3.6 BONNER-SPHERE NEUTRON SPECTROMETRY

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3.6.1 SCOPE

Described here are EML's moderated multisphere neutron spectrometers, also known as Bonner sphere neutron spectrometers, and the general principles of their use in neutron spectrometry. These spectrometers are used to measure neutron fields:

1. That result from cosmic-ray interactions in the atmosphere (Hajnal et al., 1971; Nakamura et al., 1987);

2. In the containment of pressurized nuclear reactors (Hajnal et al., 1979; Nakamura et al., 1984; Sanna et al., 1980);

3. Around unmoderated (fast) reactors (Griffith et al., 1984; Hoots and Wadsworth, 1984).

4. In plutonium facilities (Harvey and Hajnal, 1993).

5. Fusion test reactors (Kugel et al., 1994a,b).

3.6.2 GENERAL DESCRIPTION

The primary Bonner sphere spectrometer system consists of 12 moderated polyethylene spheres equipped with boron-trifluoride proportional counters. The spectrometers are usable either in parallel or in the independent mode. In the parallel mode, all the spheres are exposed simultaneously to the neutron field, while in the independent mode they are exposed sequentially. Sufficient detail is given here for the basic methodology; the references cited should be consulted for additional information (Aldrich et al., 1981; Awschalom and Sanna, 1985; Cross and Ing, 1987).

At EML, neutron spectrometry is carried out on an occasional basis, usually to answer specific research requirements or questions. Consequently, there are not rigidly defined procedures. Considerable expertise and judgement are required to perform Bonner sphere spectrometry, and this section should be considered as a guide rather than a specific procedure.

3.6.3 PERSONNEL AND TRAINING

The procedures described in this section should be conducted and/or supervised by an experienced physicist or nuclear engineer and that individual should be thoroughly familiar with the content of the references cited in this section.

3.6.4 METHODOLOGY

3.6.4.1
DESCRIPTION OF THE SYSTEM

Bonner sphere spectrometers have been used extensively in radiation protection practices to determine neutron spectral distributions around particle accelerators, nuclear power stations and other nuclear facilities, as well as in cosmic-ray neutron research for over two decades. The Bonner sphere spectrometer system is very useful since it is simple, portable, has an isotropic response, covers a wide energy range, and the data can be unfolded and interpreted fairly easily (Bramblett et al., 1960).

One drawback of this method is the low energy resolution. This is partially due to the fact that the statistical fluctuations in the number of collisions in the neutron slowing down processes are large, and the capture reactions are completely indistinguishable from one another. This results in loss of information about the primary neutron energy and, consequently, low resolution.

3.6.4.2

THE BONNER SPHERES

The 12 Bonner spheres are: one bare and one 0.075-cm Cd covered 5.08-cm diameter boron-trifluoride spherical proportional counter, and 10 spherical polyethylene moderators of 7.62-cm, 7.85-cm, 10.01-cm, 10.24-cm, 12.75-cm, 14.94-cm, 15.24-cm, 19.96-cm, 25.04-cm and 30.07-cm diameters, respectively, with spherical proportional counters placed at the centers.

3.6.4.3

THE RESPONSE FUNCTIONS

The Bonner sphere spectrometer response functions must be calculated. The calculations should be performed using different numerical methods (such as those incorporated in the ANISN and MORSE codes), different evaluated neutron cross section sets, and different energy bining. The response functions of the boron-trifluoride counter equipped Bonner spheres are calculated using DTF-IV and by ANISN transport codes in the adjoint mode. The calculated detector response functions are considered sufficiently accurate if the results obtained using different cross section sets and transport codes differ by only a few percent for the entire energy region (Burgart and Emett, 1972; Maerker et al., 1971).

3.6.4.4

CALIBRATIONS

The Bonner sphere spectrometer calibrations, whenever possible, should be performed with the National Institute of Standards and Technology (NIST) monoenergetic neutron beams, and the normalization of the overall response functions should be performed using ^{252}Cf spontaneous fission neutron sources. At EML, the ^{252}Cf calibrations are performed in an open air calibration facility, where the air and ground scattering contribution in the worst case amounts to only 3% at 1 m source-to-detector separation (Hajnal et al., 1970; Hunt, 1984a,b).

3.6.4.5 ELECTRONICS

Since the boron-trifluoride counters are not sensitive to ß or γ radiation, a simple electronic setup is sufficient: a proportional counter is connected to a preamplifier and the signal is fed to a linear amplifier, followed by a discriminator and a scaler to record the number of capture reactions. The scaler readouts can be recorded on tape, or in an appropriate logbook.

3.6.5 NEUTRON SPECTRUM UNFOLDING

The result of a set of measurements with Bonner spheres is a set of 12 count rates for the 12 detector configurations. A mathematical method known as unfolding is used to obtain a neutron spectrum from these data. This is accomplished using a computer program entitled TWOGO developed at EML (Hajnal, 1981).

The relative count rates obtained for a set of 12 counts made with the Bonner spheres are a function of the energy distribution of the neutron field. The unfolding code provides a reasonable estimate of neutron fluence rate as a function of energy, i.e., a neutron spectrum (Ing and Makra, 1978). The user of TWOGO provides an estimate of the shape, called trial vector, of the neutron spectrum and the computations performed by TWOGO iteratively adjust the spectrum to fit or be consistent with the data. The computations rely on the use of the data available in the literature regarding the response of the detector in its various configurations, as a function of neutron energy. Estimates of the relative errors of individual counts are used as weighting factors during the iterative fitting process.

Several indices are computed with the TWOGO program that serve to measure the goodness of fit of the unfolding process. These indices are based on determining the degree of agreement between the data obtained by observation. That is, count rates due to neutrons for each of the detector configurations, and synthetic counts or estimates of these same parameters obtained by folding together the response matrix and the spectrum obtained by the unfolding process.

3.6.6 ACCEPTABLE SOLUTION

A solution can be called exact, approximate, or appropriate (Gold, 1964). Exact solutions may have zero errors, and might look reasonable. However, they may have unphysical characteristics, such as oscillations, and the "tail-wags-the-dog syndrome" might appear. Usually, the unfolded data should not be expected to have too good a fit, at least not better than the error of the input data. In general, the trial vectors should contain the features of the neutron spectra one can expect from the physics of the problem. Similarly, the smoothing functions, if any, have to be properly chosen. Appropriate solutions can be obtained from good measurements, and considerable experience is needed to judge just when a reasonable spectral solution is reached.

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