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INTERMEDIATE NEUTRON SPECTRUM PROBLEMS AND THE INTERMEDIATE NEUTRON SPECTRUM EXPERIMENT

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ABSTRACT

Criticality benchmark data for intermediate energy spectrum systems does not exist. These systems are dominated by scattering and fission events induced by neutrons with energies between 1 eV and 1 MeV. Nuclear data uncertainties have been reported for such systems which can not be resolved without benchmark critical experiments. Intermediate energy spectrum systems have been proposed for the geological disposition of surplus fissile materials. Without the proper benchmarking of the nuclear data in the intermediate energy spectrum, adequate criticality safety margins can not be guaranteed. The Zeus critical experiment now under construction will provide this necessary benchmark data.

I. INTRODUCTION

In the past several years, the lack of benchmark data for critical experiments involving all forms of fissile/non-fissile systems operating on intermediate energy spectrum neutrons has become apparent. Intermediate energy spectrum systems are dominated by scattering and fission events induced by neutrons ranging in energy from 1 eV to 1 MeV. An intermediate energy spectrum system has been proposed for the potential disposition of surplus fissile disposition[1].

A review of criticality benchmark data shows that there have been no adequate tests of either fissile or non-fissile cross sections in an intermediate energy spectrum critical assembly. In this paper, the terms cross sections and nuclear data refer to actual cross sectional data, the evaluation of such data and finally the processing of the data which produce the cross section sets used in the computer codes. Nuclear data uncertainties have been reported for some types of intermediate energy spectrum systems. Depending upon the available Monte Carlo cross sections used, Parks et. al.[2,3] have reported significant variations in the k_∞ of intermediate energy spectrum metal/U-235 systems. ANSI standard ANSI/ANS-8.1-1983 states, the "bias shall be established by correlating the results of criticality experiments with the results obtained for these same systems by the method being validated". Thus to resolve nuclear data uncertainties and ensure that adequate criticality safety margins are appropriately and economically obtained, it is necessary to have experimental benchmark data for a host of fissile/non-fissile systems operating in a intermediate energy spectrum regime.

In this paper, we will discuss some of the characteristics that comprise an intermediate neutron spectrum system. We will then go on to discuss the Zeus benchmark critical experiment now under construction at the Los Alamos Critical Experiments Facility (LACEF). The purpose of this experiment is to provide a benchmark quality test bed, by which integral cross section tests can be conducted on a host of fissile/non-fissile systems with a neutron energy spectrum ranging from fast to intermediate.

II. INTERMEDIATE ENERGY SPECTRUM SYSTEMS

As stated previously, intermediate energy spectrum systems are dominated by scattering and fission events that are induced by neutrons with energies ranging between 1 eV and 1 MeV. Several conditions may be used to characterize intermediate energy systems.

The first condition is that the system contains a moderate Z non-fissile material, for example silicon-dioxide or iron. This produces a situation in which the elastic scattering events occur with little energy loss, and neutrons may undergo many collisions before being absorbed. If lower Z materials are used, i.e. hydrogen, the effect on a system is to produce an energy spectrum which contains both fast and thermal components and little intermediate energy events[4]. Such "bi-modal" systems have been reported as being intermediate energy spectrum, when in fact they are not, and hence do not constitute an adequate test of the intermediate cross sections. The second condition is that these systems typically have a non-fissile/fissile ratio that is in the neighborhood of the maximal on the critical mass curve nearest to the all metal system. Such systems tend to be very large.

We will consider a silicon-dioxide/plutonium system as an example. Figure 1 shows the critical mass for a SiO_2/Pu system reflected by SiO_2 (ref. 5). If we choose a SiO_2/Pu ratio of 90:1, which is the glass storage log of references 1 and 6 and indicated by the x on figure 1, we find that the system is an intermediate energy spectrum system. This can be shown by examining the fission rate as a function of incident neutron energy as shown in figure 2. For this system approximately 77 percent of all fissions are induce by neutrons between the energies of 1 eV and 1 MeV. This data was generated using MCNP[7] utilizing ENDF-VI data. Thus in the absence of any nuclear criticality benchmark data, neither silicon-dioxide nor plutonium's cross sectional data can be computationally tested in an intermediate energy regime; there is no way to tell if the shape of a critical mass curve like figure 1 is correct.

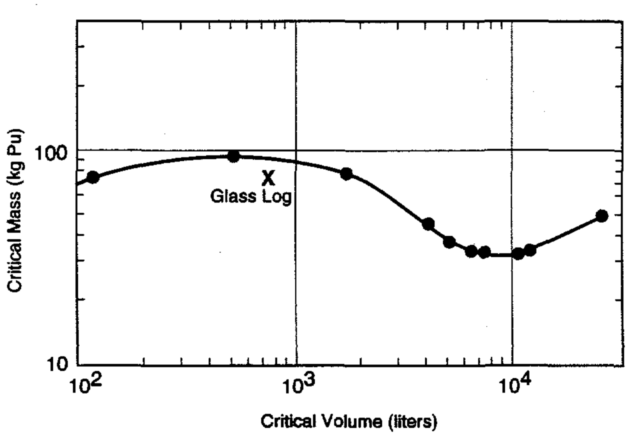

Figure 1. Critical mass of plutonium mixed with and reflected by SiO_2 as a function of the critical volume.

Cross sectional processing can have a large effect upon the predicted k_{eff} of a system. A series of calculations were performed using DANTSYS[8], MCNP, and SCALE[9] on a simple intermediate energy spectrum silicon-dioxide/plutonium-239 system. The system was composed of 100 kg of plutonium-239 uniformly loaded into a sphere of SiO_2. The radius of this SiO_2/Pu sphere was then varied so that the SiO_2/Pu ratio ranged from 24:1 to 367:1. This sphere was reflected with a 100 cm thick SiO_2 reflector. The SiO_2 used throughout the problem had a density of 2.2 g/cc.

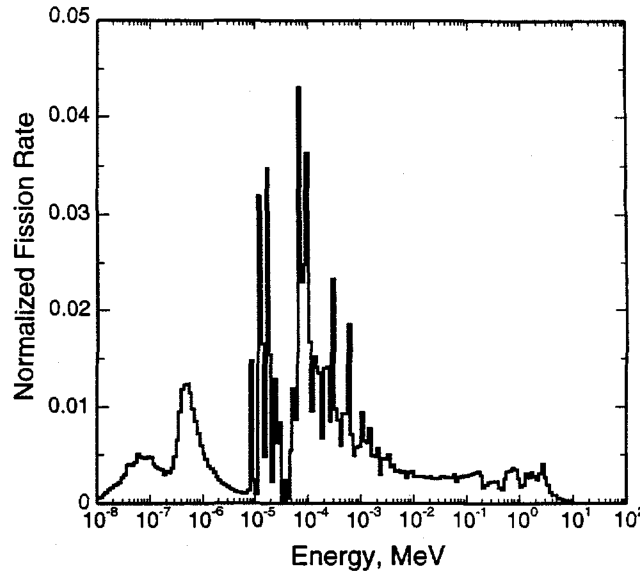

Figure 2 Normalized Fission Rate for a SiO_2/Pu = 90:1 System

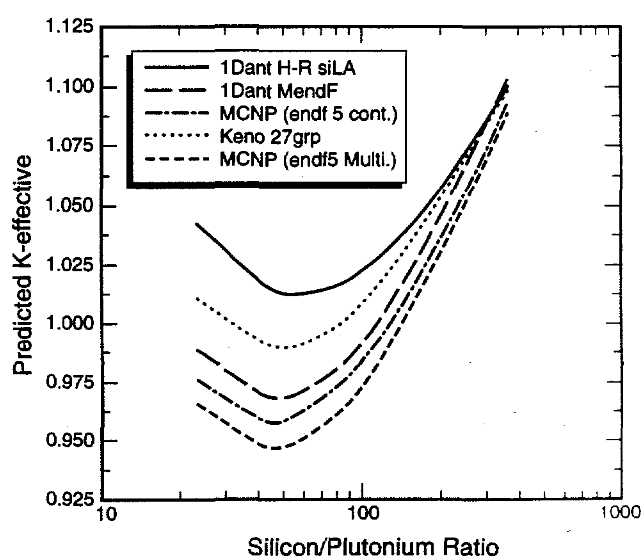

Figure 3 Predicted k_{eff} as a Function of SiO_2/Pu Ratio

The cross-section sets used to perform this calculation consisted of: 1) Hansen-Roach 16 group[10] and MENDF5 30 group[11] for DANTSYS, 2) ENDF-V continuous and multi-group for MCNP, 3) and SCALE 27 group for SCALE. Figure 3 shows the k_{eff} of the system as a function of the silicon-dioxide/plutonium ratio. As one can see, there is a spread of approximately 7.5 percent in the predicted k_{eff} of the system. This spread in k_{eff} roughly corresponds to a 30 kg change in the plutonium mass or represents a 30 percent uncertainty in the critical mass.

This particular set of calculations is a prime example of how the use of different cross section sets can lead to significant differences in the predicted k_{eff}, and hence the predicted critical mass of a system. The multigroup cross section sets were expected to have problems due to resonance-self-shielding, i.e. the weighting functions used to collapse the nuclear data to a multigroup format was inappropriate for the problem at hand. This illustrates the problems associated with the use of cross section sets outside of their intended use.

III. ZEUS, THE INTERMEDIATE ENERGY SPECTRUM EXPERIMENT

To provide the necessary benchmark data to comply with the ANSI standards and resolve any discrepancies in the cross sectional data, we are currently constructing at the Los Alamos Critical Experiments Facility (LACEF) the Zeus benchmark experiment. The purpose of this experiment is to provide criticality data for a host of fissile/non-fissile material mixtures which can be tuned to produce a neutron energy spectra that will range from fast through intermediate to thermal energies.

Currently, the assembly will be fueled with a number of 93% enriched uranium plates measuring 26.67 cm in radius and 3 mm thick. Stacked between the fuel plates will be the interstitial non-fissile material plates with a radius of 26.67 cm. To minimize the fuel loading of the system, the entire core is reflected. The current reflector is comprised of copper approximately 15 cm thick, which will have a total impurity content of approximate 100 ppm. With this thickness of copper, the assembly will be infinitely reflected to isolate the core from room return. The maximum height to diameter ratio allowed is 1.75, thus the maximum height of the core is approximately 93 cm. Additionally neutron instrumentation will be used to collect both neutron lifetime and neutron spectral data for the system in order to compare with the predicted values obtained from the computer codes.

Several methods will be used to tune the neutron energy spectrum of the assembly. Initially the spectrum is tuned by controlling the amount of interstitial material, i.e. by changing the thickness of the interstitial plates. This alone will be sufficient to adjust the neutron energy spectrum from fast to intermediate for lighter Z materials such as graphite. However, if the interstitial is of moderate to large Z, such as iron, one can introduce a scattering material, such as graphite, to produce the desired neutron spectrum. The final method by which the neutron spectrum may be adjusted is by changing out the reflector to some other type of material such as graphite or beryllium. Thus, one can achieve a thermal spectrum in which to test the interstitial material.

The initial experiment is intended to test the uranium cross sections by using high purity graphite plates as the interstitial material. This will allow for the variation of the neutron energy spectrum from the fast to the intermediate. Figure 4 shows the predicted fission rate spectrum for the uranium/graphite core with an interstitial graphite height of 6 cm. Approximately 88 percent of all fissions are produced by intermediate energy neutrons. Once the uranium/graphite system has been examined, other interstitial materials will be tested. For example figure 5 shows the expected fission rate spectrum for 3.9 cm thick SiO_2 interstitial with a total of 17 fuel plates. Approximately 80 percent of the fissions in this system are induced by intermediate energy spectrum neutrons. If one wishes to degrade the spectrum further into the intermediate energy range, one can introduce some additional moderating material like graphite.

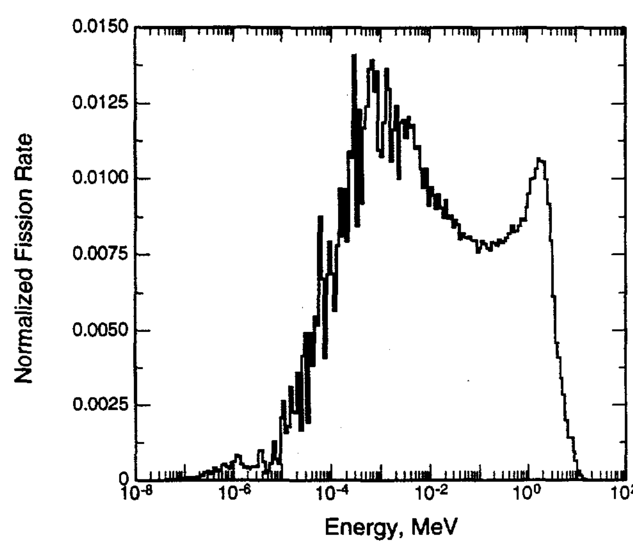

Figure 4 Normalized Fission Rate for the Zeus Graphite/Uranium Core

The Zeus experiment has been designed to be asversatile as possible. The assembly is not limited to using only highly enriched uranium as fuel. Alternative fuels such as plutonium and uranium-233 be can be used in this assembly. Additionally, the current reflector was chosen to be copper, but it is planned to utileze other materials as reflectors. One example would be to use an iron reflector and iron interstitials to perform an all iron experiment.

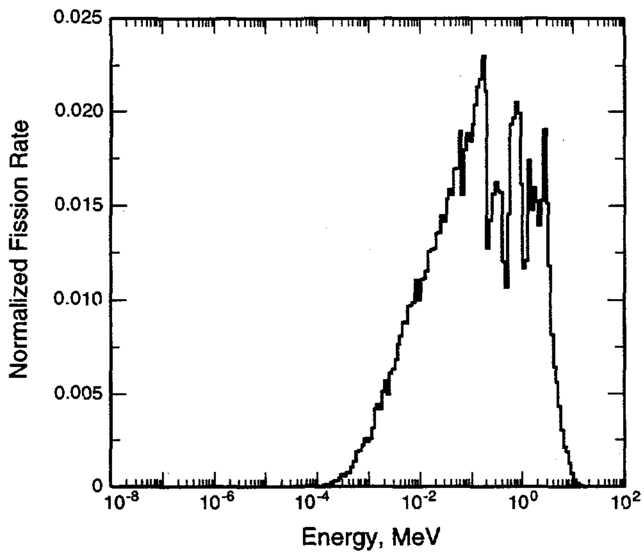

Figure 5 Normalized Fission Rate for the Zeus Silicon-Dioxide/Uranium Core

IV. CONCLUSIONS

Criticality benchmark data for intermediate spectrum systems are necessary to ensure the proper predictive capabilities of the computer codes. The Zeus intermediate energy spectrum experiment can provide much of this necessary benchmark data. Thus, Zeus will provide the data to resolve potential nuclear data uncertainties. Additionally, Zeus will provide benchmark data for a host of materials that have not been tested in a criticality benchmark experiment. This data will prove to be invaluable to the criticality safety community, as the scope and situations encountered expand.

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