs may be routed into a single analog to digital converter (ADC); up to eight ADCs can interface into each display and acquisition subsystem (DAS) and the ND6600 system can be expanded to handle three DASs, giving the total system a capacity for 384 detectors or monitoring locations. All software for the current system is written in Fortran IV.

TEPC Measurement Experience

The TEPC neutron measuring system has been applied to a variety of situations in plutonium fuel fabrication facilities and has been used as a research tool for shielding analysis studies. Because of the continuing trend toward lowering allowable occupational exposure limits, the development efforts have been directed to obtaining the lowest practicable limit of detection. It has proven a very reliable and useful instrument for determing doses at a variety of positions from various sources and at varying distances from shields.

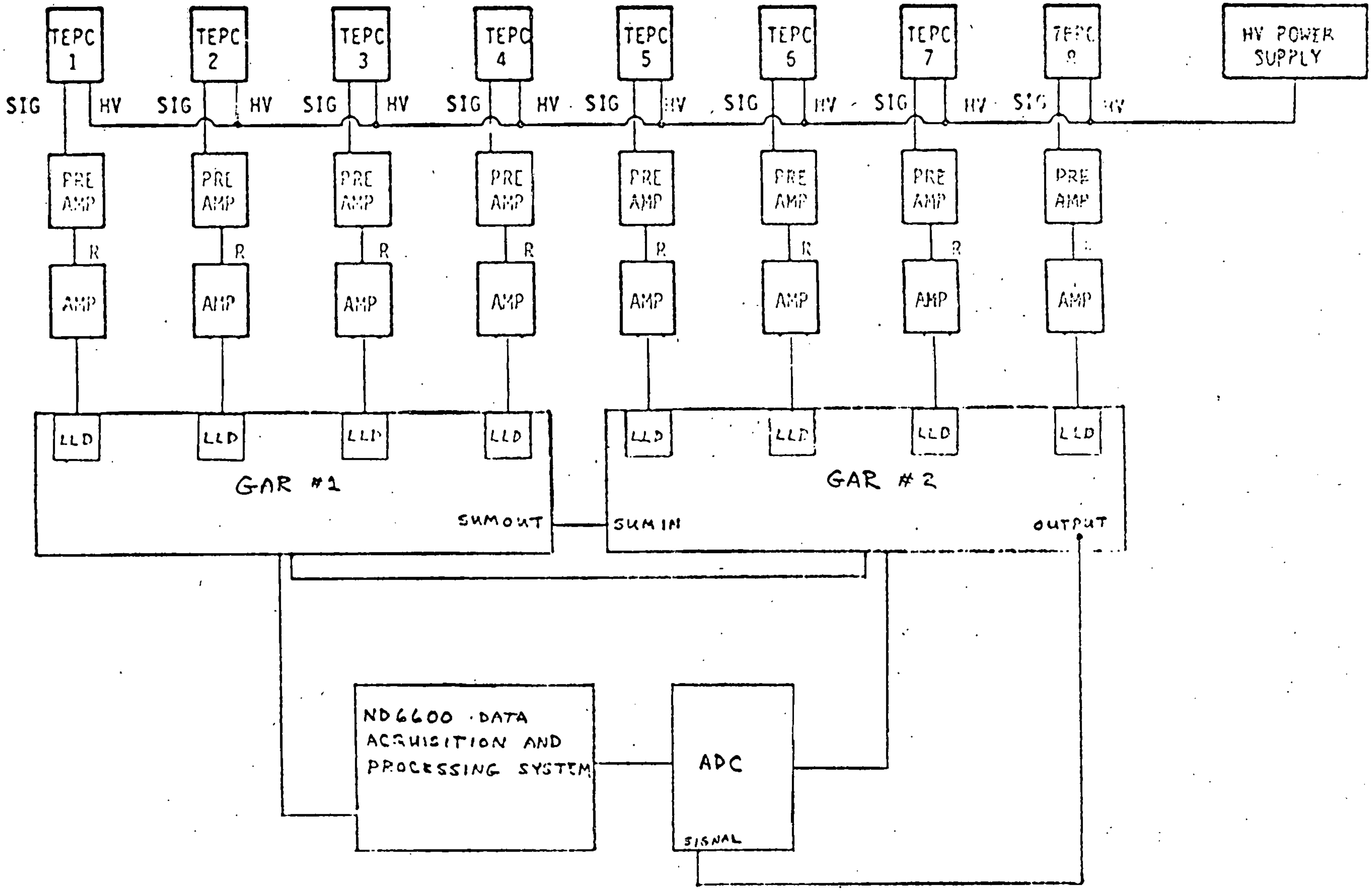

FIGURE 3: Wiring Schematic for the TEPC Neutron Monitoring System. (Photo No. 768436-1)

Early measurements were made of a Fast Fuels Test Facility (FFTF) subassembly being built at HEDL for the Fast Breeder Reactor. The FFTF subassembly contains 217 fuel pins assembled in a compact hexagonal array and contains approximately 7.3 kg of plutonium as a mixed oxide, 25% PuO_2-75% UO_2. The TEPC was located at the midplane of the 36-inch long fuel section. The results are given in Table 1. The neutron dose rates were measured on five different days at six different distances from the subassembly.

TABLE 1

Neutron Dose Equivalent Rates from "A" Type FFTF Subassembly

Dose Equivalents in M Rem/hr

Distance to Counter Center (inches/cm)

Date	2.1/5.33	6/15.2	12/30.5	24/61.0	36/91.4	48/122
12/11	24.4	10.9		2.5		0.91
12/12	23.4	10.8		2.5		0.95
12/15	24.7	11.4		2.8		0.82
12/18			5.3	2.1	1.2	0.71
12/19			5.2	2.0	1.2	0.74
Average	24.17	11.03	5.25	2.38	1.2	0.83

The largest percent difference occurred in the measurements made at the two feet distance and were about 17½ percent. Most of the differences at higher dose rate levels were below 3 percent and the maximum at the lowest dose rates, those measured at four feet from the subassembly were about ± 14½ percent. The gamma dose associated with these measurements varies widely being about three times the neutron dose at those measurements made near the surface and about equal or slightly less than the neutron component at four feet away.

An example of the use of the TEPC to measure low level occupational dose conditions is shown in Table 2. These measurements were from the fuel storage area. The pit storage area is used to store completed FFTF subassemblies or to store Model 60 inserts which contain 120 fuel pins before they have been assembled in the final fuel subassemblies for the reactor. Storage holes are approximately 14 feet deep, steel lined and are shielded by concrete within the pit area. Steel extensions three feet high were later added above floor level so that two Model 60 inserts could be stored in a single pit location. For the neutron measurements, three TEPC detectors were located at floor level, at 12 inches and 24 inches above floor level centered between two tubes. A fourth detector was centered one inch above one of the tubes. The neutron dose rates are given in Table 2.

TABLE 2

Neutron Dose Equivalent Rates In The Pit Storage Area

	Dose Rates in mrem/hr			
Measurement	Floor level	12 inches	24 inches	38 inches*
#1	0.20	0.12	0.25	0.18
#2	0.22	0.10	0.21	0.10
Average	0.21	0.11	0.23	0.14

*The detector was placed above the pit and centered over the pit hole while the other locations were equidistant between two tube extensions.

The measurement times represent 42 hours of data accumulation for each of these measurements which were made over successive weekends to assure undisturbed conditions and to obtain more accurate dose background information.

It is of interest to compare the measured dose rate from different detectors measuring the same source. Although two or more detectors cannot be placed in precisely the same radiation environment, as there is some non-assymetry around a fuel assembly, different detectors at the same distance from a source should compare reasonably well. In Table 3, measurement data are presented for different detectors measuring the dose rate from a Model 60 fuel insert containing 120 FFTF fuel pins. The active fuel length is about 36 inches and there is about 5 kg of plutonium in the source. The individual fuel pins are clad in stainless steel.

TABLE 3

Measured Neutron Dose Rate From a Model 60 Insert

Dose Rates in mrem/hr

Surface*		12 inches		24 inches			6 inches			
#2	#4	#3	#1	#3	#1		#2	#4	#3	#1
14.5	15.0	3.41	3.96	1.08	0.92		7.78	8.36	7.98	8.93
15.3	14.8	3.47	3.48	1.00	0.91					
14.3	14.9	3.48	3.55	1.06	0.89					
14.7	14.9	3.45	3.66	1.05	0.91	(Average)				

*The surface dose rate is actually the dose rate about 2.1 inches from source to effective detector point.

The maximum deviation among detectors is about 20 percent and most of the measurements are within five percent. The variation among detectors is not a great deal different from that between measurements taken on different days with a single detector. Actually, experience has shown much of the variation to be caused by shifting backgrounds. All of these measurements had to be made under actual operating conditions in a fuel fabrication facility where other fuel was being moved by, around, or occasionally stored temporarily within the effective measurement capability of the monitoring system.

The counting time for these measurements varied from 16 to 41 hours; however, this was to obtain maximum counting statistics since the primary purposes of the measurements were to obtain dose rates and to develop a dose rate vs distance profile.

The measured dose rates also were compared to calculated values and in most cases were found to be within 11 percent of values calculated from the given plutonium mass, isotopic composition and the spontaneous fission and (alpha, neutron) yields. We have also compared the TEPC measured neutron dose rates with TLD measurements on several occasions. There is usually a greater scatter in the TLD data and the TLD dose rates are generally from 10 to 35 percent higher than the TEPC values. In the case of TLD measurements the quality factor is placed arbitrarily at 10.

The TE detectors do respond to gamma events as well as those from neutrons, however, the discriminators and the system software are set to disallow gamma events. Very high gamma to neutron ratios have not been tested but there has not been interference in measurements where the gamma component was ten times the neutron component.

TEPC Development

There have been been two factors which have probably prevented a more widespread use of TEPC's for personnel exposure monitoring. First, they cannot be worn as a personnel badge and, therefore, do not truly measure the dose to the individual. Secondly, the TE gas becomes contaminated with time and so must be frequently replaced. During much of our development studies we found it necessary to change out and refill our detectors every week. Gas degradation studies indicated most of the degradation products came from the TE detector components. HEDL now has a developmental contract with EG & G* to develop improved, long life detectors, and significant improvements have been accomplished. With the old detectors, gain changes of 40% and greater were experienced over a period of seven days. The new detectors currently being tested showed gain changes from 2 to 8% the first week and then leveled off to only from 5 to 15% after 3 months; some have operated successfully without need of refilling for over six months. We consider this a major breakthrough for the practical use of TEPC's in measuring radiation exposure.

The maximum sensitivity or detection level achievable with a TEPC is a function of the detector size. We are currently testing three different diameters; a one half inch, the regular 2 1/4 inch and a large 5 inch diameter detector. The small unit is only useful under relatively high level restricted geometry situations. The regular 2 1/4 inch size is used for most of our work. It has been found very reliable for operation in 0.2 mrem/hr fields. It usually requires a minimum of eight and preferrably 16 hours to define the proton drop point for accurate quality factor analyses. After the proton drop point is established, reasonably accurate data can be established for eight hour intervals at 0.2 mrem/hr or even 0.1 mrem/hr levels. A program is currently underway to define the minimum acceptable levels of detection, minimum variances and the reliability of the instrument at neutron dose rates at the general operating levels to which future facilities must control operational personnel exposure.

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The larger more sensitive 5 inch detectors have also been tested. Data indicate the 5 inch detector is about a factor of 5 more sensitive than the 2 1/4 inch detector if one is willing to accept ± 100% deviation at very low dose rate levels of 0.02 to 0.05 mrem/hr.

Summary and Conclusions

The TEPC has been under development at Hanford for the past seven years as an area neutron monitor and research tool. It has been found to be accurate in measuring neutron dose at dose rates as low as 0.1 to 0.2 mrem/hr and should be able to provide "real time" neutron monitoring at these levels on a daily basis. A system is described which would be capable of monitoring 128 separate locations in a nuclear facility and which could be programmed to alarm when specified preset dose rates were exceeded.

References

1. Rossi, H. H. and Rosenzweig, M. S., "A Device for the Measurement of Dose As A Function of Specific Ionization", Radiology, Vol. 64, No. 3, March 1955.

2. Rossi, H. H. and Rosenzweig, M. S., "Measurements of Neutron Dose As A Function of Linear Energy Transfer", Radiation Research, Vol. 2, No. 5, July 1955.

3. Brackenbush, L. W., Endres, G. W. R., and Faust, L. G., "Measuring Neutron Dose and Quality Factors With Tissue Equivalent Proportional Counters", IAEA-SM-229/52, Stockholm, Sweeden, June 1978.

4. International Commission on Radiation Units and Measurements, "Neutron Dosimetry for Biology and Medicine", ICRU Report 26, ICRU Publications, Washington, D.C. (1977).