First Critical for Zeus, an Intermediate Neutron Energy Spectrum Experiment

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ABSTRACT

The Zeus experiment has been constructed to provide experimental data for validation of nuclear criticality safety calculations in both the fast and intermediate neutron energy ranges. Since neutrons ranging in energy from 1 eV to 0.1 MeV dominate intermediate neutron energy spectrum systems, the overall neutron economy is inefficient, and hence these systems have a tendency to be physically very large. In order to minimize the critical mass, and reduce the room return, the Zeus experiment is reflected with approximately 6350 Kg of copper. The reflector is a modular parallelepiped surrounds the cylindrical core, and measures 88.29 cm square and 103.251 cm tall. The top and bottom of the reflectors are 14.427 cm thick, while the inner radius of the reflector is 26.797 cm. The cylindrical core has a radius of 26.67 cm, and due to the modularity of the reflector, the core may have a maximum height to diameter ratio of 1.75.

Zeus is constructed to accommodate a wide variety of fissile/non-fissile combinations. For the initial set of critical experiments an uranium/graphite core has been chosen. This was done in order to provide a base line for the assembly and a benchmark of the uranium-235 cross sections in the intermediate energy spectrum, thus reducing the number of uncertainties in future experiments. On March 29th 1999, fuel loading of the assembly commenced. An incremental 1/M approach to critical was performed using fuel/moderator units consisting of 4 cm of graphite, a fuel plate, and another 4 cm of graphite. Two 10 unit subcritical configurations were obtained which had an extrapolated critical number of units as 10.32 and 10.10. On April 26, 1999, a modified core loading of 10 fuel/moderator units, nine units consisting of 4 cm of graphite, a fuel plate, and another 4 cm of graphite and a unit consisting of 4 cm of graphite, a fuel plate, 1.5 cm of graphite, 0.152 cm of aluminum, and 1 cm of graphite, achieved first critical. The reactor period obtained from this configuration was approximately 1100 sec, or if on assumes a β_{eff} of 0.0065, the excess reactivity of the system was determined to be 0.011$.

1. 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 0.1 MeV. An intermediate energy spectrum system has been proposed for the potential disposition of surplus fissile materials[1].

A review of criticality benchmark data shows that there have been no adequate tests of either fissile or non-fissile cross sections in intermediate energy spectrum critical assemblies. In this paper, the terms cross sections and nuclear data refer to actual cross section data, the evaluation of such data and finally, the processing of the data which produces 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 that 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 fissile/non-fissile systems operating in an intermediate energy spectrum regime.

The Zeus experiment is intended to provide benchmark quality nuclear criticality data for a wide variety of fissile and non-fissile materials in both fast and intermediate neutron energy spectra systems. In this paper, we will present a description of the Zeus assembly. We will then go on to present experimental results, from three configurations, produced during the first core loading and approach to critical.

2. 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 0.1 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. It is of interest to note, that the design calculations, using MCNP[4], for Zeus indicate that the average neutron undergoes approximately 80 collisions before removal. 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 few intermediate energy fission events[5]. 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. Thus such systems tend to be physically large.

3. ZEUS

The Zeus critical experiment has been constructed at the Los Alamos Critical Experiments Facility (LACEF). Figure 1, shows the Zeus experiment on the general-purpose assembly machine Comet. The experiment has been designed to accommodate a wide range of fissile and non-fissile materials. The core is split into two portions. The top portion is supported on a 0.264 cm thick 304 stainless steel membrane, while the lower portion rides on the lower movable reflector. In general, the critical assembly consists of a core region that is 26.67 cm in radius, and due to the modularity of the copper reflector it can have a maximum height to diameter ratio of 1.75.

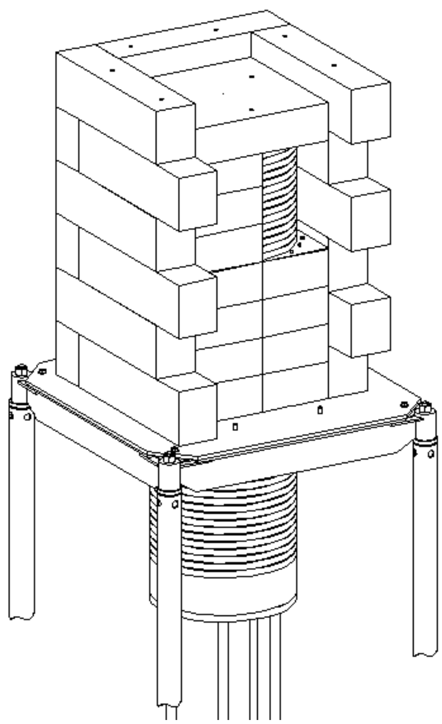

Figure 1. Cut Away View of Zeus

For the first series of Zeus experiments, the core consists of graphite and uranium plates. The purpose of the initial set of experiments is to provide a base line measurement for testing the ^{235}U cross sections in an intermediate spectrum; thus limiting the number of uncertainties in subsequent experiments, which will use other moderating materials. The current configuration of Zeus may be broken down into three basic components: the 93% enriched uranium fuel plates, the graphite moderator, and the copper reflector. These three basic components may be further characterized by the shapes of the their respective components.

The 93% enriched uranium fuel plates consist of two pieces, an inner disc and an outer ring, both of which are 0.318 cm thick. The inner fuel disk has a nominal outer radius of 19.05 cm, and may be either solid or have a central hole of 3.19, 7.63, or 12.71 cm in radius. The average masses for the solid and the holed 3.19, 7.63, and 12.71 cm disks are 6477, 6308, 5460, and 3595 gm respectively. The outer rings have an inner radius of nominally 19.05 cm and an outer radius of 26.67 cm, and have an average mass of 6132 gm. These disks and rings can be used in various combinations to limit the excess reactivity of the system.

The copper reflector serves several purposes. The first is to minimize the critical core volume; this is necessary since intermediate energy systems are physically large. The second purpose is to reduce the effects of room return on the system being studied. The copper reflector consists of four basic pieces. The first is the bottom reflector plug that is 26.67 cm in radius and 14.427 cm tall, and weights 279.42 Kg. Located in the center of this bottom reflector plug is a 3.175 cm radius hole, through which an aluminum alignment spindle is placed. The side reflector may be broken down into two portions; the outer blocks that form the parallelepiped, and the inner blocks that mate the cylindrical core to the outer reflector. The blocks that form the outer reflector are 20.650 cm tall by 16.205 cm wide by 72.085 cm long, and on average weigh 210.65 Kg. These blocks are stacked in an interlocking fashion for stability. The inner reflector parts are essentially square blocks with a quarter circle removed. These parts are 27.940 cm square with a radius of 26.797 cm. The height of the inner pieces is 14.427, 7.620, 3.810, 1.905, and 0.953 cm. The average weight of the inner reflector pieces is 27.30, 14.38, 7.14, 3.56, and 1.80 Kg for the 14.427, 7.620, 3.810, 1.905, and 0.953 cm high pieces respectively. The majority of the inner reflector parts are the 14.427 cm tall pieces, with the other parts used as shims for the variable height core. The final piece of the reflector is the top reflector plug. This piece is 55.880 cm square and 14.427 cm tall, with a weight of 396.44 Kg. The top reflector plug rests on the inner reflector pieces inside the outer reflector blocks. The copper used in the reflector has a nominal impurity content of 0.04 % oxygen and 22-ppm metal impurities, most of which is silver.

The final component of the core is the graphite moderator. The moderator consists of 26.67 cm radius disks that are either 1.0 or 0.5 cm thick. Approximately half of the graphite disks have a 3.175 cm radius hole located in the center. This hole is present to accommodate 3.175 cm radius 0.616 cm thick aluminum alignment spindle. The graphite plates have been manufactured from high purity graphite with an average ash content of approximately 0.4 ppm. The average weight of the plates are as follows: 1.0 cm thick with no hole is 3873.85 gm, the 0.5 cm thick with no hole is 1900.86 gm, 1.0 cm thick with 3.175 cm hole is 3732.05 gm, and the 0.5 cm thick with 3.175 cm hole is 1836.77 gm.

4. FIRST CORE LOADING

For the first core loading of Zeus, a unit cell consisting of 4 cm of graphite, a fuel plate, and another 4 cm of graphite was chosen. This core configuration was chosen since it was estimated that the resulting core would be near the maximum height to diameter ratio for the assembly. A 1/M incremental approach to critical was used during the fuel loading. Figure 2 shows the results of the incremental approach to critical during which successive units were added to the assembly.

During the approach to critical, two subcritical configurations, consisting of 10 units, were obtained. The first subcritical configuration consisted of 5 units on the bottom portion of the assembly, each with a 3.175 cm radius hole, and 5 units on the top portion of the core, 4 with no hole and one with a 3.175 cm radius hole in only the fuel. The extrapolated critical number of units for this case was determined to be 10.32 units. In an effort to obtain a critical configuration, a second subcritical configuration was obtained. This second configuration consisted of 4 units on the bottom portion of the assembly, each with a 3.175 cm radius hole, and 6 units on the top portion of the core, 5 with no hole and one with a 3.175 cm radius hole in only the fuel. This configuration was again subcritical with an extrapolated critical number of units now approximately 10.10 units.

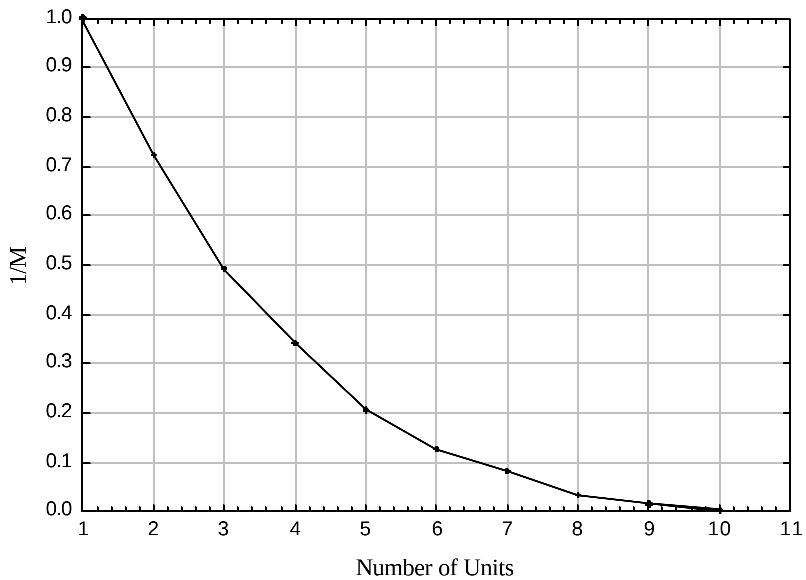

Figure 2. One Over Multiplication Approach to Critical

The reflector configuration during the 1/M approach to critical consisted of 6 tiers of outer reflector blocks, 4 tiers of inner reflector pieces each 14.427 cm tall, the stainless steel membrane, 3 tiers of inner reflector pieces each 14.427 cm tall, and one tier of shim inner reflector pieces. For the final critical and the second subcritical configuration, the tier of shim inner reflector pieces consisted of the 7.620 cm tall pieces.

On April 26, 1999 a critical configuration was finally achieved. This configuration consisted of the above second configuration with the exception that the fourth unit from the bottom of the assembly had been modified. This fourth unit consisted of 4 cm of graphite, a fuel plate, 1.5 cm of graphite, 0.152 cm of aluminum, and 1 cm of graphite. This configuration was arrived at by incrementally removing graphite from the system. The reactor period for the assembly on full closure was determined to be approximately 1100 sec. If one assumes a β_{eff} of 0.0065, the excess reactivity of the system was determined to be 0.011$. It is of interest to note that there were two competing effects that the removal of graphite from the fourth unit had on the system. The first effect was to produce a geometrically more favorable condition, since the fourth and fifth fuel plates were closer together. The competing effect was to change the uranium to graphite ratio in a high worth cell, which drove the critical mass of the overall system up.

5. FUTURE WORK

The work on Zeus thus far has comprised a four-year effort. The current plans for Zeus are to repeat the above experiment with gradually diminishing amounts of graphite. Therefore, one may map out the critical mass curve for a reflected cylindrical uranium/graphite system. Once the uranium/graphite system is completed, we will go on to examine other moderator materials, such as iron, in both the intermediate and fast neutron energy spectrum systems. When the currently desired approvals are obtained, the rate at which the criticality data is obtained will increase dramatically.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Charlene Cappiello, John Bounds, Joetta Goda, Ken Butterfield, Bill Casson, Al Criscuolo, Robert Kimpland, and the NIS-6 support staff whose assistance made this project possible.

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