Critical Assembly Data Testing for Nuclear Cross Sections

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The fast critical assemblies at the Los Alamos Critical Experiment Facility (LACEF) represent a unique capability within the DOE/NNSA complex for studying nuclear criticality. Measurements over the last 50 years at LACEF have provided integral data that provide important tests of fundamental nuclear cross sections that Group T-16 develops for applications in nuclear technology. It is widely known that measurements of the criticality ("k-eff") of a system, can be used to test certain aspects of the fundamental nuclear data quantities such as the fission cross section play a key role here. In this article we discuss a less well-known use of critical assemblies, where they have been used to measure reaction rates of certain important nuclear processes within the neutron spectrum provided by the assembly in order to provide important integral tests of the underlying nuclear cross section databases that we develop.

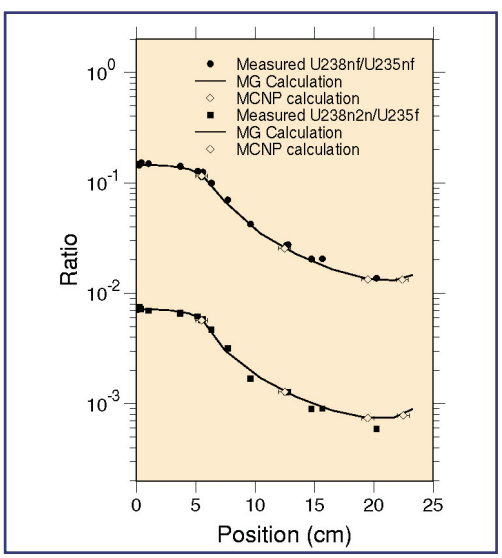


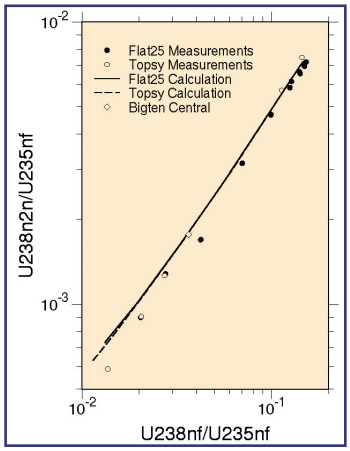
Figure 1— ***Traverse data and calculations.***

Many different critical assemblies have been developed over the years: Godiva is a bare sphere of highly enriched uranium (HEU); Jezebel is a bare sphere of plutonium; Jezebel-23 is a bare sphere of ^{233}U. The Flattop experiments involved spherical cores of HEU or plutonium surrounded by ^{238}U reflector material to make the composite systems critical. These different systems all produce neutron spectra within them that are "fast," i.e., the neutrons are predominantly of energies in the 100 keV – few MeV region, but the exact spectra vary from system to system. Holes were drilled into the critical assemblies to allow foils of different materials to be placed such that they are exposed to different neutron spectra depending upon their location. An assembly with a softer neutron spectrum is BigTen whose core was made up of interleaved plates of ^{235}U and ^{238}U so as to have a lower effective enrichment than the fast assemblies.

The neutron spectrum gets softer as one moves out from the center of the assembly, thereby giving additional information about the quality of the cross-section data. An example of radiochemical ratio data as taken in traverses of the Flattop-25 and Topsy assemblies is shown in Fig. 1. The calculations were done using multigroup methods based on MATXS cross sections from NJOY formatted with TRANSX for PARTISN. A very fine group structure was used for high accuracy. The multigroup results were checked by tallying in several 1-cm shells using MCNP5, and good agreement was obtained.

Figure 2 shows a different presentation of these data in a form often used by radiochemists. The abscissa is a measure of the hardness of the spectrum, and this kind of plot often allows data from different assemblies to be compared on a common basis. This is demonstrated here using data from Flattop-25 and Topsy. Note how the calculated central ratio for BigTen also fits into this kind of plot. These comparisons of prediction with experiment provide some confidence in the quality of the ^{238}U(n,2n) cross section—both its magnitude and its energy-dependence.

In Fig. 3 we show a calculation compared with experimental values for ^{238}U neutron capture. Good agreement is found for most of the critical assembly measurements, though for harder-spectrum systems (large values of 238-fission/235-fission) there is an indication of an underprediction of the data by 5–10%. This is valuable information as it tells us that a new study of ^{238}U neutron capture in the ~1 MeV region is needed. Furthermore, for this reaction and many other similar capture reactions, there is a lack of fundamental capture cross-section data measurements in this energy region, so the integral critical assembly information is particularly useful.



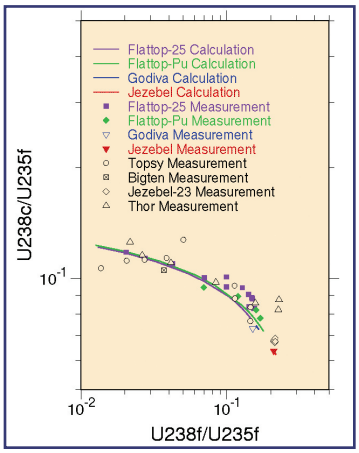
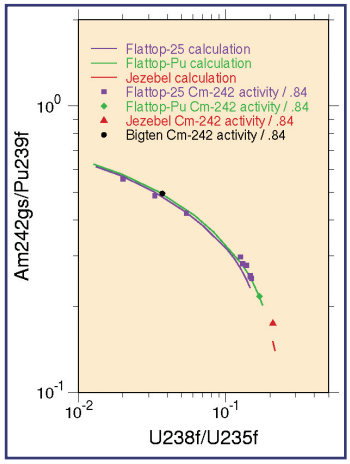


Figure 2— ***Radiochemical plot from traverse.***

Figure 3— ***Radiochemical plot for ^{238}U(n,g).***

Neutron capture on ^{241}Am is shown in Fig. 4 for different critical assembly spectra. In this reaction, the capture can lead to both an isomeric and ground state in ^{242}Am. It is the ground state that then beta decays relatively quickly to make ^{242}Cm, which is then measured by radiochemists. Again, we see good agreement between the calculations and the measurements, except for the harder-spectrum systems where the measurements appear to be underpredicted by up to 15%. This tells us that the ^{241}Am capture cross section to the ground state may be too low in our current evaluation in the MeV region—something that we will be studying using theory and experiment in a new LDRD/DR on americium that is now starting.



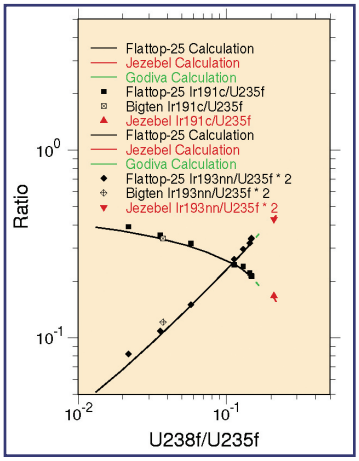


Figure 4— ***Radiochemical plot for ^{241}Am(n,g).***

Figure 5— ***Radiochemical plot for iridium.***

Finally, in Fig. 5, we show two important reaction rates for iridium: the ^{193}Ir(n,n') cross section for creating the isomer, and the ^{191}Ir(n,g) cross section. Iridium plays an important role as a radiochemical detector in weapons diagnostics. A new evaluation for the iridium cross sections has been recently completed, representing collaborations between T-16 and T-6 theorists, Los Alamos Neutron Science Center and Chemistry Division experimentalists, and Applied Physics Division. The good integral testing performance shown in this figure provides some confidence in the accuracy of the new iridium cross sections. Again, the fact that the calculation predicts reasonably well the shape of the (n,n') isomer reaction provides confidence in the energy-dependence obtained from the recent T/LANSCE cross-section evaluation.

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