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A TUNGSTEN-CARBIDE CRITICAL ASSEMBLY

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ABSTRACT

The tungsten-carbide critical assembly mainly consists of three close-fitting spherical shells: a highly enriched uranium shell on the inside, a tungsten-carbide shell surrounding it, and a steel shell on the outside. Ideal critical specifications indicate a rather low computed value of k_{eff} . Observed and calculated fission-rate distributions for ^{235}U , ^{238}U , and ^{237}Np are compared, and calculated leakage neutrons per fission in various energy groups are given.



THE CRITICAL ASSEMBLY

Ten years ago, interest in the neutronic properties of highly enriched uranium reflected by tungsten carbide and steel led to the design of the tungsten-carbide critical assembly (TCCA). Because of declining interest in this project, it was shelved until recently when requests were made to document its principal characteristics. To obtain radiation leakage measurements, and still retain a very fast neutron spectrum in the interior, the TCCA uses a U(93.16) core shaped like a spherical shell rather than the usual solid core.

Figure 1 shows the almost spherically symmetric TCCA as set up on the Comet assembly machine. The U(93.16) shell, consisting of ten segments, weighed about 70 kg before being machined to the proper size. Multiplication measurements with this overweight (70-kg) shell established the final internal dimension for all delayed-critical operations.

Average radii of the close-fitting shells are given in Fig. 2, except that the cavity radius was adjusted to agree with an assumed U(93.16) mean density of 18.75 g/cm^3 and the known mass of 65.14 kg. The tungsten-carbide shell that surrounds the uranium weighs 334 kg and contains ~5 wt% cobalt, which is estimated from 6 wt% cobalt content of the tungsten-carbide (WC) mix before hot pressing. The

outermost shell of 4340 steel weighs 1508 kg (nominally 1.8 wt% nickel, 0.8 wt% chromium, 0.7 wt% manganese, 0.4 wt% carbon, and 0.25 wt% molybdenum).

CRITICAL SPECIFICATIONS

The dimensions in Fig. 2 correspond to an idealized equivalent of the TCCA with snug-fitting shells of the following nuclear densities ($\text{b}^{-1}\text{cm}^{-1}$). Region I is void; II has $N(^{235}\text{U}) = 0.0450$ and $N(^{238}\text{U}) = 0.0030$; III has $N(\text{W}) = N(\text{C}) = 0.04306$ and $N(\text{Co}) = 0.0084$; IV has $N(\text{Fe}) = 0.0820$, $N(\text{Ni}) = 0.0021$, and $N(\text{C}) = 0.0016$. The measured excess reactivity of this system, 0.62\$, and the observed reactivity equivalent of U(93.16) at the cavity surface, 0.78-kg U/\$, give the following delayed- and prompt-critical masses and equivalent cavity radii

$$m_{\text{dc}} = 64.66 \text{ kg U(93.16)}, \text{ or } (r_1)_{\text{dc}} = 11.185 \text{ cm};$$

$$m_{\text{pc}} = 65.44 \text{ kg U(93.16)}, \text{ or } (r_1)_{\text{pc}} = 11.158 \text{ cm}.$$

COMPUTED PROPERTIES

The reproduction number of the above idealized TCCA delayed-critical description was computed

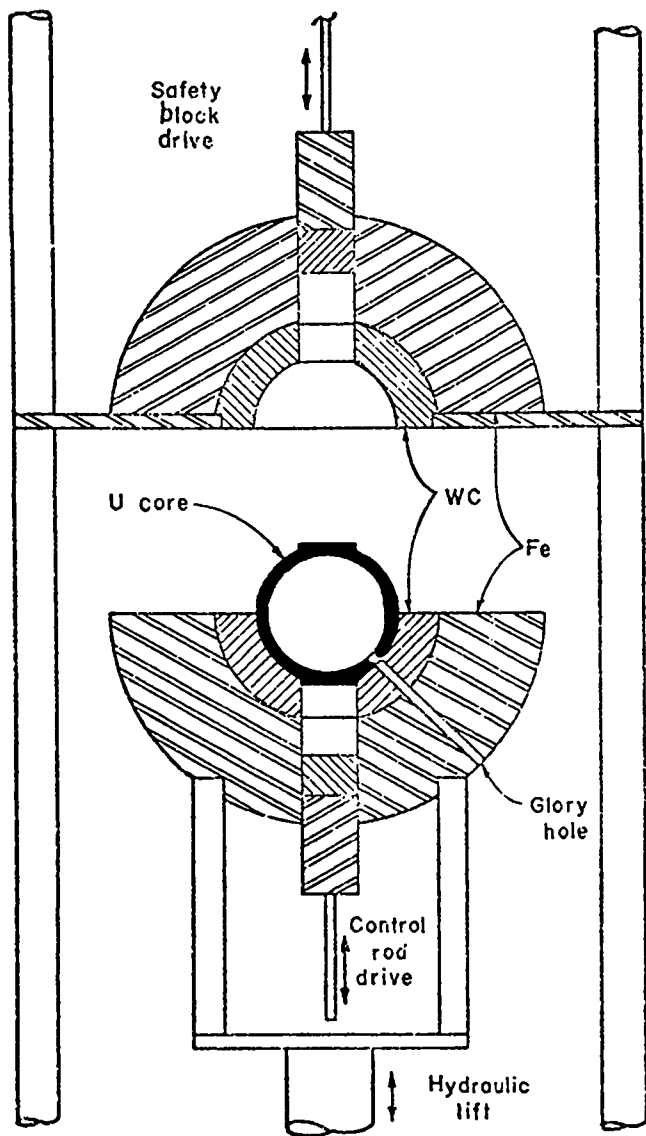


Fig. 1.
The TCCA on the Comet assembly machine.

using the S_n code. The S_8 approximation with 16-group Hansen-Roach cross sections¹ gave the value $k_{eff} = 0.983$, which is a somewhat greater bias than usual for small, very fast neutron systems.

Multigroup flux distributions from the same calculation, with cross sections for ^{235}U , ^{238}U , and ^{237}Np , led to the following computed activation distributions.

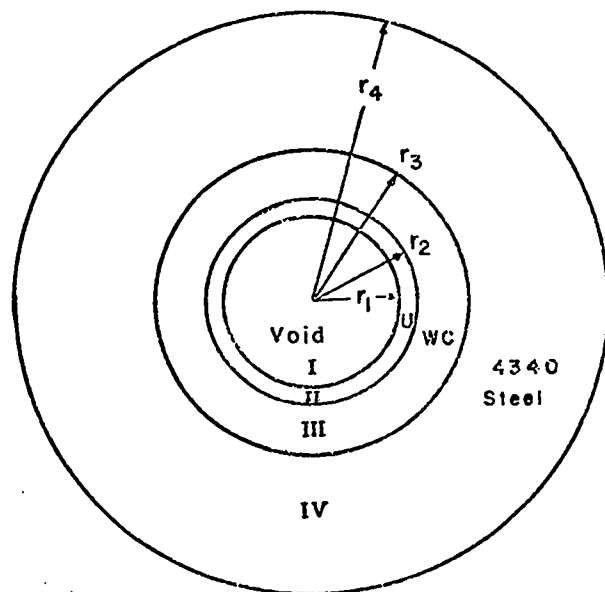


Fig. 2.
Idealized equivalent of the TCCA, where $r_1 \cong 11.17$, $r_2 \cong 13.05$, $r_3 \cong 19.66$, and $r_4 \cong 37.66$ cm.

ACTIVATION TRAVERSES AND SPECTRAL INDEXES

Fission-rate traverses reported here were obtained using a Jarvis four-barrel chamber (Quad 1A)² that contained ^{235}U , ^{238}U , and ^{237}Np . The observed results, corrected for chamber perturbation and isotopic composition of deposits, and the calculated values, included for comparison, are given in Table I for the ^{235}U fission-rate distribution $[\phi\sigma_f(^{235}\text{U})]$ and spectral indexes $\sigma_f(^{235}\text{U})/\sigma_f(^{238}\text{U})$ and $\sigma_f(^{237}\text{Np})/\sigma_f(^{238}\text{U})$.

Throughout the region within the WC-steel interface, which has the most influence on reactivity, there is no pronounced disagreement between experiment and calculation. Matters deteriorate progressively, however, as responses are followed outward through the steel—the region that strongly affects leakage. Disagreement becomes serious for $\phi\sigma_f(^{235}\text{U})$ and $\sigma_f(^{235}\text{U})/\sigma_f(^{238}\text{U})$, whereas the values do not differ significantly for $\sigma_f(^{237}\text{Np})/\sigma_f(^{238}\text{U})$. This suggests a problem with iron cross sections below the ^{237}Np threshold.

TABLE I
OBSERVED AND CALCULATED TCCA FISSION TRAVERSES

Radius (cm)	$\phi\sigma_f(^{235}\text{U})$		$\sigma_f(^{235}\text{U})/\sigma_f(^{238}\text{U})$		$\sigma_f(^{237}\text{Np})/\sigma_f(^{238}\text{U})$	
	Obs	Calc	Obs	Calc	Obs	Calc
0	0.84	0.85	11.0	10.9	5.9	6.3
11.15	1.000 ^a	1.000 ^a	8.8	8.8	5.4	5.9
11.17 Void-U						
12.74	0.98	0.95	9.0	9.5	5.4	6.0
13.05 U-WC						
13.69	0.85	0.83	14.2	14.4	6.3	6.8
16.22	0.63	0.58	29	27	7.2	8.1
19.07	0.47	0.38	54	42	9.2	9.2
19.66 WC-Fe						
20.26	0.44	0.36	69	51	9.7	9.5
22.75	0.40	0.34	106	79	11.2	10.9
32.44	0.172	0.140	306	228	17.8	16.6
35.80	0.120	0.069	303	230	19	18.5
37.10	0.090	0.041	300	200	20	18
37.66 Fe-air						

^aNormalized to unity.

Because of this difficulty, the neutron leakage from the S₈ calculation and Hansen-Roach cross sections will be distorted. Nevertheless, we show in Table II the calculated leakage neutrons per fission in various energy intervals for whatever insight they may help to provide into cross-section biases.

TABLE II
COMPUTED LEAKAGE NEUTRONS PER FISSION^a

Energy Interval	Leakage
3 - ∞ MeV	0.0055
1.4 - 3.0	0.0182
0.9 - 1.4	0.0348
0.4 - 0.9	0.1582
0.1 - 0.4	0.3255
17 - 100 keV	0.2190
3 - 17	0.0342
0.55 - 3	0.0154
100 - 550 eV	0.0054
0 - 100	0.0059
Total	0.8221

^aThe computed number of fission neutrons produced per core fission is 2.54.

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2. C. G. Chezem, "A Uranium-Metal Exponential Experiment," Nucl. Sci. Eng. 8, 652-669, p. 654 (1960).