Neutron Transmission Measurements of BoroBond™ Blocks

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INTRODUCTION

A Rackable Can Storage Box (RCSB) has been proposed for use in the storage of highly enriched uranium (HEU) in the HEU Materials Facility (HEUMF) at the Y-12 National Security Complex. The RCSB is designed to provide efficient, safe, and secure storage of HEU. More detailed nuclear criticality safety goals as well as preliminary design sketches are provided in [1,2]. The RCSB will use Eagle-Picher Technologies BoroBond4™ (4.1 weight percent $^{nat}B_4C$) as the filler material. BoroBond™ is a borated, chemically-bonded, phosphate-based ceramic solid formed from an exothermic chemical reaction:

$$\mathrm{MgO(powder) + KH_2PO_4(powder) + 5H_2O(liquid)}$$
$$\mathrm{\rightarrow MgKPO_4 \cdot 6H_2O(solid)}$$

Ceramic water content provides neutron moderation while fly ash and B_4C powder may be added in varying proportions in order to produce a neutron-absorbing material. In order to characterize the material, BoroBond™ blocks of varying boron concentration, thickness, and water content were studied using fast neutron transmission techniques.

DESCRIPTION OF WORK

For this work, four sets of test blocks, with 8 blocks in each set, of varying boron concentration and thickness were provided in order to investigate water concentration sensitivity as a function of hydrogen concentration and block thickness. Nominal block dimensions were 12x12x2 inches and 12x12x4 inches with nominal $^{nat}B_4C$ concentrations of 0, 2.3, 4.6, or 9.1 weight percent.

Fast neutron transmission should depend strongly on water content in the blocks. Source neutrons for these measurements were provided by ^{252}Cf electroplated on one plate of a parallel plate ionization chamber that produces a timing pulse each time ^{252}Cf spontaneously fissions. The fission neutrons have an energy distribution similar to that of uranium fission but slightly higher in energy. The emitted fission gamma rays and fast neutrons enter the BoroBond™ blocks, and their transmission is measured by a proton recoil scintillation detector placed on the opposite side from the source. The times of detection are measured after Cf fission with the Nuclear Materials Identification System (NMIS)[3].

RESULTS

Fig. 1 presents results of measurements of the unbaked nominal 4.6 weight percent $^{nat}B_4C$ blocks for various thicknesses. Counts per Cf fission as a function of detection time following Cf fission are plotted (cross correlation function). The first particles to arrive at the detector are the prompt fission gamma rays, followed by directly transmitted fast neutrons and scattered neutrons. The neutron detection threshold was approximately 0.5 MeV.

The analysis of these measurement results relies on the selection of features from the cross-correlation functions that are sensitive to the quantity of interest (in this case, water content). The feature most sensitive to water content was the integral of the neutron peak for time lags corresponding to transmitted neutron energy from 0.5 to 2.0 MeV. The integral of the neutron distribution was insensitive to $^{nat}B_4C$ content. Half of the blocks were baked to remove approximately 5/6 of the water content. The ratio of the neutron integral for the baked and unbaked measurements was approximately 3 for block thickness equal to 8 inches. Fig. 2 presents measurement results and calculations for the neutron integral for 8 inch thick blocks.

A number of simulations were performed with the Monte Carlo code MCNP-PoliMi [4] for blocks of varying water content. Monte Carlo calculations of neutron integrals were fit to an exponential function of water content. With this functional dependence of the neutron transmission on water content, one can determine the water content of unknown BoroBond™ samples. Calculations were performed for 8 and 10 inch thicknesses since these approximate the distance between fissile storage locations in the RCSB. There was good agreement between the Monte Carlo simulations and measurements.

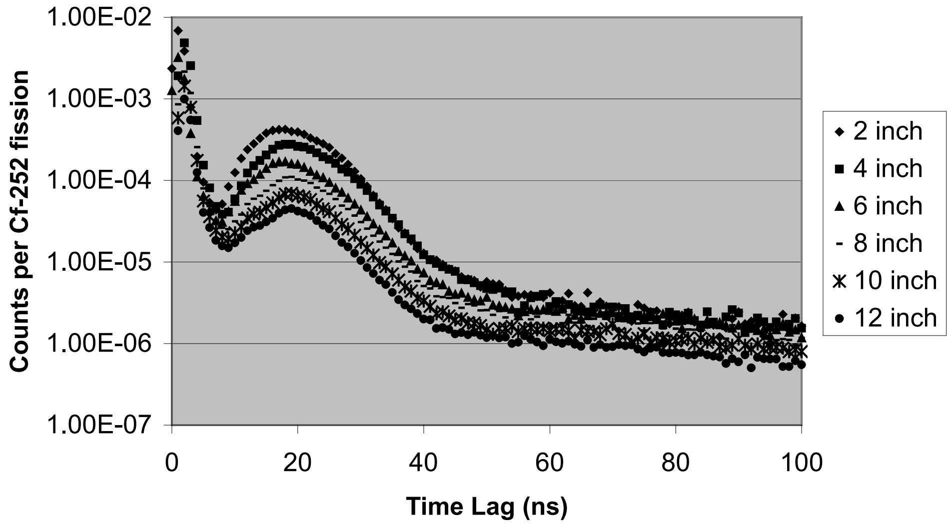

Fig. 1. Time-of-flight transmission measurement for unbaked blocks, 4.6% $^{nat}B_4C$, as a function of thickness.

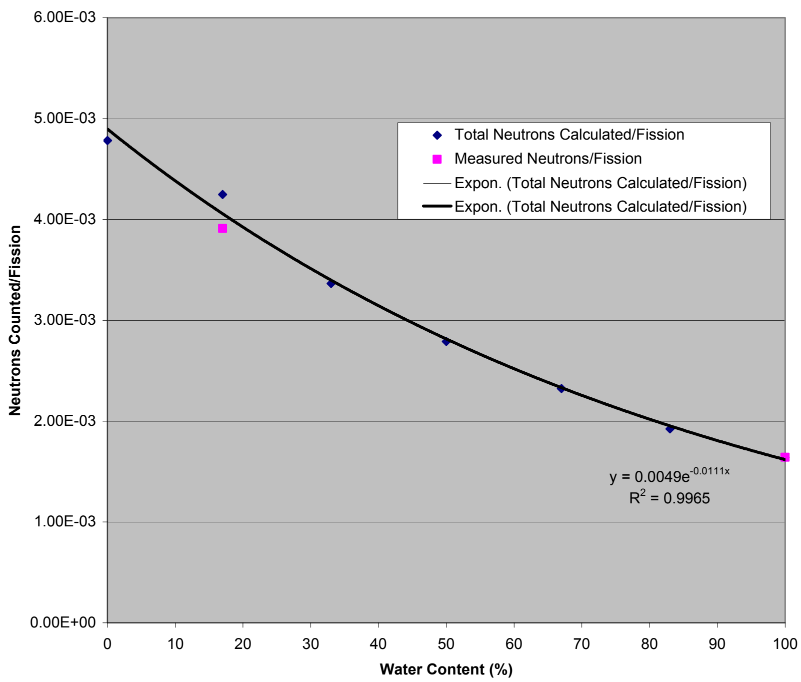

Fig. 2. Area of neutron peak transmission simulations as a function of water content for 8 inch-thick blocks of 4 wt% B_4C and measurements.

Fast neutron transmission measurements and simulations of BoroBond™ blocks have led to a method for quantifying water content in blocks. Neutron transmission measurements yield estimates of the water content to ±3% for full water content in the BoroBond™ blocks. This type of fast neutron transmission method is being considered for verification of the water content of RCSBs at the production site or anytime during their useful life at the HEUMF.

ACKNOWLEDGEMENT

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