Derivation of Criticality Safety Benchmarks from ZPR Fast Critical Assemblies

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Scores of critical assemblies were constructed, over a period of about three decades, at the Argonne National Laboratory ZPR-3, ZPR-6, ZPR-9 and ZPPR fast critical assembly facilities. Most of the assemblies were mockups of various liquid-metal fast breeder reactor designs. These tended to be complex, containing, for example, mockups of control rods and control rod positions. Some assemblies, however, were "physics benchmarks". These relatively "clean" assemblies had uniform compositions and simple geometry and were designed to test fast reactor physics data and methods. Assemblies in this last category are well suited to form the basis for new criticality safety benchmarks. The purpose of this paper is to present an overview of some of these benchmark candidates and to describe the strategy being used to create the benchmarks.

A good example of the relevance of these assemblies to the criticality safety community is ZPR-9 Assembly 34, also known as the Uranium/Iron Benchmark. An article in the Criticality Safety Quarterly[1] describes an investigation of large discrepancies among criticality predictions for simple metal/^{235}U systems. The article states, incorrectly, "there are no experiments that adequately represent the characteristics of these metal/^{235}U systems, and so the ability to predict the 'correct' critical configuration is not known." In fact, the Uranium/Iron Benchmark, which was built in 1980, is closely related to the iron/^{235}U system described in the article, since it was a critical assembly composed predominantly of iron and 93% enriched uranium. Furthermore, the problems with treatment of resonance cross section behavior in the neutron cross sections of iron and other structural materials uncovered in the investigation were discovered previously, in connection with analysis of the Uranium/Iron Benchmark.[2] A benchmark description of this assembly is being submitted to the International Criticality Safety Benchmark Evaluation Project (ICSBEP).[3]

About a dozen basic assemblies have been identified as suitable candidates. As illustrated in Fig. 1, the characteristic neutron spectra are in the 1 keV to 10 MeV range and within this band they vary from narrow and hard to broad and relatively soft. Metal, oxide and carbide fuel types were mocked up. The fissile species were ^{239}Pu, ^{235}U or a combination of the two. The mock-up fuel enrichments varied from 9% to 95%. In some cases a single diluent material was predominant while in other cases there were two or more important diluents. Those materials include aluminum, beryllium, graphite, iron, lithium, polyethylene, sodium and stainless steel.

Benchmarks are being derived from as-built critical configurations using continuous energy Monte Carlo. The as-built critical assemblies are much too complicated to serve directly as criticality safety benchmarks. Accordingly, the strategy involves the calculation of a Monte Carlo model of the as-built configuration, which includes plate by plate detail, and a simplified benchmark. The measured eigenvalue is adjusted by the difference between the eigenvalues of the two models. To minimize the Monte Carlo extrapolation of the experimental data, the benchmark model should deviate as little as practical from the exact model and, at the same time, be easily calculable by a variety of standard criticality safety codes. In the case of the Uranium/Iron Benchmark, the assembly has been reduced to a few-region, two-dimensional cylinder, which retains the essential composition and geometry features of the actual assembly.

The fully detailed model is created using a ZPPR database and the BLDVIM code, which were developed in the last years of ZPPR operation. The database and code recently were extracted from the old ZPPR data acquisition computer and were rewritten for a UNIX-based workstation environment. The code reads the assembly description on the database and prepares the model input to the VIM continuous energy Monte Carlo code. BLDVIM yields a high fidelity, quality assured model, and makes quite tractable a task that would take months of effort to do by hand for even a single loading.

The accuracy of VIM has been proven through many years of use in conjunction with the analysis of ZPR critical experiments and with British and Los Alamos benchmarks. The features that are difficult to deal with deterministically (e.g., plate heterogeneity) are no problem with continuous energy Monte Carlo. Thus, the adjusted eigenvalue of the benchmark model will be very precise; a total uncertainty on the order of 0.2% Δk is expected with this approach, which is much better than the $\approx$0.5% Δk precision of the ZPR CSEWG benchmarks.[4]

Each benchmark is being evaluated, analyzed and documented in accordance with the ICSBEP guidelines.[3] All uncertainties associated with the measurement and the model transformation are included in the benchmark uncertainty. The benchmarks are being calculated with standard criticality safety codes, such as TWODANT, KENO and MCNP.

The project is beginning to tap a wealth of criticality data that heretofore has been largely inaccessible to the criticality safety community. These benchmarks will allow testing of criticality safety tools for a number of conditions where data are lacking or sparse.

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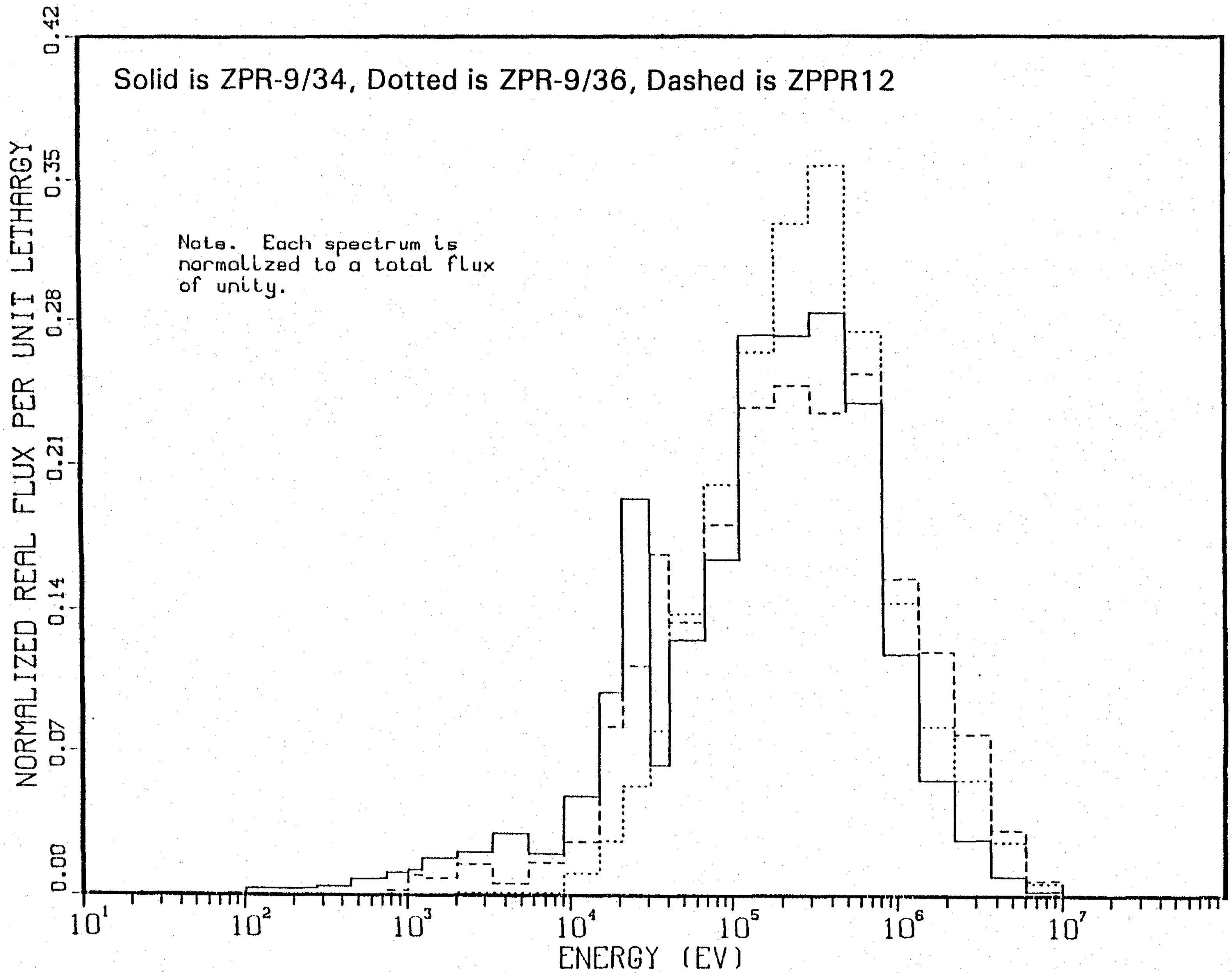

Fig. 1. Comparison of Core Neutron Spectra From Three ZPR Assemblies