U.S. DEPARTMENT OF ENERGY
NUCLEAR ENERGY RESEARCH INITIATIVE
ABSTRACT

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Title: **Development and Validation of Temperature Dependent Thermal Neutron Scattering Laws for Applications and Safety Implications in Generation IV Nuclear Reactor Designs**

The University of Cincinnati (UC), Oak Ridge National Laboratory (ORNL), and the Institute Balseiro (IB) propose to perform theoretical, computational, and experimental investigations on temperature dependent neutron thermalization in moderating materials that are of major importance to the safety of nuclear systems. The objectives of this work are: to critically review the currently used thermal neutron scattering laws for various moderators and fuel cells as a function of temperature, to use the review as a guide in examining and updating the various computational approaches in establishing the scattering law, to understand the implications of the obtained results on the ability to accurately define the operating and safety characteristics (e.g. the moderator temperature coefficient) of a given reactor design -- that is, to know not only the reactivity coefficients but also their errors, sensitivity coefficients and covariance matrices, to develop and generate new sets of temperature dependent thermal neutron scattering laws, $S(\alpha,\beta)$, either by an evolutionary process or by changing the models entirely (e.g., introducing the coherent part of the inelastic scattering or using the synthetic kernel approach), and finally to test and benchmark the developed models within the framework of a neutron slowing down experiment. In particular, the studies will concentrate on investigating the latest ENDF/B thermal neutron cross sections for reactor grade graphite, beryllium, beryllium oxide, zirconium hydride, high purity light water, and polyethylene at temperatures greater than or equal to room temperature. These materials are neutron moderators/reflectors that will be used in the development of Generation IV nuclear power reactors and in many applications in the nuclear science and engineering field. Of major importance is graphite, which is the moderator in the modular pebble bed reactor (MPBR) that is being examined internationally as a possible Generation IV power reactor, as the subcritical reactor in accelerator driven concepts, and as the incinerator of radioactive waste and weapon's plutonium. Furthermore, a newly developed highly conductive form of graphite, known as graphite foam, is currently under study as a reactor material. Added to that, these materials of interest in research reactors such as zirconium hydride (i.e., TRIGA), and in Nerva derivative power sources for space applications (e.g., zirconium hydride, Be and BeO reflectors).

To begin this work, we will perform a critical analysis of the models that are the basis of the present ENDF/B evaluation of the scattering law for a given moderator, and determine the sensitivity of calculated thermal neutron spectra to the details and parameters of the models. Furthermore, we will consider the impact of model parameters on the behavior of the neutron flux around nearby neutron absorption resonances that are going to define global quantities such as the asymptotic neutron spectra and, consequently, reactivity coefficients. We will also study the impact of model parameters on other measured observables such as neutron pulse and wave propagation parameters, and decay constants as a function of size and transuranium buildup and depletion. In addition, we will examine the latest developments in

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thermalization theory and condensed matter physics. Experiments, like the direct measurement of the double differential cross sections and specific heats, and theoretical developments (e.g., new phonon distribution in graphite) will be evaluated to define the degrees of freedom of the scattering media as well as the mechanisms for the transference of energy between the media and the neutrons. All this information will be included as input for new calculations of the scattering matrices with an updated version (to be developed as part of this research) of the present "state of the art" computer codes (used for ENDF/B compilations). As a result, thermal scattering laws, $S(\alpha,\beta)$, will be regenerated using basic input data and modern computational methods. Using these new sets of $S(\alpha,\beta)$, we will analyze the computational anomalies in the thermal scattering data that is in general use today and can cause "strange" behavior in the computational determination of the temperature coefficient of reactivity in nuclear reactors. Discrepancies of up to 150% have been encountered, which may have important safety implications [1]. Consequently, the impact of condensed matter models, and their respective input parameters, on the temperature coefficient of reactivity in nuclear reactors will be determined. Moreover, the computationally regenerated scattering data for the moderators of interest will be used in neutronics calculations of the temperature coefficients of reactivity for several Generation IV nuclear power reactors (e.g., MPBR).

Finally, since graphite is the moderator in various Generation IV reactor concepts, we will benchmark the developed $S(\alpha,\beta)$ model for graphite by performing a neutron thermalization experiment in a graphite (and if available in graphite foam) moderator that is driven by a pulsed neutron source. This measurement approach has the ability to observe the neutron behavior in a moderator as it passes through the slowing down and thermalization energy ranges before its diffusion and escape. Therefore, it is applicable to measurements in the energy range below 1 eV, which is not accessible using the traditional out-of-pile leakage spectrum measurements. The experiment will take place using the Oak Ridge Electron Linear Accelerator (ORELA) facility, and will be performed to obtain the integral time dependent reaction rate of a neutron detector that is placed within the moderator at various temperatures greater than or equal to room temperature (including temperatures encountered in normal operations and during reactor accident conditions). In addition, a beam will be extracted from the moderator to perform temperature dependent measurements (using the ORELA time of flight facilities) of the thermal neutron energy spectrum in the moderator. We will also introduce the new graphite $S(\alpha,\beta)$ data into time and energy dependent 3-D Monte Carlo (e.g., MCNP) computer simulations of the experiments. This will provide computational predictions of the experimental data and will enable validation of the nuclear data libraries for graphite in the thermal energy region.