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Topsy, A Remotely Controlled Critical Assembly Machine[1]

ROGER H. WHITE

Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico

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A remotely operated facility for the study of reacting metal assemblies with thick reflectors is described. Design of the assembly machine permits adaptation to nuclear components of various materials and geometries. Data resulting from experimental programs on the behavior of reflected critical assemblies can be applied to fast reactor problems.

INTRODUCTION

The original design specifications for Topsy were set during the early stages of development of the remotely controlled facilities at the Los Alamos Pajarito Canyon site. A machine was needed to assemble known amounts of potentially dangerous fissionable material using a control system operable from a control station 1200 ft distant. The machine was to have sufficient flexibility to permit the safe investigation of reacting assemblies of various sizes and shapes.

Specific design considerations were governed by two basic requirements: (1) for the protection of personnel and equipment, the remote assembly operation must proceed safely under controlled conditions after the machine is "loaded" by hand, and (2) sufficient precision must be built into the machine to ensure the proper alignment and positioning of mating active material pieces, the accurate position indication of moving parts, and the reproducibility of position of moving parts. During design, flexibility of operation was constantly kept in mind. The term "universal" is frequently applied to the machine in the sense that it is not restricted to one particular setup, but can be adapted to nuclear components of various arrangements.

The completed machine, as shown in schematic Fig. 1, consists of four main subassemblies: track section, carriage, safety test section, and critical assembly section, each with associated hydraulic and electrical systems.

MACHINE DESCRIPTION

The 16-ft track section is essentially the bed for the entire machine, its triangular-type rails ensuring accurate location of the carriage under the safety

[1] Work done under the auspices of the Atomic Energy Commission.

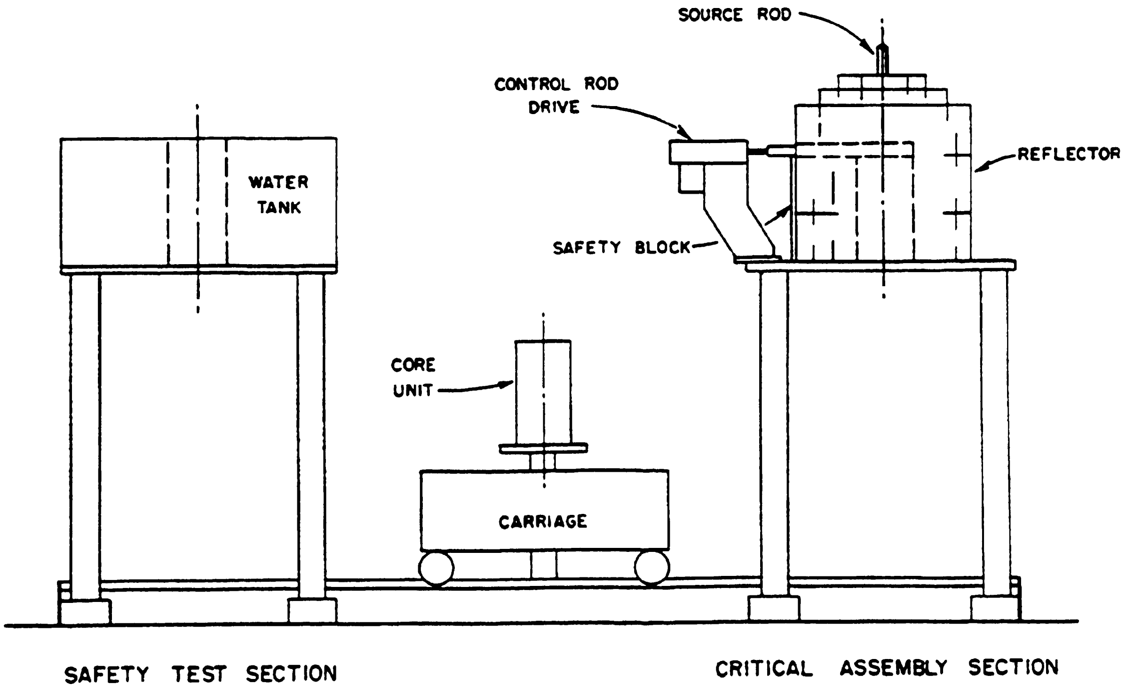

FIG. 1. Schematic assembly drawing of the complete Topsy machine. The carriage is moved to the water tank or reflector section before raising the core unit into position.

test and critical assembly sections. The chief purpose of the carriage is to carry and to raise into position all or part of the active material core unit by means of a hydraulic motor and cylinder.

An oil hydraulic system was chosen for Topsy as it provides the necessary smooth positive action, variable speed, and quick reversal of motion which must be available when heavy nuclear components are run into position. Pressure relief valves in the system protect the assembly from excessive stresses which could result in possible damage to expensive nuclear materials.

The electrical control system is designed for fail-safe operation so that, in case of a power failure or faulty equipment, all devices will remain in, or return to, a safe position. Various electrical interlocks are incorporated into the apparatus to prevent equipment damage and to establish a safe nuclear assembly procedure.

During the initial stages of critical mass determinations it is frequently desirable to evaluate, by remote control, a safe mass limit for handstacking the active material in the core unit carried on the lift. For this purpose, the safety test section contains a toroidal water tank to simulate the reflection provided by three or four people closely surrounding the active material unit.

The critical assembly section provides the means for obtaining critical mass measurements, and for conducting studies under delayed critical conditions. Its principal components are a spring-released safety block assembly, lead-screw driven control rod unit, source rod assembly, and the major part of the reflector

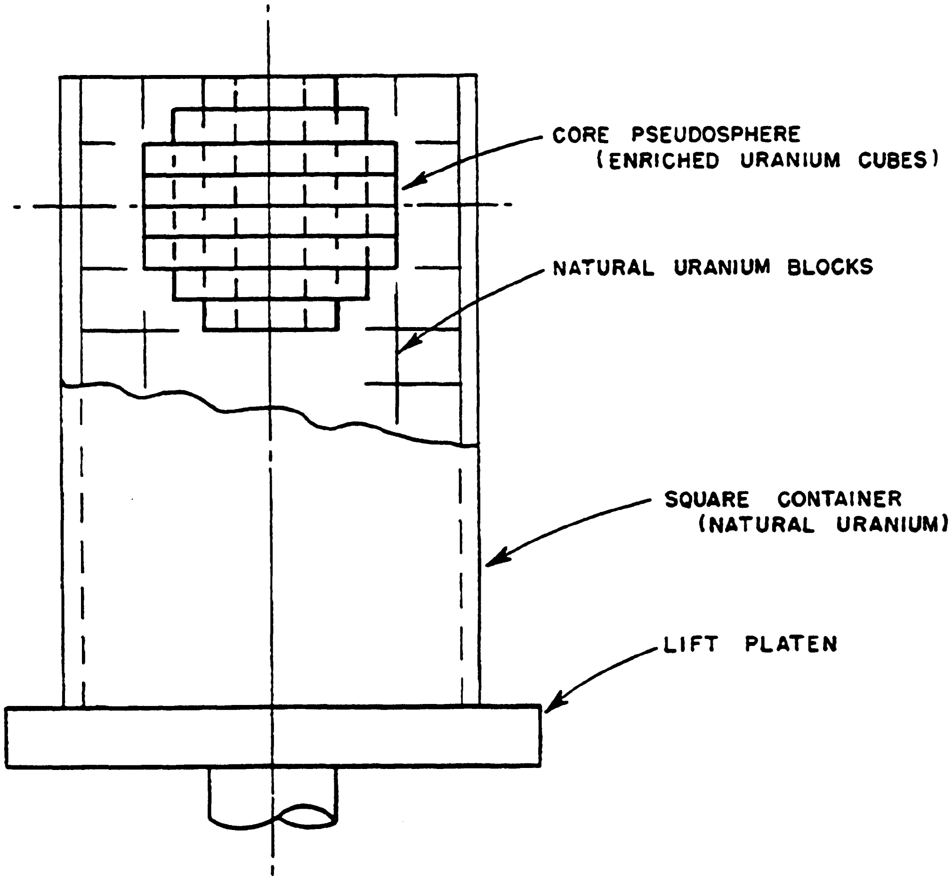

FIG. 2. Construction of the active core unit in the normal uranium container on the Topsy carriage lift.

material. The assembly operation is completed by positioning the carriage under the platform of the critical assembly section (see Fig. 2) and raising the active core unit into the natural uranium reflector.

To satisfy the requirements imposed by many different types of experiments, a nuclear assembly built of various sizes of cubes and blocks was adopted because of its flexibility, relative ease of fabrication, and economical use of materials. However, the mechanical stability of a critical assembly constructed of many pieces is of considerable importance since reactivity is sensitive to cracks, especially those close to the core. The development of cracks during operation at delayed critical would result in poor reproducibility of the critical point. It was, therefore, necessary to fabricate the cubes to close tolerances and to take precautions to prevent warping of plates and rods. The material requiring the most careful attention was the normally dense natural uranium used to build up a 200-piece reflector assembly. Frequent tests during Topsy's history have shown that the all-uranium metal assembly is capable of reproducing the critical point to within $\frac{1}{50}$ cent. This is equivalent to a change in critical mass of approximately 0.08 surface gram.

OPERATION AT DELAYED CRITICAL

To determine the critical mass of a given assembly, steps are first taken to ensure personnel safety during the handstacking of the active core unit. A preliminary series of neutron multiplication measurements is made remotely on successively larger core masses in the water-reflected safety test section. The multiplication limit is set arbitrarily at a value of 10, which corresponds to about three-quarters of a critical mass. Frequently a complete core may be stacked in its container. When multiplications indicate an unsafe condition the material is divided, one half being stacked in the lift container, the other supported within the reflector material on the critical assembly section.

The critical mass determination proceeds by remote control, and consists of a series of neutron multiplication measurements as the core mass is gradually increased. By plotting the reciprocal of multiplication, $1/M$, as a function of core mass, the critical mass, m_c, can be determined by extrapolating to $1/M = 0$.

With the establishment of m_c, the core unit may be stacked for operation at delayed critical. Should the first of these stackings be slightly subcritical, the mass is increased until it is possible to reach delayed critical by running in the control rods. Further mass adjustments may be necessary at this point to utilize the linear reactivity response region of the rods.

SOME TYPICAL CRITICAL ASSEMBLIES

All of the systems investigated on Topsy represent relatively small, low-power experimental assemblies. These systems are elementary in geometry and operation so that data may be compared directly with clean theory. Some experimental values of U^{235} critical masses, as determined in various Topsy assemblies, are listed in Table I (*1*).

The critical assembly on which the most complete measurements were made consisted of a pseudospherical core of uranium enriched to about 90% U^{235}. This core is built up of $\frac{1}{2}$-in. cubes in contact with a 9-in.-thick natural uranium reflector, as shown in Fig. 2. This particular reflector is considered to be infinitely thick as far as critical masses are concerned. This "all-metal assembly" was the first to be installed on Topsy and for several years was the subject of many experimental programs designed to furnish results for comparison with theoretical predictions and with other reflected and bare assemblies.

Another assembly set up early in Topsy's history was one using nickel as a reflector material and an enriched uranium core. The natural uranium reflector was faithfully duplicated in commercial Type "A" nickel, all pieces being fabricated to the same dimensions and tolerances as specified for the natural assembly. Critical mass was determined and operation at delayed critical was successfully conducted in order to obtain characteristics for comparison with the natural uranium assembly.

TABLE I

VALUES OF U^{235} CRITICAL MASS DETERMINED IN TOPSY ASSEMBLIES CONSISTING OF ROUGHLY SPHERICAL ENRICHED URANIUM CORES IN THICK REFLECTORS OF NORMAL DENSITY

Core properties	Reflector material	Critical mass U^{235} (kg)
Uranium $\rho_0 = 18.7$ gm/cm^3, c_0 (U^{235}) $\sim 90\%$	Natural U	16
Uranium $\rho_0 = 18.7$ gm/cm^3, c_0 (U^{235}) $\sim 90\%$	Nickel	19
Uranium $\rho = 70\%\ \rho_0$	Natural U	25
Uranium $\rho = 50\%\ \rho_0$	Natural U	37
Uranium $c = 70\%\ c_0$	Natural U	21
Uranium $c = 50\%\ c_0$	Natural U	27
Uranium hydride[a], $\bar{\rho} = 7.40$ gm/cm^3	Natural U	12.1
Uranium hydride	Nickel	12.1

[a] Average empirical formula for the hydride composition is $UH_{2.97}C_{1.11}O_{0.25}$.

The flexibility of the Topsy system was utilized to obtain a series of measurements relating critical mass and core density and concentration. Using the thick natural uranium reflector, enriched uranium cores of various concentrations and densities were stacked in the lift container. For low concentrations, the pseudo-spherical cores were built up with natural and enriched uranium blocks in the correct proportions. Low densities were obtained by leaving ½-in. cubic voids, maintained by thin walled cylinders, appropriately spaced throughout the core assembly. Critical masses were measured by carrying reactivity to delayed critical. Core densities ranged from 50 to 100% of normal density, and concentrations varied from 47 to about 90%. The resulting data served to establish a density-concentration law which relates the dependence of U^{235} critical mass to core properties by the expression

$$m_c(U^{235}) \propto c^{-0.7}\rho^{-1.2}$$

where $c = U^{235}$ concentration and ρ = core density.

The behavior of a natural uranium reflected plutonium assembly was investigated after adapting the lift container to the plutonium core. The core consisted of a 4-piece true spherical ball, a protective uranium shell, and 10 plutonium mass adjustment buttons, all of which were carried on the lift. The ⅛-in.-thick shell contained cavities for holding the close-fitting buttons next to the core, thus providing reactivity adjustments for different operations. Runs at delayed critical furnished information on critical masses, limited neutron distributions, and time constants associated with prompt neutrons.

Interest in reacting systems in general led to a series of measurements on critical assemblies consisting of an enriched uranium hydride composition surrounded by effectively infinite natural uranium and nickel reflectors. The hydride was fabricated into various sizes of cubes and blocks from a mixture of enriched UH_3 powder, uranium powder, and polythene. Small cubes of the hydride composition were used to construct pseudospherical cores in the lift container in the same manner as with the all-metal assembly. From Table I it can be seen that the hydride critical masses in thick uranium and nickel reflectors are almost identical. Reactivity contribution measurements (described below) made at the core surface indicated that a relatively thin nickel layer within the thick uranium reflector should reduce the critical mass. This effect was confirmed with a 1-in.-thick nickel liner between the core and the natural uranium, the resulting critical mass being 7.5% less than that with the simple reflector.

SOME CHARACTERISTICS OF THE TOPSY URANIUM METAL ASSEMBLY

Reactivity Contributions in the Core

One of the useful characteristics of a critical assembly is the reactivity contribution per unit mass of core material at various points throughout the assembly. Measurements were made by a material replacement method which consisted of observing the change in the delayed critical point produced by inserting core material into a $\frac{1}{2}$-in. cubic cavity. Data are collected as a function of the radial position of the cavity. Then, using the control rod calibration curve, the results are converted to units of cents per gram-atom of material. Table II contains reactivity contribution values observed in the all-metal assembly.

An extensive replacement program was completed during which many different perturbing materials were investigated. The accumulated data (danger coefficients) were used to derive the corresponding values of the apparent absorption

TABLE II

Topsy All-Metal Assembly: Enriched (About 90%) U^{235} Reactivity Contributions for Normal Core Density from Material Replacement Data

Radius (in.)	$\Delta K(r)$ (cents/gm-atom)
0.51	194.1
0.715	187.6
1.12	170.6
2.06	106.7
2.55	65.0
2.93	43.4

TABLE III

APPARENT ABSORPTION AND TRANSPORT CROSS SECTIONS (IN BARNS) DERIVED FROM MATERIAL REPLACEMENT DATA OBSERVED IN THE TOPSY NATURAL URANIUM AND NICKEL REFLECTED ASSEMBLIES

Element	Normal uranium σ_a	Nickel σ_a	Normal uranium σ_{tr}	Nickel σ_{tr}
B	0.110	0.103		
C	−0.022	−0.023	2.13	2.20
Al	−0.006	−0.008	2.12	2.17
Ti	0.017	−0.001	2.16	2.29
Fe	0.020	0.013	2.29	2.53
Ni	0.066	0.056	2.77	2.36
Au	0.143	0.093	4.17	4.11
U^{238}	−0.228	−0.271	5.10	
U^{235}	−1.893	−1.887		

and transport cross sections. A few of these values, as found in the Topsy uranium and nickel reflected assemblies with an enriched uranium core, are presented in Table III. The apparent absorption cross section, σ_a, of the perturbing material generally includes effects attributable to processes which change the neutron energy. It would be, however, strictly equal to the absorption cross section averaged over the flux spectrum if the neutron effectiveness function (the adjoint to the flux function) were energy independent.

TIME SCALE MEASUREMENTS—ALPHA

In a reacting assembly fission chains sustained by prompt neutrons will either grow or decay as $e^{\alpha t}$, depending on whether the assembly is operating above or below prompt critical. Since this alpha, or time constant, is a significant characteristic of a given assembly its value is determined experimentally to confirm a calculated alpha which depends on the proper choice of cross sections and neutron spectrum.

Measurements on the Topsy uranium metal assembly have been made by a method first suggested by B. Rossi in 1944. This method provides a straightforward measurement of alpha by examining the prompt neutron decay of the system through statistical observations of the time distribution of counts from single chains. Alpha, as defined above, for the metal assembly operating at delayed critical has been found to be -0.38×10^6 sec^{-1}.

POWER LEVEL

Topsy was designed for low-power operation only, since it has no forced cooling or personnel shielding. The power level is usually determined by the type of experiment being performed. When the reactor is being used as a source for the

TABLE IV
FISSION RATIOS OBSERVED IN THE TOPSY URANIUM ASSEMBLY USING A FOIL COMPARISON CHAMBER

Radius (in)	$\sigma_f(U^{235})/\sigma_f(U^{238})$	$\sigma_f(Np^{237})/\sigma_f(U^{235})$
0.25	6.63	4.56
0.75	6.70	4.59
1.75	7.53	4.73
2.75	12.88	5.84
3.75	21.26	7.12
4.75	31.70	8.36
5.75	43.44	9.50
6.75	56.60	10.53
7.75	70.68	11.52
8.75	83.40	12.31
9.75	91.34	12.74

irradiation of sample materials, the power settings may be as great as 1 kw, which is approximately the point where loss of reactivity from self-heating overcomes the excess reactivity available in the control rods. For programs such as the precise material replacement measurements, changes in reactivity from self-heating are important and the power level is therefore held to about 1 watt.

SPECTRAL INDICES

Investigations of the neutron spectra in the all-metal assembly were carried out using primarily a comparison between the fission rates of U^{235} and U^{238}. The most complete information was obtained by two methods: (1) gamma counting of fission products from irradiated foils, and (2) observing the fission rates in a pair of foils in a spiral-wound fission chamber. Measurements at various radii through the core and reflector yielded fission ratios such as those tabulated in Table IV. These ratios characterize, for example, neutron spectral changes as a function of radius. It should be pointed out that no effort was made to obtain neutron spectra directly from experimental data. The data are used as spectral indices which permit checks on the calculated neutron behavior of the assembly.

TOPSY'S RETIREMENT

After eight years of almost continuous use as a versatile critical assembly system, Topsy has finally been retired. The large amounts of information accumulated from a variety of assemblies are rewarding evidence of Topsy's contribution to development programs, especially in the fast neutron power reactor field. Although the nuclear assembly on Topsy has been dismantled, the basic machine and controls still remain for further use with special temporary assemblies.

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