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# LOS ALAMOS SCIENTIFIC LABORATORY
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## University of California
LOS ALAMOS • NEW MEXICO



# Critical Mass Reduction



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# Critical Mass Reduction

by

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ABSTRACT

A new low value for the critical mass of $^{235}U$ in a critical reactor assembly has been determined. This value is 250 grams of $^{235}U$ in a polyethylene core surrounded by a thick beryllium reflector.

## INTRODUCTION

The lowest limit for the critical mass of nuclear reactors has been of interest since the earliest days of fission physics. The first reactor neutron source, the Water Boiler[1,2] used the lowest critical mass consistent with design and safety considerations. In the development of this assembly, the very low value of 565 grams of $^{235}U$ was measured as the critical mass of an assembly with a central region of water and a BeO reflector. Because of recent interest in small reactor design for space and ocean power, as well as continued concern with chemical processing and handling safety, a re-examination of critical mass minima was undertaken. For the reactor fuel $^{235}U$, a new low value of critical mass between 250 and 300 grams was found.

## METHOD OF STUDY

Exploratory work in reactor physics can be done simply and well with the highly developed reactor computing codes and data on neutron cross sections. We will use the results of previous studies rather than display the reactor neutronics techniques, which are generally familiar. The approach will be to recognize that neutron conservation — reduction of all losses not directly associated with the fission process — is the essential problem. Figures 1 and 2 show the critical condition[3] for core- (water) moderated and reflector-moderated assemblies using $^{235}U$ fuel. Both computed parametric displays are validated by experimental studies. Figure 1 exhibits experimental points with enriched

(93%) $^{235}U$; Fig. 2 is supported in the same way by relatively complex experimental arrays, not shown. Together, the figures suggest that a thick moderating reflector, with a very low absorption cross section, on a hydrogeneous core should reduce the critical mass below either set of limits. Figure 3 shows the result of several calculations, using beryllium, $D_2O$, and graphite reflectors. The new low critical mass, using a beryllium reflector, appears to be 250 grams of $^{235}U$.

## EXPERIMENTAL PROCEDURE

An experimental assembly was constructed, consistent with Fig. 3, of enriched uranium and a hydrogenous material in the core surrounded by a thick moderator reflector. Structural problems were eased by the use of $^{235}U$ foils (93% enrichment), polyethylene sheets, and beryllium blocks in a cubic array. The experiment was carried out on the Comet critical assembly machine at Los Alamos. This machine consists of a platform upon which part of the critical assembly was placed. Beneath this is a plate carried on a hydraulic cylinder, upon which additional parts of the critical system were assembled. The plate was raised by remote control to complete the final assembly of the critical system.

Figure 4 shows the essential details of the Comet machine, the beryllium reflector, and the plastic core. The beryllium reflector is stacked on the upper platform. Centered in the bottom of the reflector is a hole 10-1/8 in. square and 19-1/2 in. high. A closure plug of beryllium, with a cavity for the fuel core at its top, is centered on the plate below the hole in the bottom of the reflector. The maximum size of the fuel core was an 8-1/8 in. cube. When the core dimensions were reduced, more beryllium liner was added.

The hydrogen-moderated core consisted of stacked 1/8-in.-thick lucite or polyethylene plates and 93.15% enriched $^{235}U$ metal foil approximately 0.0012 in. thick. The sheets of $^{235}U$ metal foil were separated by one, two, or more layers of the plastic plates, depending on the requirements of a particular critical configuration.

Three sizes of fuel cells, approximately 8, 6.5, and 6 in. square, were studied. In each case, the critical mass was determined as a function of the core height. The core height was varied by replacing part of the plastic moderator with added layers of beryllium at the top and bottom of the fuel cell. The results of these studies are shown in Table I and Fig. 5. The lower limit of enriched $^{235}U$ critical mass is near 290 grams with this experimental assembly.

The effect on critical mass of the use of polyethylene and enriched uranium layers, rather than the homogeneous mixture assumed for Fig. 3, was measured simply by comparing the critical mass of single with that of doubled layers of the two components. A 6.5 in. cubical core consisted of 22 uranium foils, each 0.0012 in. thick, with an average thickness of 0.257 in. of polyethylene between adjacent foils. This configuration was critical with 339.0 grams of $^{235}U$. Then both fuel and moderator layers were doubled in thickness. The critical mass for this configuration was 383.6 grams of $^{235}U$, an increase of 44.6 grams or 13.1%. Accordingly, a homogeneous $^{235}U$ + polyethylene cube at the minimum critical condition shown in Fig. 5 should contain 250 grams of $^{235}U$.

Further measurements were made to permit design variations in possible structural materials that might be used with this kind of reactor, if it were developed for power production. Table II summarizes the reactivity values of several common reactor materials.

A further reduction in critical mass may be effected by a spatial redistribution of the $^{235}U$ fuel. Figure 6 shows the reactivity distribution of uranium before and after changing from a constant density throughout the core. With 20% of the fuel moved to the outer 0.4 cm, the reactivity distribution becomes almost constant, a pronounced peak in fission density (a factor of two) develops, and there is a 3% decrease in critical mass.

## SUMMARY

It has been shown that the minimum critical mass of $^{235}U$ in a hydrogenous core with a thick beryllium reflector is between 250 and 300 grams. This value is lower than any found in the literature including the very early Water Boiler study.

## REFERENCES

1. R. F. Christy and J. A. Wheeler, "Chain Reaction of Pure Fissionable Materials in Solution," University of Chicago Metallurgical Laboratory report CP-400, January 1943.

2. L. D. P. King, "Critical Assemblies," Vol. V, Part II, Chapter 4, Los Alamos Scientific Laboratory report LA-1034, December 1947.

3. Carroll B. Mills, "Reactor Minimum Critical Dimensions," Los Alamos Scientific Laboratory report LA-3221-MS, October 1959.

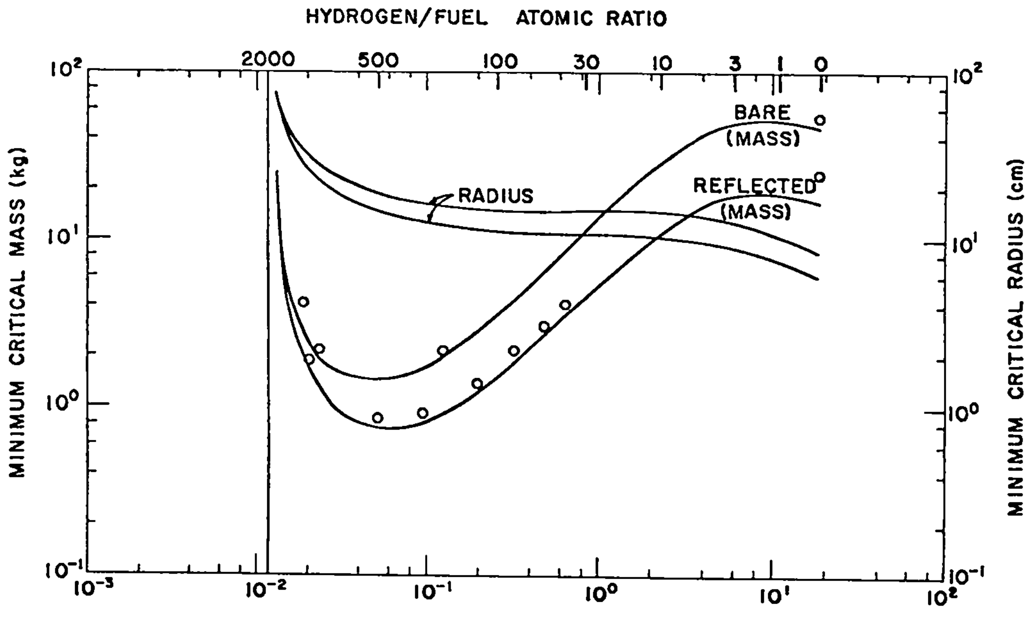


Fig. 1. Minimum critical masses of bare and water-reflected spheres of $^{235}U$-$H_2O$ solution.

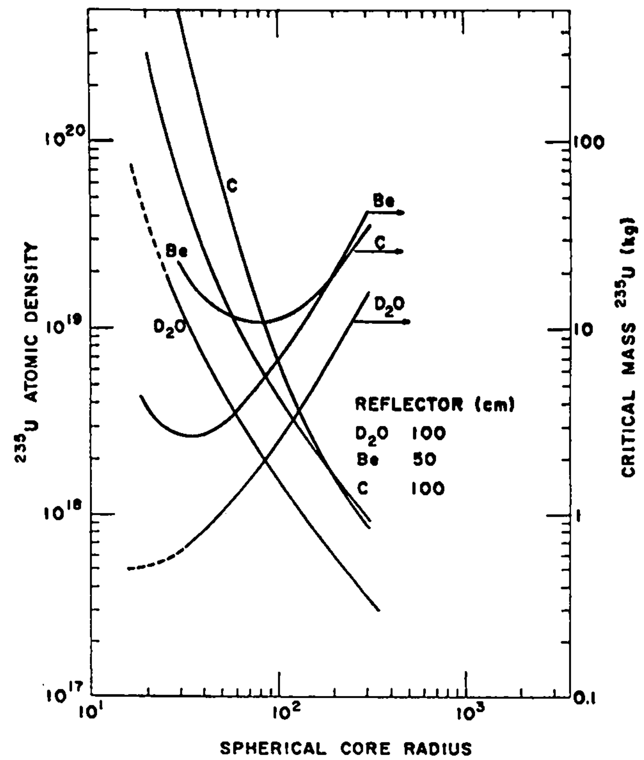


Fig. 2. Critical concentration of $^{235}U$ gas as a function of $D_2O$-beryllium-, and graphite-reflected core radii.

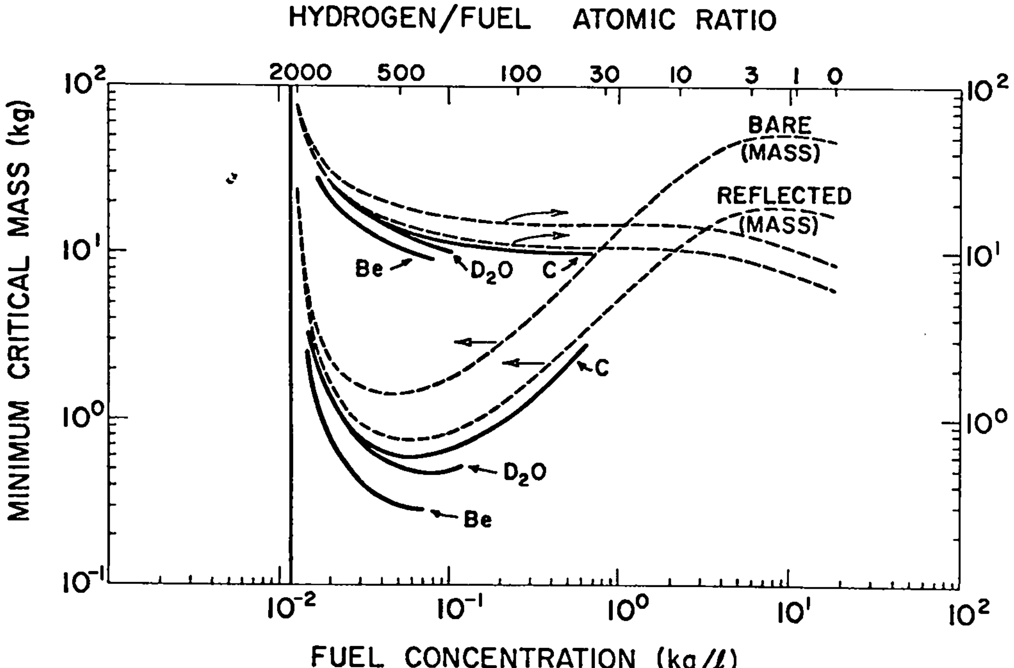


Fig. 3. Effect on $^{235}U$ critical mass of thick beryllium, $D_2O$, and graphite reflectors on a $^{235}U$-$H_2O$ core.

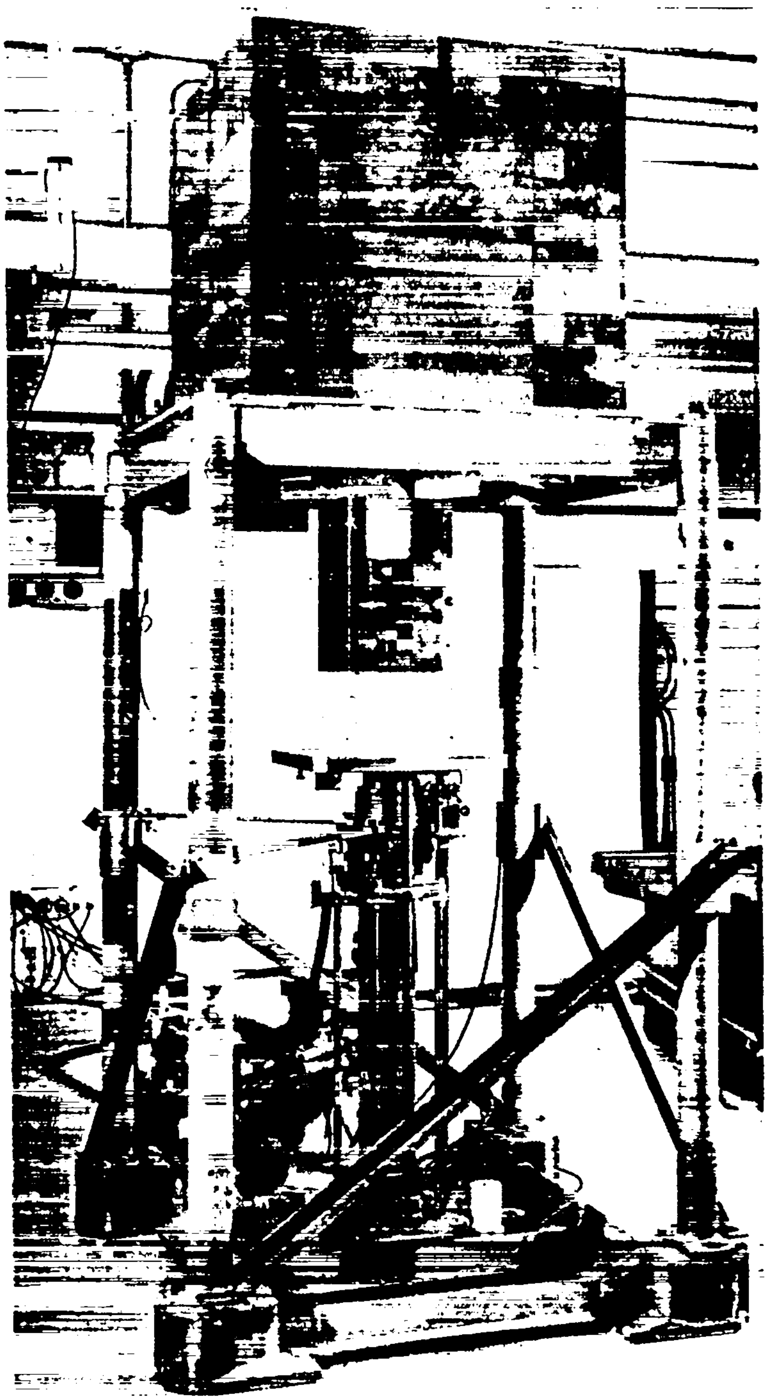

Fig. 4. The Comet critical assembly machine showing the minimum critical mass experiment with the core in the disassembled position.

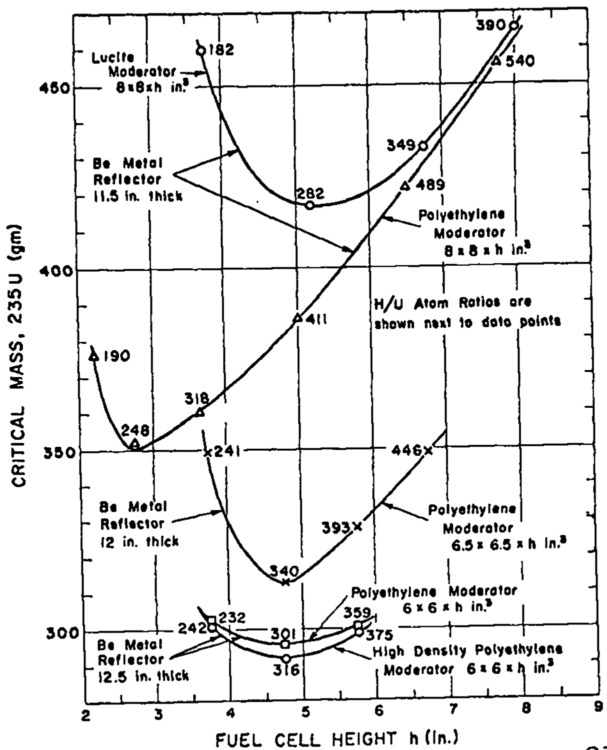


Fig. 5. Critical conditions for a polyethylene and $^{235}U$ foil core in a beryllium reflector.

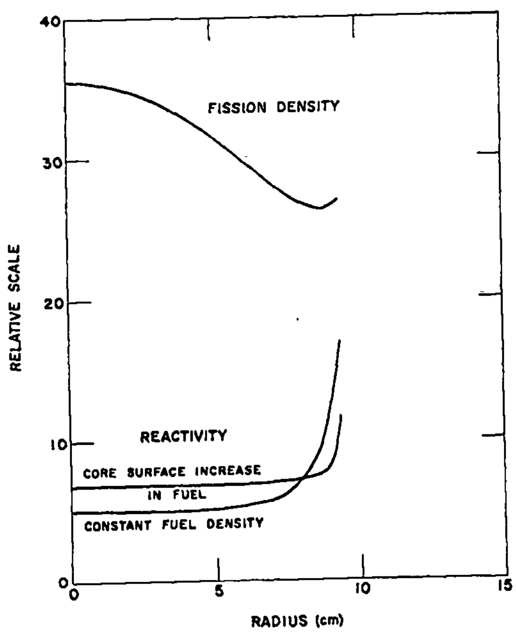


Fig. 6. Reactivity distribution and fission density in the critical experiment with constant fuel density. The effect on reactivity distribution of moving 20% of the fuel to the core boundary is also shown.

Table I. Critical Conditions for a Hydrogenous Core in a Thick Beryllium Reflector

| Moderator Material | Fuel Cell Cross Section (In.) | Fuel Cell Height (In.) | Beryllium* Reflector Thickness (In.) | Weight of Core Moderator Material (kg) | Average Moderator Thickness Between Foils (In.) | Critical Mass $^{235}U$ (grams) | Atomic Ratio $H/^{235}U$ |
|---|---|---|---|---|---|---|---|
| Polyethylene | 6.0 x 6.125 | 5.75 | 12.5 | 3.327 | 0.271** | 299 | 375 |
| Density = | " | 4.75 | " | 2.749 | 0.224** | 292 | 316 |
| 0.961 g/cc | " | 3.75 | " | 2.170 | 0.167** | 301 | 242 |
| Polyethylene | 6.0 x 6.125 | 5.75 | 12.5 | 3.215 | 0.256** | 301 | 359 |
| Density = | " | 4.75 | " | 2.656 | 0.211** | 296 | 301 |
| 0.928 g/cc | " | 3.75 | " | 2.097 | 0.167** | 303 | 232 |
| Polyethylene | 6.5 x 6.625 | 6.75 | 12.0 | 4.506 | 0.257 | 349 | 446 |
| Density = | " | 5.75 | " | 3.839 | 0.230 | 328 | 393 |
| 0.947 g/cc | " | 4.75 | " | 3.171 | 0.200 | 313 | 340 |
| | " | 3.75 | " | 2.504 | 0.200 | 349 | 241 |
| Polyethylene | 8.0 x 8.125 | 7.75 | 11.5 | 7.331 | 0.625 | 456 | 540 |
| Density = | " | 6.50 | " | 6.148 | 0.520 | 422 | 489 |
| 0.888 g/cc | " | 5.00 | " | 4.729 | 0.500 | 386 | 411 |
| | " | 3.63 | " | 3.429 | 0.322 | 360 | 318 |
| | " | 2.75 | " | 2.601 | 0.275 | 352 | 248 |
| | " | 2.25 | " | 2.128 | 0.225 | 376 | 190 |
| Lucite | 8.0 x 8.125 | 8.00 | 11.5 | 9.670 | 0.625 | 466 | 390 |
| Density = | " | 6.56 | " | 8.034 | 0.540 | 433 | 349 |
| 1.132 g/cc | " | 5.20 | " | 6.248 | 0.420 | 417 | 282 |
| | | 3.76 | " | 4.463 | 0.342 | 460 | 182 |

**These six stackings had uranium foil on all six sides of the fuel cell.

Table II. Reactivity Measurements

| Kind of Structural Material Added | Weight of Structural Material Added (m grams) | Change in Critical Mass $M(^{235}U)$ (grams) | $M(^{235}U)/m$ (grams/grams) |
|---|---|---|---|
| Polyethelene | 72.3 | - 3.83 | - 0.053 |
| Aluminum | 148.0 | - 0.56 | - 0.0038 |
| Iron | 347.0 | + 6.48 | + 0.019 |
| Carbon (Graphite) | 127.8 | - 2.39 | - 0.019 |
| Stainless Steel Alloy No. 347 | 143.5 | + 2.94 | + 0.021 |
| Molybdenum | 28.2 | + 0.51 | + 0.018 |
| Zirconium | 38.4 | + 0.21 | + 0.005 |
| Tungsten | 51.0 | + 3.89 | + 0.076 |
| Normal Uranium | 51.3 | + 0.27 | + 0.005 |
| Tantalum | 41.2 | + 4.60 | + 0.112 |

The reference critical configuration for these measurements was a 6 x 6 x 6-in. fuel core, surrounded by a 12.5-in.-thick beryllium metal reflector. The fuel core moderator was polyethylene, having a density of 0.961. The reference configuration critical mass was 299 grams of $^{235}U$. The test material was in the form of a thin sheet added to the top surface of the fuel core.