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MONITORING OF HIGH-RADIATION AREAS FOR THE ASSESSMENT OF OPERATIONAL AND BODY DOSES

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INTRODUCTION

The International Commission on Radiological Protection (ICRP) recommended a system of dose limits for the protection of ionizing radiation. [1,2] This system was established based on the effective dose , E, and the equivalent dose to an organ or tissue, H_T, to assess stochastic and deterministic effects. In radiation protection monitoring for external radiation, operational doses such as the deep dose equivalent index [2,3], $H_{I,d}$, shallow dose equivalent index, $H_{I,s}$, ambient dose equivalent [1,4-6], H*, directional dose equivalent, H', individual dose equivalent-penetrating, H_p, and individual dose equivalent-superficial, H_s, are implemented. These quantities are defined in an International Commission on Radiation Units and Measurements (ICRU) sphere and in an anthropomorphic phantom under simplified irradiation conditions. They are useful when equivalent doses are below the corresponding limits. In the case of equivalent doses far below the limits, the exposure or air kerma is commonly applied. For workers exposed to high levels of radiation, accurate assessments of effective doses and equivalent doses may be needed in order to acquire legal and health information.

In the general principles of monitoring for radiation protection of workers, ICRP [7] recommended that: "A graduated response is advocated for the monitoring of the workplace and for individual monitoring—graduated in the sense that a greater degree of monitoring is deemed to be necessary as doses increase of as unpredictability increases. ····· Gradually more complex or realistic procedures should be adopted as doses become higher. Thus, at low dose equivalents (corresponding say to those within Working Condition B) dosimetric quantities might be used directly to assess exposure, since accuracy is not crucial. At intermediate dose equivalents (corresponding say to Working Condition A and slight overexposures) somewhat greater accuracy is warranted, and the conversion coefficients from dosimetric to radiation protection quantities should be applied. ····· For significant exposures that are deemed abnormal, according to the recommendations in ICRP Publication 28, actual doses in the body, from an assessment of the accident, should be used." In order to assess radiation protection quantities and actual absorbed doses in the body stated above, information on the energy and irradiation geometry of the incident radiation is required. ICRP in its Publication 35 [8] recommended that: "In minor accidents, when the deep dose equivalent index is only slightly above the limit, the organ and tissue dose equivalents themselves may still comply with the annual limit for effective dose equivalent. Information on the energy spectrum and orientation of the incident radiation may then allow more realistic estimates of these dose equivalents to be made."

In this work, we surveyed high radiation areas in the nuclear power plants in Taiwan. We measured energy and angular distributions of photons in these areas by a portable NaI detector. We then analyzed the irradiation geometries using the ICRU classifications. Applying these results, the Taiwan Power Company should be able to evaluate actual body doses more accurately for workers exposed to high-levels of radiation.

EXPERIMENTAL

An experimental setup established in this work consists of a NaI detector, a lead collimator and the mutichannel system, all in portable units. A layout of this setup at the Drywell in the Second Nuclear Power Plant is sketched in Fig. 1. Here the assignment of front (F), back (B), left (L), right (R), up (U) and down (D) directions was arbitrary. This was for the purpose of recording the collimator alignment. Four different locations in the Drywell area and six directions per each location have been measured. An initial survey showed that the exposure rates were ~13-75 mR/h. The counting time per each measurement was two minutes.

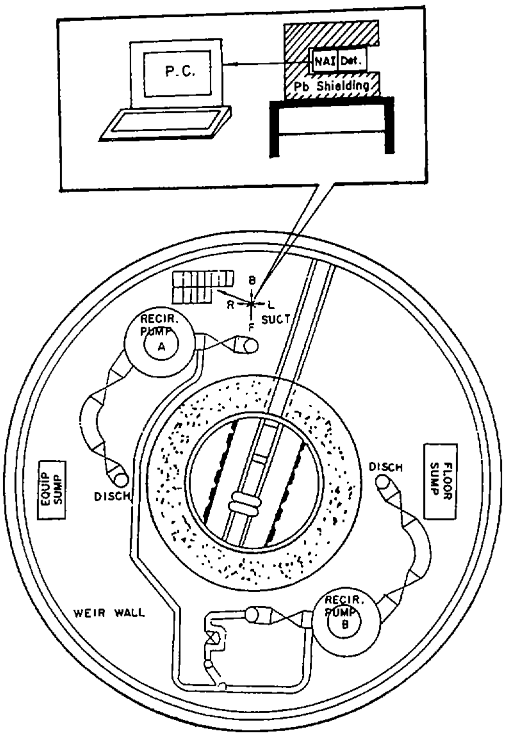

Figure 1 - A layout of experimental setup used in the measurement of energy and angular distributions at the Drywell area in the Second Nuclear Power Plant.

A total of seventeen workplaces in three nuclear power plants was monitored. The exposure rates ranged ~1.5-310 mR/h. In most workplaces, two or three locations of potential occupancy by workers were selected for measurements. Radiation exposures were possible only during maintenance in normal and outage operation times.

RESULTS AND DISCUSSION

Figure 2 shows the results of measured photon energy spectra at the Drywell area in the Second Nuclear Power Plant. Prominent ^{60}Co and ^{54}Mn gamma-ray peaks are clearly identified. It is seen that photons irradiated from the front direction dominate the contribution to the total counting rate. The peak-height ratio of gamma-rays from the front direction to those from other directions ranges ~6-28 at ^{60}Co energies. This indicates that external irradiations at the workplace are most likely unidirectional. The determination of irradiation geometries, classified as AP (anterior-posterior), PA (posterior-anterior), LAT (lateral), PLIS (planar isotropic) and IS (isotropic) by ICRU [5], may be made by a knowledge about the body orientation during irradiation. In the present case, AP, PA and LAT irradiation geometries are the most probable situations.

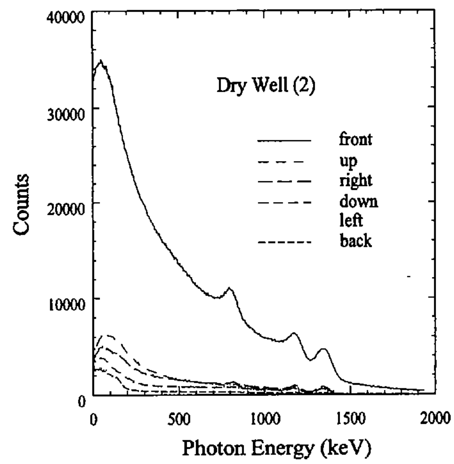

Figure 2 - Photon energy spectra measured at the Drywell area in the Second Nuclear Power Plant in Taiwan. The arrangement of the collimator alignment, specified as photon incoming directions in the figure, is illustrated in Fig. 1.

Figure 3 shows a similar plot of measured photon energy spectra at the Residual Heat Removal area in the Third Nuclear Power Plant. Here, again, prominent ^{60}Co and ^{54}Mn gamma-ray peaks are identified. Radiations from the right, down and up directions contribute most importantly to the total counting rate. The peak-height ratio of gamma-rays from the down direction to those from the right and up directions is ~1.2 and 1.4, respectively, at ^{60}Co energies. This ratio for the rest directions is greater than 7. Thus, it indicates that external irradiations are relatively isotropic in the sense that right, up and down directions make somewhat more contributions. Therefore, irradiation geometries are most probably belonging to the PLIS and IS situations.

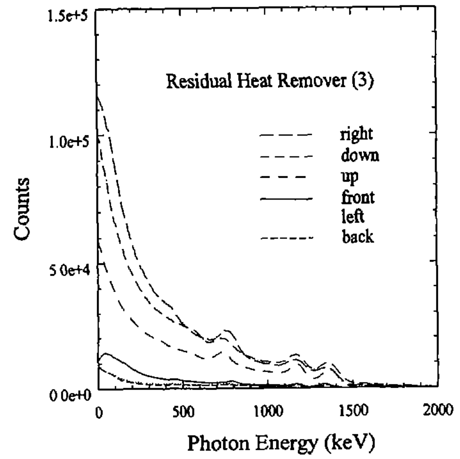

Figure 3 - Photon energy spectra measured at the Residual Heat Removal area in the Third Nuclear Power Plant in Taiwan.

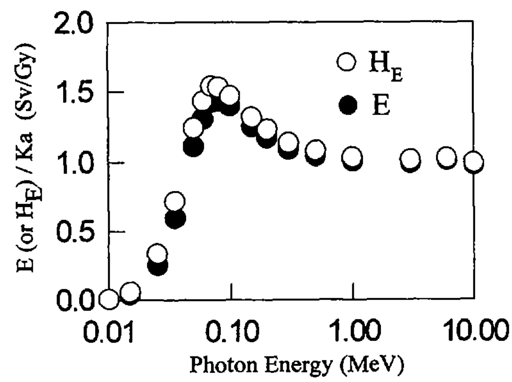

Figure 4 - The ratio of the effective dose, E, and the effective dose equivalent, H_E, to air kerma, K_a, as a function of photon energy for whole-body irradiation by the parallel beam.

ASSESSMENT OF DOSES

Utilizing the measured energy and angular spectra, one can assess body doses more accurately. Figure 4 shows the ratio of effective dose and effective dose equivalent to air kerma as a function of photon energy for a parallel-beam whole-body irradiation [9]. The maximum value of this ratio occurs at around 80 keV photon energy. Below ~20 keV, this ratio drops to essentially zero. When one assesses effective dose by air kerma, the assessment is conservative only if the above ratio is less than one. Therefore, this assessment shows under-estimating for photon energies between ~50 and 500 keV but too much over-estimating for energies less than ~30 keV. For an accurate assessment of actual doses in the body, one requires information on the photon energy distribution.

For other irradiation geometries of a parallel beam, Fig. 5 shows a plot of effective dose equivalent per unit ambient dose equivalent at tissue depth 10 mm, i.e. H*(10), as a function of photon energy [5]. Since the ratio of effective dose equivalent to ambient dose equivalent is always less than one, it reveals that the ambient dose equivalent is a conservative quantity for the measure of effective dose equivalent. Although the ambient dose equivalent is a good operational quantity for high-energy photons, it is too much conservative for low-energy photons. Besides, the ambient dose equivalent is defined under an expanded and aligned radiation field [4]. This field resembles the AP irradiation geometry closely but is far from other irradiation geometries. Thus, the ambient dose equivalent is strictly useful only for the AP irradiation. The over-conservation should be avoided if significant exposures take place. For workers exposed to high-levels of radiation, the ambient dose equivalent may be only slightly above the limit. Whereas, the organ and tissue dose equivalents themselves may still comply with the annual limit. In such cases, more realistic estimates of effective dose equivalent may be essential.

Figure 6 shows a plot of the dose equivalent to ovaries per unit ambient dose equivalent as a function of photon energy [5]. Again, the ratio of ovary dose equivalent to ambient dose equivalent is less than one for all irradiation geometries at any photon energies. The criteria of accepting the ambient dose equivalent as a good operational quantity to assess ovary dose equivalent remain the same. The conclusion, i.e. ambient dose equivalent is a good operational quantity only for the AP irradiation geometry at high photon energies, remains unchanged.

Finally, we show in Fig. 7 the effective dose equivalent per unit individual dose equivalent-penetrating, $H_p(10)$, as a function of photon energy for different exposure conditions [5]. Here, AP-Front refers to the AP irradiation geometry and the front-body personal dosimeter. Similar explanations may be adopted to other symbols. It is noticed that two exposure conditions, i.e. AP-Back and PA-Front, yield greater than one ratio of effective dose equivalent to individual dose equivalent-penetrating. This means that individual dose equivalent-penetrating is under-estimating the effective dose equivalent. This under-estimation is critical for low-energy photons. Also, the individual dose equivalent-penetrating is too much over-estimating at photon energies below ~50 keV for other exposure conditions. In all such cases, the individual dose equivalent-penetrating is not a good operational quantity for the assessment of effective dose equivalent.

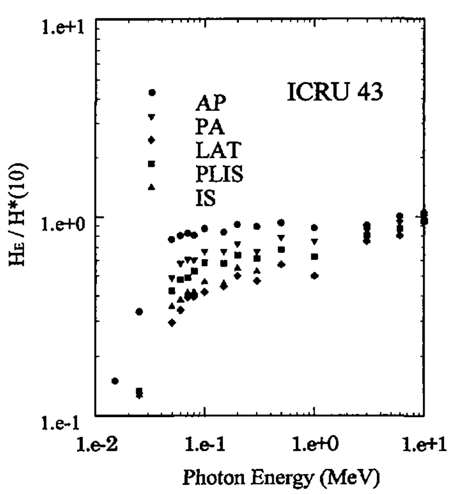

Figure 5 - Effective dose equivalent, H_E, per unit ambient dose equivalent, H*(10), as a function of photon energy. Irradiation geometries and symbols are explained in the text.

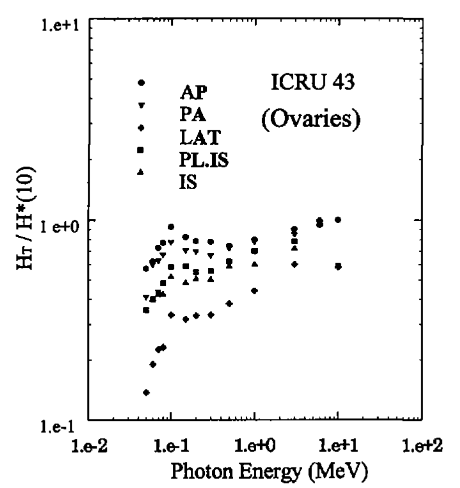

Figure 6 - Dose equivalent, H_T, to ovaries per unit ambient dose equivalent, H*(10), as a function of photon energy. Irradiation geometries and symbols are explained in the text.

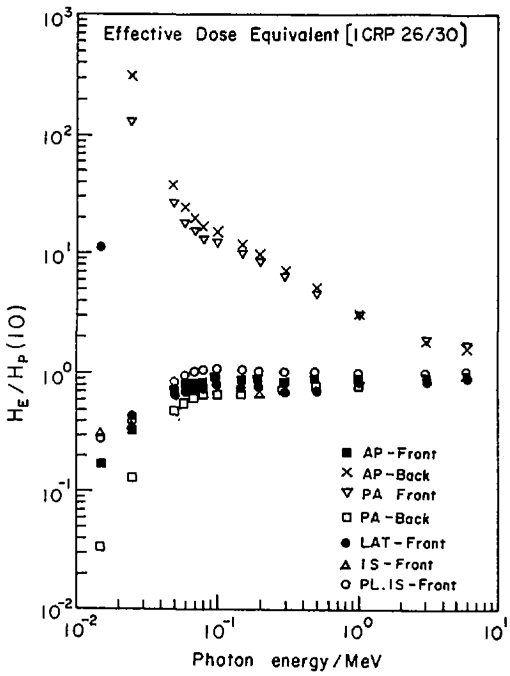

Figure 7 - Ratio of effective dose equivalent to individual dose equivalent-penetrating as a function of photon energy for different exposure conditions. Irradiation geometries and personal dosimeter locations on the body corresponding to these conditions are explained in the text.

CONCLUSIONS

In this work, we have measured energy and angular distributions of photons at high radiation areas in the nuclear power plants in Taiwan. With these measurements, irradiation geometries can be determined as suggested by the International Commission on Radiological Protection. Information on irradiation geometries and energy spectra should be applied to allow more realistic estimates of the actual doses in the body. For workers exposed to high levels of radiation, these estimates are necessary for legal and health purposes. Data and algorithm studied in this work will be incorporated into Taipower's dose assessment program for future evaluation of organ and tissue doses if required.

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