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NEUTRON SPECTRUM MEASUREMENTS AT THE  
WHITE SANDS MISSILE RANGE FAST BURST REACTOR (FBR).

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1976

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126p.

The White Sands Missile Range Fast Burst Reactor (FBR) is an unmoderated, unreflected bare critical assembly of the Godiva II type. The FBR is extensively used for producing a nuclear environment which stimulates the neutron portion of a nuclear weapon (1). Military systems are exposed to this environment for testing and analysis of their response to a nuclear weapon.

The primary system degradation at the FBR is produced by neutron interactions within the system. Most of the military systems tested use solid state electronic devices. Neutron displacement and other neutron effects in the silicon devices cause the electronic degradation. The amount of damage produced by a neutron is a function of the neutron energy. The neutrons produced by the FBR have a continuous (fission) spectrum of energies. A complete characterization of this spectrum is essential in the evaluation of the nuclear effects on the system under evaluation.

Because neutron spectra are of such wide interest, numerous methods have been investigated for their measurement. Nuclear emulsions have been used successfully, but the method is limited by tedious data analysis and low sensitivity (2). Spectrometers consisting of a 'sandwich' of  $^6\text{Li}$  or  $^3\text{He}$  between two surface barrier or gas proportional detectors have proven useful in both fast and thermal neutron environments (3), (4), (5)

However, radiation damage to the solid state detectors and high level gamma intensities are a serious problem (6). Proton-

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recoil proportional counters have been widely used to measure angle-integrated neutron spectra. However, the proton-recoil method is complex in nature, requiring considerable experience and skill in (a) calibration, (b) in coping with linearity and saturation problems, (c) in gamma-ray discrimination, (d) in two-parameter data storage, (e) in counter diagnostics, (f) in response calculations and (g) in spectrum unscrambling codes (7). Time-of-flight techniques are widely used for neutron spectrum measurement where angular flux information is desired. The time-of-flight method is basically simple and as accurate as the detector efficiency versus energy is known. Time-of-flight requires many of the considerations mentioned for proton-recoil as well as necessitating a rather large capital expenditure (7). Activation measurements employing neutron sensitive reactions are widely used, however, results from this technique depend somewhat on the particular set of reactions chosen (8). The activation method is generally considered incapable of providing high resolution neutron spectra measurements but is one of the most useful and widespread techniques currently in use for measuring "smoothed" neutron spectra. Activation measurement of neutron spectra is, in fact, the only practical method available when exposures are conducted in transient neutron fields such as those produced by pulsed reactors or nuclear weapons.

The activation technique was used in this work. The basis of the technique is the neutron energy threshold required for a specified neutron reaction to occur. Reactions are chosen which have activated (radioactive) nuclei as their product. The activated nucleus is then quantitatively assayed using gamma ray spectroscopy. When many different threshold reactions are used it is possible to iterate to an "unfolded" neutron spectrum.

It is convenient to use a single parameter to characterize the neutron spectrum. This parameter, the spectral index (SI), is defined as the ratio of the total neutron fluence by the fluence with energy above 3 MeV.

Spectrum measurements were made at Godiva II type reactors by Sayeg at Los Alamos Godiva II (9), Morrison at Sandia Pulsed Reactor (10) and Humphries at the WSMR FBR (11). The spectral index derived from these studies was  $8-9 \pm 25\%$ . For about ten years this spectral index has been the best measured value.

WSMR initiated a program of refining the activation technique for neutron measurements in 1970. Particularly of

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interest was the use of high resolution gamma ray detectors used to pick out a single gamma ray from fission products. Fissionable foils (such as U235, U238, Pu239, Np237) are used for the activation fission reaction because of their desirable energy threshold. The fission product of interest for the assay of the neutron activated foil is Lanthanum 140. An error in its reported gamma ray intensity was found and corrected by the WSMR Group (12). This gamma ray intensity directly affects the assay of the activation foil, and thus the measurement of the neutron spectrum.

Two major experiments have been completed. The first of these (referred to as Operational Hog Ring) was designed to establish the 'free-field' neutron leakage spectrum from the FBR as determined by activation techniques. There was extensive duplication of activation detectors in Operation Hog Ring to increase the statistical accuracy of the data. This test provided the data necessary to evaluate perturbation effects of the neutron spectrum by Boron-10 shields used by the fission detectors.

A total of 72 individual activation detectors were exposed to the neutron leakage spectrum of the FBR during a 40 minute power run. These activation detectors were arranged symmetrically around the FBR core on a 20-inch radius, mid-plane to the reactor core.

The second test (referred to as Glory Hole) was designed to measure the neutron spectrum within a cavity inside the FBR core. Due to size limitations, duplication of activation measurements was not possible as in Operation Hog Ring. Careful selection of activation detectors was exercised in order to provide the most efficient and accurate coverage of the neutron spectrum as possible.

Data analysis entails many facets and each one must be considered care. First, a choice of the nuclear data must be made in order to select the most reliable and up-to-date parameters such as gamma ray abundances and half-lives. Secondly, detector efficiencies must be measured using radiation standards supplied by the National Bureau of Standards. Furthermore, any factors that affect or influence these detector efficiencies must be considered. Last techniques employed for analysis of gamma ray spectra resulting from activity measurements of the activation detectors are critical factors that must be carefully analyzed. The activities from all activation detectors were measured by high resolution Ge(Li) gamma spectroscopy.

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This free-field neutron spectrum (13) of the FBR has shown that there are more high energy neutrons than has been predicted and measured in the past. The spectral index was measured as  $6.7 \pm 0.6$ . It appears most likely that the difference arises from the radiation measuring techniques developed. Furthermore, the direct tie of all radiation measurements to a primary NBS standard places the new and "harder" free-field spectrum measurement on firm ground.

The neutron spectrum measurement of the Glory Hole was the first spectrum measurement in this configuration. (The Glory Hole has only recently been incorporated into the FBR). The measured spectral index was  $8.3 \pm 0.7$ .

The primary results from this study has been the complete characterization of the 'free-field' neutron leakage spectrum and the Glory Hole neutron spectrum from the FBR. It must be emphasized that the foundation of this study, i.e., the experimental techniques and measurements, are based upon calibration by primary standards which were supplied and certified by the National Bureau of Standards (NBS). In the process of the free-field neutron spectrum measurement, a question concerning neutron scattering/absorption and spectrum perturbation by Boron-10 shielding of fission foils was resolved.

The results of this study have made significant contribution to the complete characterization of the neutron radiation environment of the WSMR FBR. Furthermore, essentially all of the results from this study can be applied to the neutron radiation environment characterization of similar FBR's (Godiva type critical assemblies).

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