ALARA PRACTICES DURING NEUTRON SPECTRAL MEASUREMENTS INSIDE REACTOR CONTAINMENT

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The accurate assessment of radiation dose to personnel who enter reactor containment is a difficult problem compounded by the presence of mixed radiation fields of betas, neutrons, and high- and low-energy photons. Many present dosimeters do not adequately assess the true dose from neutrons, betas, or high-energy photons. In 1980, the National Council on Radiation Protection and Measurements (NCRP) announced that it is considering lowering the maximum permissible dose for neutrons, perhaps by a factor of 3 to 10 less than existing limits. These changes could have serious consequences for the operation of present commercial nuclear power plants and the design of new plants. Present personnel dosimeters will not be adequate if these proposed changes are adopted; in fact, many dosimeters are not sufficiently accurate to be adequate with existing limits.

Knowledge of the neutron radiation fields inside light water reactor (LWR) power plants is required for adequate interpretation of neutron monitoring instruments and personnel dosimetry. The needed information includes: neutron dose rates, neutron dose equivalent rates, and the spectra of neutron energies present. The measurements to acquire this information should be conducted inside reactor containment during power. These measurements will supply data needed to accurately assess personnel neutron dose and to determine the adequacy of the bioshield design.

Battelle Northwest Laboratories (BNW) has conducted neutron dose and energy spectral measurements inside reactor containment at many LWRs over the past five years. Preliminary studies have shown a degraded neutron spectrum inside reactor containment at LWRs with few neutrons with energies greater than 1 MeV. Neutron dose rates were found to vary significantly from location to location inside containment. Measurements have indicated that present neutron monitoring instruments may respond from 50 percent to 600 percent high, depending on the instrument and location inside reactor containment. Personnel neutron dosimeters have responded high by up to factors of 25 depending on the dosimeter type and the calibration method. Although measured spectra at the different locations are somewhat similar, differences related to shielding design rather than reactor and pressure-vessel design are apparent. The BNW staff have primarily used the following neutron measurement systems: 1) the multisphere spectrometer system, 2) the ^{3}He spectrometer system and 3) the Tissue Equivalent Proportional Counter (TEPC).

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The multisphere spectrometer system is a commercially available system for measuring a wide range of neutron energies from thermal (0.025 eV) to 20 MeV. The spectrometer consists of a ^{6}LiI scintillator detector and a set of polyethylene spheres of different diameters. The ^{6}Li scintillator is inserted into a hole drilled into each sphere and is used to measure the slow neutron flux at the center of each sphere. The scintillator detector is connected to a multichannel analyzer (MCA), which is used to determine the count rate from neutron-induced events. Measurements are made with the bare scintillator, the detector covered with cadmium, and the detector at the center of 3-inch to 12-inch-diameter spheres. The count rate from each configuration is used as input to a computer code which determines the neutron fluence as a function of energy and the neutron dose equivalent.

The ^{3}He spectrometer consists of a ^{3}He proportional counter and associated electronics. Neutrons interact with the ^{3}He to produce a proton and a triton. If the reaction products are absorbed in the gas of the proportional counter, the resultant pulse is proportional to the original neutron energy plus 764 keV. A simple computer code corrects for the energy dependence of the ^{3}He detector and calculates the relative flux. The ^{3}He neutron spectrometer has much better resolution and accuracy than the multisphere spectrometer in the higher neutron energy regions above 20 keV, where neutrons are more effective in producing dose. However, the He-3 is only used at neutron energies below 5 MeV due to the limitations in the present analysis method.

The TEPC is a hollow sphere of tissue-equivalent plastic with the 3.2 mm-thick walls filled with tissue-equivalent gas. Details of plastic and gas composition and methods of construction can be found in Report 26 of the International Commission on Radiation Units and Measurements (ICRU 1977) [1]. This form of TEPC, called a Rossi counter, has a helical grid around the central anode wire. The helical grid establishes uniform electric field strength along the entire length of the anode. This produces the needed uniformity in gas amplification at all points along the anode for proper pulse-height analysis. The plastic sphere is contained inside a metal pressure vessel with a valve for admitting tissue-equivalent gas. The gas pressure is maintained at a pressure so that charged particles crossing the cavity lose only a small amount of energy as they traverse the counter. Energy deposited in the cavity is then equal to the linear energy transfer (LET) of the particle times the path length. At these low pressures, the gas-filled cavity has the same mass-stopping power as a sphere of tissue (ρ = 1 gm/cm^3) with a diameter of about 1 μm and is said to have an "equivalent diameter" of 1 μm. The TEPC is a device which measures neutron absorbed dose directly and is now under development by the United States Department of Energy (DOE) as a next-generation neutron monitoring instrument. It is anticipated that within the next 2-3 years, it will replace the instruments now in use. The TEPC can also be used directly to determine quality factors.

The above detectors are used with a multichannel analyzer and supporting electronics (e.g., high-voltage power supplier, linear amplifier, portable computer, etc.). Including the detectors and auxiliary equipment, up to 500 pounds of detection systems are taken into containment during the measurements. Because of the high temperature and humidity in reactor containment and the high radiation areas in some locations, it is necessary to limit the time of the personnel in containment to a minimum. The BNW staff follow ALARA principles to minimize the non-radiological hazards as well as the radiological hazards while performing neutron measurement inside reactor containment during power.

Probably the most important method of observing ALARA during these measurement conditions is planning. Prior to the measurements a planning meeting is held with the staff at the reactor site and the measurement procedure is thoroughly reviewed. Topics at this meeting include: 1) identification of detector and MCA setup locations, 2) personnel responsibilities and task assignments, 3) dressing procedures, 4) emergency escape hatch locations, 5) emergency signals and appropriate responses, 5) identification of dose levels in the radiation zones to be entered, and 6) any special radiation work procedures.

Each neutron detection system is thoroughly checked over at BNW before shipping offsite to the power plant. This reduces the time spent trouble-shooting the equipment in containment. All cables are sheathed in plastic at BNW prior to shipping. The equipment is wrapped in plastic at the plant. This, of course, reduced the chance of contamination to the instruments inside containment.

It is beneficial to select measurement locations inside containment that have high neutron dose rates because sufficient data can be collected in shorter periods of time. Thus, we have developed methods to limit the amount of time the equipment operator actually needs to spend in these higher-dose areas. With the use of 50-ft to 100-ft signal and pre-amp power cables, the neutron detector/counter can be placed at the measurement location and the associated electronics can be separated at a significant distance. The equipment operator needs to spend just a few seconds at the high-dose area setting up or removing the detector. The remainder of the time, the operator can be at the controls for the detector, located in a lower-dose rate area. If the collection time is long enough and/or the dose rates high enough, the operator can keep the instruments running and leave containment to further reduce his exposure. Generally, each system requires just one person to operate. However, the buddy system is always employed so that the people are always in sight of each other and easily accessible. Two people are used to set up and remove the equipment. Carts on wheels are used to move the system faster and more safely.

Because of the high temperature and humidity in reactor containment, precautions are also taken to reduce the effects of heat stress to the personnel. Ice vests are worn to allow operators to work more comfortably and efficiently. Stress monitors are used to determine the maximum stay time for an individual in a certain area or in containment in general. The analyzer is usually set up near a blower since this is normally a low-dose area. It also cools the equipment and the operator of the equipment is more comfortable.

The BNW staff have conducted many measurements inside reactor containment that have had temperatures in excess of 120°F and greater than 90% relative humidity. Yet the staff have been able to stay in containment long enough to conduct the measurements in all the desired locations (generally 8 to 12 locations are measured). To date, no one has been incapacitated due to heat stress. Although some of the dose rates measured were as high as several hundred R/h no one has exceeded 1500 mrem exposure for a complete set of measurements. The average is typically 200-800 mrem per person for four people, or about 2 man rem per set of measurements. No one has exceeded an internal administrative limit of 2800 mrem annually.

REFERENCE

[1] International Commission on Radiation Units and Measurements (ICRU). 1977. Neutron Dosimetry for Biology and Medicine. ICRU Report 26, International Commission on Radiation Units and Measurements, Washington, D.C.