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THE NEED OF COUPLED DIFFERENTIAL AND INTEGRAL SPECTRAL RADIATION MEASUREMENTS (U)

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The Need for Coupled Differential and Integral Spectral Radiation Measurements (U)

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Abstract

The criticality safety community has historically directed a significant amount of effort toward attempting to quantify the integral behavior of fissioning systems via critical and subcritical experimental measurements. Some typical integral characteristics include critical masses, geometries, or concentrations for particular fissile isotopes in different chemical forms.

While information such as this can be invaluable for determining criticality safety operating limits and for benchmarking computational methods, it is only a part of what is necessary for analyzing criticality accident alarm detectors. These analyses also require determination of the differential behavior of the leakage radiation (neutron and/or photon) emanating from the source, and an integral estimate of the corresponding detector dose response.

This paper will address part of the work done at the Savannah River Technology Center to validate version 4.2 of the Monte Carlo transport code MCNP_[1] for application to criticality detector response analysis. Additionally, the paper will discuss some observations about existing experimental data which can be used for code validation, as well as the need for further experiments.

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Introduction

As part of an overall program to improve criticality accident alarm placement documentation at the Savannah River Site (SRS), a sitewide initiative was undertaken. The Savannah River Technology Center of the Westinghouse Savannah River Company was assigned the responsibility of developing new calculational methodologies to perform the detector placement analyses. In addition, the Technology Center also performed and documented the alarm placement analyses, and determined evacuation zones as required by DOE order 5480.5.

In order to establish the technical basis for using calculational methods to evaluate the coverage areas of criticality detector systems, a survey of the existing experimental data to validate the computer codes must be done. The validation of computer codes requires experimental data which characterizes the leakage source behavior of the criticality event, as well as quantifies the dose response behavior of detectors from this source.

Discussion

Fission Source Leakage

There have been numerous critical (and subcritical) experimental measurements performed throughout the nuclear industry over the past fifty years. These experiments have focused primarily on quantifying some integral characteristic (usually k_{eff}) of the system as a function of several independent variables. It was these experiments which established the criticality safety technical basis for many of the nuclear processes which have operated to this day. However, there has been comparatively little experimental work done to quantify the behavior of these critical fissioning systems treating them purely as neutron and photon radiation sources. Only a few of the very early experiments (Jezebel and Godiva in the 1950's) and one relatively recent experiment (SHEBA in the 1980's) involved characterization of the radiation leakage spectra from critical fissioning systems.

The Jezebel experimental set-up^[2;3;4] is essentially a highly enriched (95.5% ^{239}Pu , 4.5% ^{240}Pu) metal sphere of radius 6.3842 cm. The

metal has a density of 15.66 g/cc, and the total mass of Pu metal is approximately 16.5 Kg. The sphere is encased in a thin nickel coating and there is modest steel support structure surrounding the assembly. The core is suspended approximately 13 feet above a concrete floor which provides minimal neutron reflection.

The Godiva^[5;6] experimental configuration is the ^{235}U analog to Jezebel. It is a bare, spherical, high-enriched (93.0% ^{235}U , 6.0% ^{238}U , 1.0% ^{234}U) metal system of radius 8.7313 cm with a metal density of 19.0 g/cc. The experimental configuration is similar to that of Jezebel with a steel coating and nominal steel structural supports.

Simple models of these two systems were created with MCNP for the purpose of comparing measured and calculated neutron leakage spectra. Figures 1 and 2 show the results of the benchmark calculations^[7]. The results indicate good agreement between the measured and MCNP calculated neutron behavior with 1 to 10% error for most data points. The one standard deviation (1σ) statistical uncertainties for the Monte Carlo calculations were <2% for all cases.

The most current and relevant series of open literature experimental measurements^[8;9] which consider the leakage radiation behavior from critical fissioning systems were performed with SHEBA (Solution High Energy Burst Assembly) at Los Alamos during the early 1980's (Figure 3). SHEBA is a solution critical system employing low enriched (4.95%) ^{235}U in fluoride form. The assembly is essentially a cylindrical 304SS tank with an outer diameter of 55.88 cm, a wall thickness of 0.635 cm, and a height of approximately 104 cm. There is a central safety rod position (hollow during operation) which has a 7.62 cm diameter and a wall thickness of 0.635 cm. The system is filled with a fuel solution of UO_2F_2 (density of 2.16 g/cc), with a ^{235}U content of 1.04 g/cc.

These experiments were designed primarily to investigate the neutron and photon leakage spectra from a solution critical system, to estimate the n/ γ ratios for different solution types, and to calibrate criticality accident alarm systems. A detailed, 3-D MCNP model of SHEBA was created and the radiation leakage through a surface 5 m from the tank was calculated for a simulated critical solution level in the tank. Figures 4 and 5 show the results of neutron and photon leakage spectrum calculations versus measurement^[10;11]. Agreement

is generally good with the exception of several data points in the higher energy ranges where differences as large as >100% are seen.

Undoubtedly there is more data on criticality leakage source measurements performed throughout the nuclear industry than presented in this brief discussion. However, it is interesting to note that compared to experiments which were designed to establish criticality safety operating limits, there have been relatively few experiments which have directly measured radiation leakage from criticality source systems.

Detector Response

The second type of experimental data needed to benchmark codes for criticality alarm analysis is radiation detector response data. Treating the criticality event as a radiation source enables the analyst to perform a "shielding type" detector dose response calculation for the various criticality detectors located near the postulated event. While experimental shielding measurements have a history equally as long as criticality measurements in the nuclear industry, comparatively few experiments have been performed using criticality fission source terms.

A traditional method of testing the performance of criticality accident alarm systems is to put them through a series of "burst" response tests to determine if the electric/mechanical aspects of the detection system are able to meet the criteria outlined in ANS 8.3[12]. These tests can be performed at open area test sites (usually in a desert environment) or in a reactor facility where neutron and gamma-ray radiation fields are sufficient to alarm the detectors positioned at prescribed locations from the source. In many cases, the ability of the detection system to alarm in a certain amount of time, to a certain radiation dose rate is the only criteria used to determine the systems success. Characterization of the effects of the radiation spectra (both leaving the source and entering the detector) on the measured alarm system's response is usually not quantified.

Observations/Recommendations

The two previous discussions; (1) defining the criticality leakage source behavior and; (2) analyzing the remote detector dose response, have historically been treated as two separate problems.

This approach of decoupling the source calculation from the transmission calculation has been used effectively in shield design work for many years since there is usually not much discontinuity of the radiation flux (and/or current) at the boundary which exists between the two parts of the problem. Because of this, most experiments which have been designed to test criticality accident alarm systems have also either focused on determining the leakage source or calculating remote detector response; but not both simultaneously.

Since both the differential behavior of the leakage radiation and the integral behavior of a remote detector response depend on many of the same system variables for a critical fissioning system, a well designed benchmark quality experiment which *directly couples* these two characteristics is needed. This is particularly true for unmoderated and/or unreflected (i.e., bare) metal systems for which very little openly published experimental data could be found.

An example experiment would be one in which a critical source configuration would be operated at a steady-state power level for a certain time in an semi-open air environment (to minimize room reflection). The neutron and photon radiation leakage distributions would be measured near the surface of the source to derive the leakage spectra and to obtain an estimate of the n/ γ ratio. Simultaneously, neutron and gamma-ray detector responses would be measured at various distances from the reactor with various intervening shielding materials. The steady state reactor power level (or fission rate) can be used to derive a radiation source intensity needed for the dose rate calculation, and the effects of changing the differential behavior of the leakage source (i.e., through spectrum modifying materials) can be used to determine the induced changes on the detector dose rate response. Additionally, detailed measurements of the radiation spectra entering the detectors can be made to observe their behavior as a function of changes in the starting source spectra.

Conclusions

An outcome of the validation effort undertaken at the Savannah River Technology has been the observation that experimental data which is needed to properly benchmark computational methods for the analysis of criticality accident alarm systems is lacking (compared to experimental data for criticality safety). Valuable

information on the radiation physics aspects of critical fissioning systems could be gained with a few, relatively simple, well designed benchmark quality experiments.

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Figure 1.
Jezebel Neutron Leakage Spectra
MCNP vs. Experiment

Figure 2.
Godiva Neutron Leakage Spectrum
MCNP vs. Experiment

Figure 3.
Solution High Energy Burst Assembly (SHEBA)

Figure 4.
SHEBA Neutron Leakage Spectra
MCNP vs. Experiment

Figure 5.
SHEBA Photon Leakage Spectra
MCNP vs. Experiment

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