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Critical Masses of Highly Enriched Uranium

Diluted With Matrix Material

by

Rene Sanchez, David Loaiza, and Robert Kimpland

Introduction

Radioactive waste containing fissile material is frequently encountered in decontamination and decommissioning activities. For the most part, this waste is placed in containers or drums and stored in storage facilities. The amount of fissile material in each drum is generally small because of criticality safety limits that have been calculated with computer transport codes such as MCNP,[1] KENO,[2] or ONEDANT.[3] To the best of our knowledge, no experimental critical mass data are available to verify the accuracy of these calculations or any calculations for systems containing fissile material (U-235, Pu-239, U-233) in contact with matrix material such as Al_2O_3, CaO, SiO_2, Al, MgO, etc. The experiments presented in this paper establish the critical masses of highly enriched uranium foils diluted to various $X/^{235}U$ ratios with polyethylene and SiO_2, polyethylene and aluminum, polyethylene and MgO, polyethylene and Gd, polyethylene and Fe, and moderated and reflected with polyethylene. In addition, these critical mass experimental data will be used to validate cross section data.

Description

The experiments were performed on the Planet[4] general-purpose vertical assembly. The moderating plates used were made of high-density polyethylene. There were two types of moderating plates. The first type had dimensions of 39.12-cm square and 1.91-cm thick. Each polyethylene plate had a central recess 28.86-cm square by 0.64 cm deep and was used to accommodate the SiO_2, aluminum plates, MgO powder, or polyethylene inserts.

The second type of moderating plates was 66.04-cm square and 1.05-cm thick. Each plate had a central recess 45.72-cm square and 0.64-cm deep. For the first type of moderating plates, there were eight 39.12-cm square and 2.54-cm thick high-density polyethylene plates that formed the top and bottom reflector (four at the top and four at the bottom). For the second type, there were also eight plates 66.04-cm square by 2.54-cm thick that were used for the top and bottom reflectors.

The dimensions of the SiO_2 plates, polyethylene inserts, and aluminum plates were on the average 22.86-cm square by 0.64-cm thick. The iron foils were 22.86-cm square by 0.038-cm thick. Two types of Gd foils were used in the experiments. For this first type, its dimensions were 5.08-cm square by 0.041-cm thick. For the second type, the Gd foils were 5.08-cm square by 0.02-cm thick.

The density of the MgO powder was determined by first weighing the empty polyethylene plate. This was followed by filling the central recess in the polyethylene plate with MgO powder and one more time weighing the plate. The density of the MgO was calculated by dividing the weight difference between the empty and filled polyethylene plate by the recess volume.

The highly enriched uranium (HEU) foils were approximately 22.86-cm squared by 0.008-cm thick and each foil weighed approximately 70-g. The foils were laminated with thin plastic sheets to reduce the amount of airborne contamination.

The starting configuration for all of the experiments contained less than 800 g of HEU. A 1/M approach to critical was performed following the guidelines of the existing operating procedures. Once the hand-stacking limit was reached, the experiment was split into two parts. The bottom part of the core, which contained approximately half of the critical mass, was placed on the movable platen of the Planet assembly. The top part of the core was placed on the top platform and typically contained two or three cell units. The lower portion of the assembly, which contained a Pu-Be source, was then raised remotely until it contacted the top portion of the assembly. The neutron leakage from the assembly was measured with four BF_3neutron detectors and a 1/M as a function of number of cell units was plotted. After disassembly and following the existing guidelines, uranium foils and diluent materials were added to the top portion of the core. The lower portion of the core was then raised remotely. This operation continued until delayed critical or a high multiplication was attained.

Results

Curves were plotted based upon the normalized counting rates as a function of the number of cell units (Uranium Mass) and as a function of separation distance. Table I summarizes the critical configurations attained. Note that for $Si/^{235}U=42$ and $H/^{235}U=312$, the configuration is approaching an infinite cylinder and it may never go critical. However, an MCNP[2] model of this experiment, which excluded the gaps between uranium foils and polyethylene plates and the lamination of the foils, predicted that a mass of 1820-g of uranium would be needed to attain criticality. The effect of the gaps in this configuration will be investigated in the future.

For the Gd experiments with $Gd/^{235}U = 0.09$ and $Gd/^{235}U = 0.04$, it is interesting to point out that thicker gadolinium foils do not make a significant difference in the critical mass. This is because the thinner gadolinium foils are already black to neutrons.

Table I Critical masses and parameters of Uranium diluted systems.

Final measured configuration			Critical configuration		
Diluent	$X/^{235}U$, $H/^{235}U$	Mass of Uranium (g)	Extrapolated critical mass g of U	Core average density (g/cc) Uranium	Core average density (g/cc) diluent
SiO_2/ polyethylene	$Si/^{235}U = 42$, $H/^{235}U = 312$	2196	2878	0.071	For SiO_2 density = 0.74 For CH_2 density = 0.64
SiO_2/ polyethylene	$Si/^{235}U = 21$, $H/^{235}U = 156$	2233.1	2285.3	0.149	For SiO_2 density = 0.77 For CH_2 density = 0.66
Al/ polyethylene	$Al/^{235}U = 60$, $H/^{235}U = 159$	2604	2609.1	0.145	For Al density = 0.93 For CH_2 density = 0.66
MgO/ Polyethylene	$Mg/^{235}U = 18$, $H/^{235}U = 160$	2878	2950.8	0.145	For MgO density = 0.42 For CH_2 density = 0.64
Gd/ Polyethylene	$Gd/^{235}U = 0.09$, $H/^{235}U = 230$	1951.3	1958.3	0.146	For Gd density = 0.008 For CH_2 density = 0.96
Gd/ Polyethylene	$Gd/^{235}U = 0.046$, $H/^{235}U = 228$	1811.0	1893.6	0.15	For Gd density = 0.004 For CH_2 density = 0.96
Gd/ Polyethylene	$Gd/^{235}U = 0.18$, $H/^{235}U = 245$	2801.0	2872.8	0.141	For Gd density = 0.016 For CH_2 density = 0.96
Fe/ Polyethylene	$Fe/^{235}U = 4.51$, $H/^{235}U = 224$	1388	1408.9	0.154	For Fe density = 0.15 For CH_2 density = 0.96
Polyethylene	$H/^{235}U = 220$	1251.0	1301.4	0.157	For CH_2 density = 0.96
Polyethylene	$H/^{235}U = 471$	1319.0	1331.6	0.073	For CH_2 density = 0.96
Polyethylene	$H/^{235}U = 239$	2233.1	2454.3	0.145	For CH_2 density = 0.96

References

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