NEUTRON SPECTRA AND DOSE EQUIVALENT INSIDE REACTOR CONTAINMENT*

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INTRODUCTION

The purpose of this study is to measure, characterize and evaluate neutron radiation dose equivalent rates and neutron energy spectra at selected commercial nuclear facilities where operating plant workers may be exposed to neutron radiation fields. Improved understanding and control of occupational neutron exposure should result from this study.

Neutron exposures to operating plant workers have not been observed on dosimeters in the past due to the lack of sensitivity of the personnel dosimeters used and the energy ranges suspected to be present in commercial nuclear facilities, particularly PWR plants. Most of the facilities presently use nuclear track emulsions to detect fast neutrons. The emulsions and most of the newer dosimeters based on track-etch techniques are not sensitive to the neutrons in the energy ranges of the leakage spectra which may be present in the commercial power reactor plants. Average energies are expected to be below 500 keV.

Recently, albedo type neutron dosimeters have become available for use at these facilities and relatively large neutron dose equivalents are being observed, especially when workers enter containment during full power operation.

At the present time, the albedo type of personnel dosimeter is the only available dosimeter which seems to have adequate sensitivity for neutrons in this energy range.

This study was designed to provide measurement data from a minimum of six nuclear power sites, which were selected to include reactors manufactured by each of the four U.S. NSSS vendors and nuclear plants with at least four different architect-engineers. The measurement data include: 1) a determination of neutron dose and dose equivalent rates inside and outside of containment; 2) neutron spectral and flux distributions at selected locations both inside and outside of containment; 3) special monitoring with currently available neutron dosimeters, i.e., albedo, film and fission fragment, at each site; and 4) correlate instruments and dosimeter data to flux and spectral distributions to determine their proper response and interpretation. Lawrence Livermore Laboratory personnel have assisted with measurements at two of the sites and analysis of multisphere data taken at all the sites.

To accomplish this study, tissue equivalent proportional counters (TEPCs) were used to measure the neutron dose and dose equivalent rates.

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At the same time, currently used neutron survey instruments, such as the Snoopy, were used for dose equivalent rate measurements. The multisphere technique and other spectrometers were used to estimate the neutron spectrum at selected locations inside the outside containment and were supplemented by TEPC data. Currently available dosimeters were then placed on phantoms to provide data which can be used to establish their capability for adequate personnel dosimeter measurement requirements as stated in Regulatory Guide 8.14.

The personnel dosimeters used were obtained from vendors who normally supply this service to licensees and include film, TLD and track etch detectors. We used an improved version of the Hanford Multipurpose Dosimeter (MPD). A combined track-etch-albedo neutron dosimeter developed by Hankins and Griffith of Lawrence Livermore Laboratory (1) was also used.

Neutron calibration exposures were conducted with a bare Cf-252 neutron source, and with spheres of Al, H_2O and D_2O surrounding the Cf-252 source. Neutron monitoring instruments, which use moderated BF-3 detectors, tend to read high in the moderated Cf-252 spectra when they are calibrated with the bare Cf-252. The tissue equivalent proportional counter correctly measures all absorbed dose and dose equivalent for event sizes larger than about 5 keV/μm. Albedo TLD dosimeters were exposed on phantoms to the various Cf-252 source configurations. When calibrated with bare Cf-252, the albedo dosimeters read a factor of 2 to 3 high for the moderated Cf-252 sources.

EXPERIMENTAL RESULTS

The multisphere spectrometer system consists of five polyethylene spheres of various sizes plus a bare and cadmium covered neutron detector. For a measurement point, the thermal neutron count rate was measured using a ^{6}LiI(Eu) detector in seven different configurations. A spectrum unfolding computer program, known as LOUHI (1), is used to determine the neutron spectrum from each set of data. Response functions for each of the detector geometries are included in the computer program. The response functions for each of the sphere sizes,7.6, 12.7, 20.3, 25.4 and 30.5 cm diameter, were calculated by Sanna (2).

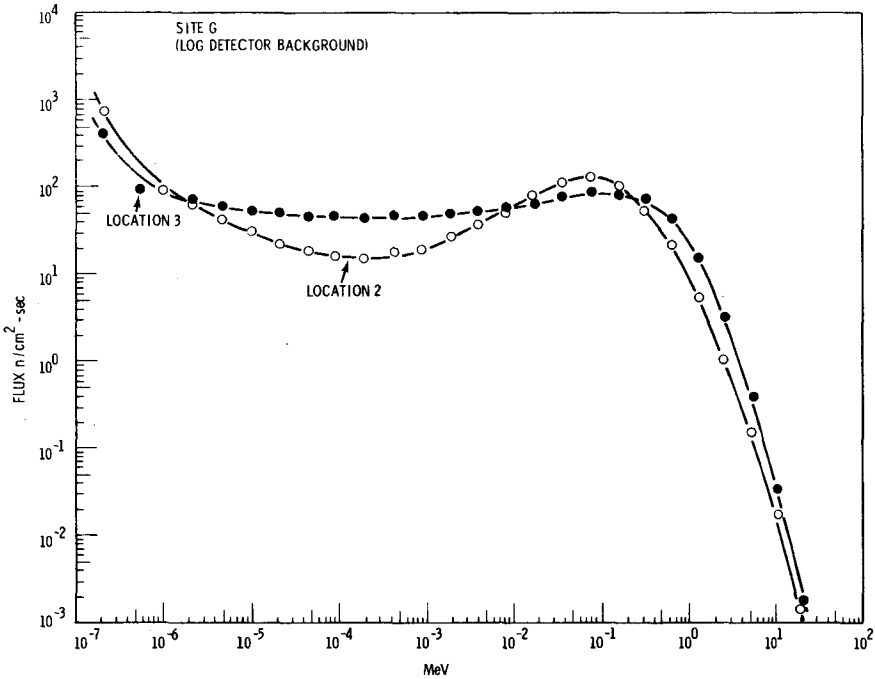
Typical results for spectra measured inside containment at a PWR nuclear power plant are shown in Figure 1.

Because of the "low" resolution of the multisphere system, the unfolded spectra show no sharp peaks or edges. The computer program provides 26 neutron energy groups from thermal to about 20 MeV.

The differential flux, integral flux, integral dose equivalent, energy band width, and flux density are provided for each energy. Kerma rate, dose rate and average energy for each spectrum is also given. The average energy for the spectrum is 62 keV at Location 3. The range of average energies for all locations at all the PWR sites was from about 10 keV to 90 keV. Readings taken with standard neutron survey instruments at the same locations as the multisphere system show a response about a factor of 2 higher than the multisphere.

Tissue equivalent proportional counters (TEPCs) were used at several locations inside containment to measure absorbed dose directly for comparison with "Snoopy" and Rascal monitoring instruments. At most locations a 12.7 cm diameter spherical counter filled to 1 μm equivalent size with tissue equivalent gas was used.

FIGURE 1. Typical Spectra Inside Containment at a PWR

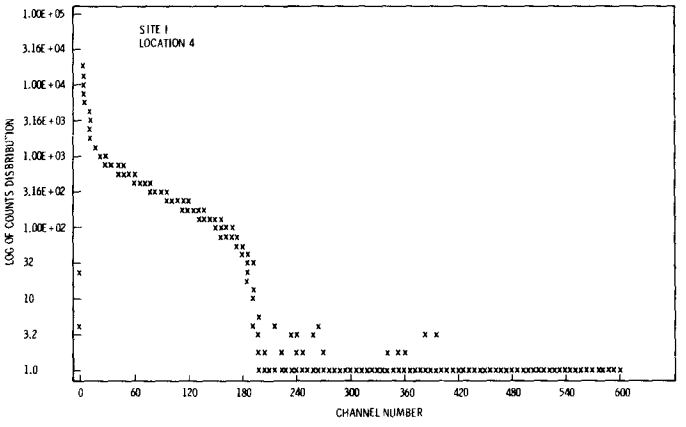


A typical event size spectrum from the TEPC is shown in Figure 2. Data are shown as they appear on a multichannel analyzer for Location 4 at Site I. The sharp drop in the number of events per channel at about channel 200 corresponds to 28 keV/μm, the maximum energy loss a proton recoil can have in the TEPC.

This drop point is often called the proton drop point and is used to calibrate the measurement system. Absorbed dose is obtained by multiplying the number of events at each energy by the energy and integrating over the spectrum.

The absorbed dose rate for the spectrum in Figure 2 is 0.51 Gray/hr. The quality factor determined by Rossi (3) analysis is 10.8. In this case the analysis of the data for quality factor includes all events greater than 5 keV/μm. At this location the dose equivalent is about 560 mrem/hr. Measurements with monitoring instruments gave readings of 1300 to 1600 mrem/hr.

FIGURE 2. Typical Event Size Spectrum from TEPC



Both the multisphere system and the TEPC indicate that the monitoring instruments are a factor of 2 or so high in the well-scattered neutron fields inside containment.

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