NASA CR 72329

CAVITY REACTOR GAS-CORE CRITICAL EXPERIMENT

J. F. Kunze, L. S. Masson, G. D. Pincock, R. E. Wood: General Electric Company (Idaho Test Station)

R. E. Hyland: NASA-Lewis Research Center

November 6, 1967

Presented at the 1967 Winter Meeting
American Nuclear Society
Chicago, Illinois
November 5, 1967 to November 9, 1967

Prepared for

National Aeronautics and Space Administration Contract C-67747-A

GENERAL ELECTRIC COMPANY

Nuclear Materials and Propulsion Operation

Nuclear Technology Department

Idaho Falls, Idaho

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Work reported in this paper was supported by the National Aeronautics and Space Administration, Lewis Research Center, under Agreement No. C-67747-A with the Atomic Energy Commission (Related Services Supplement No. 8 to AEC Contract No. AT(40-1)-2847).

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INTRODUCTION

The cavity reactor concept has been proposed for a number of applications, such as magnetohydrodynamic power production and nuclear rocket propulsion. The latter application led the National Aeronautics and Space Administration to undertake a critical experiment of a full size mockup rocket reactor to determine if the reactor physics design calculations were correct. This experiment is currently in operation at the National Reactor Testing Station by the General Electric Company for NASA*. This recent critical experiment reactor is substantially larger than those previously measured (1). Results of various configurations that simulated the gas of the core with thin, 0.001 in. thick, uranium foils have been reported previously (2), (3), (4).

The critical mass vs. fuel radius for these configurations is shown in Figure 1. All configurations had a central cavity 6 ft in diameter by 4 ft long, and the fuel radius was adjusted while maintaining the 4 ft fuel length of the full cavity. Calculations of these configurations, using diffusion theory for the case in which fuel occupied nearly the full cavity diameter and transport theory when a void existed between the fuel and the heavy water, have generally failed to predict the measured critical mass within the order of 10%.

An unevaluated experimental bias was postulated for the effect of fuel sheet distribution vs. the effect of a uniformly dispersed gas which was assumed in the calculations. The fuel sheets were arranged on aluminum fuel trays as shown in Figures 2 and 3. There are paths through this arrangement that encounter no fuel sheets (approximately 1/2% of the total paths) and other paths that encounter a much greater effective fuel thickness than would be encountered in a uniform gas of the same average fuel density. The fuel distribution effects, though not analyzed rigorously at the present, have been analyzed statistically. Variations of as much as 5% to 10% in fuel interaction rate have been indicated between the two types of fuel, with the higher interaction rate existing in the uniform gas configuration as illustrated in Figure 4. To determine if the foil distribution was indeed introducing a bias of this magnitude, the gas-core critical experiment was undertaken. An actual gaseous (UF_6) core configuration was made critical, on May 17, 1967, and subsequent measurements were made to compare the results from the real gas configuration with those from a mockup foil configuration of the identical dimensions.

SYSTEM DESIGN

The gas-core tank was designed to contain the fuel in a 4 ft diameter, by 43 in. long tank which is shown in Figure 5. This arrangement was tested in a mockup experiment prior to performing the gaseous core experiment. Since UF_6 is a solid at ordinary temperature, it was necessary to provide a mechanism for heating the core-tank to temperatures of the order of 200°F. Because of the significant effect of neutron absorbers on the critical mass, it was

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* Under contract to the Atomic Energy Commission

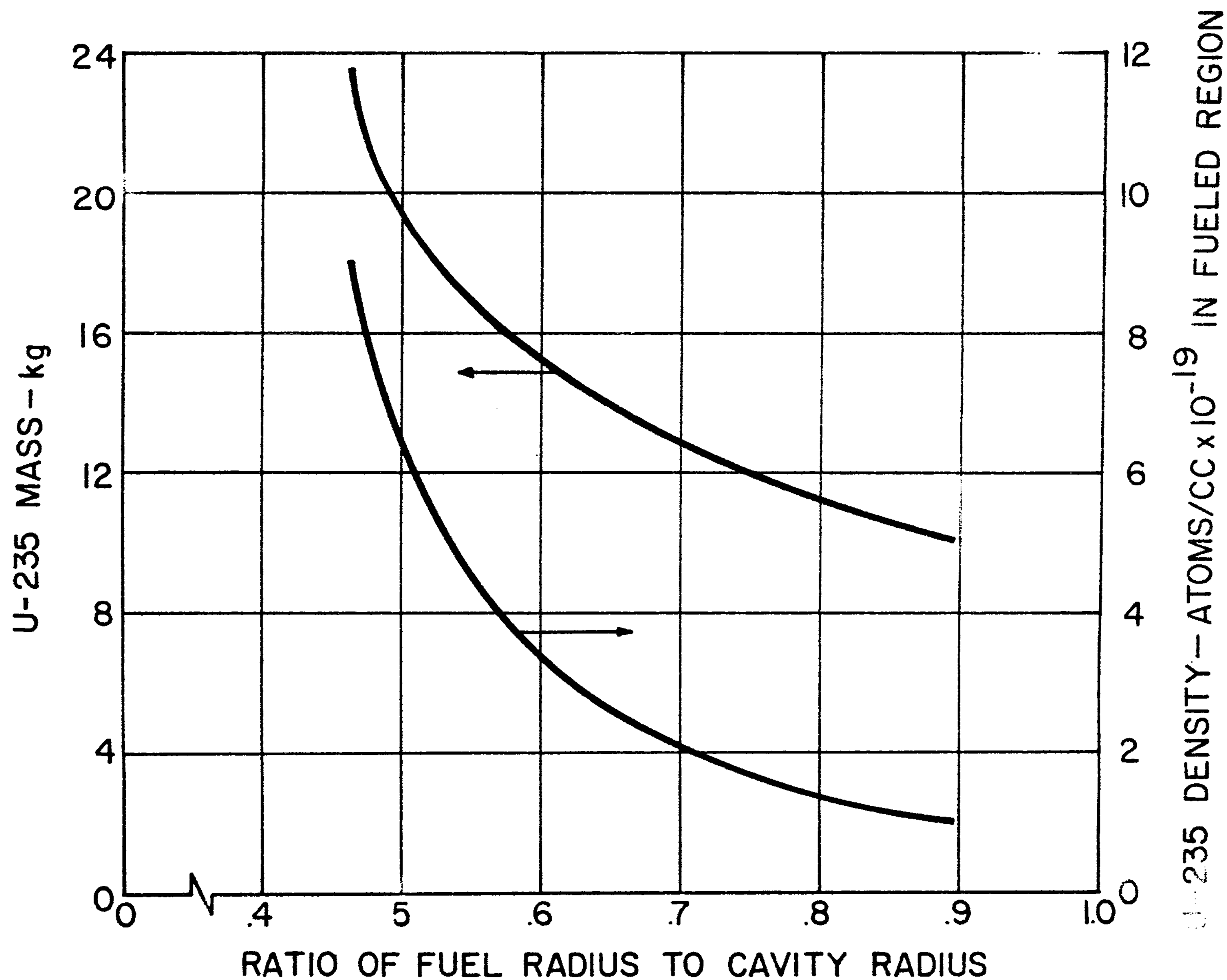


Fig. 1 Fuel radius effects on fuel mass and density

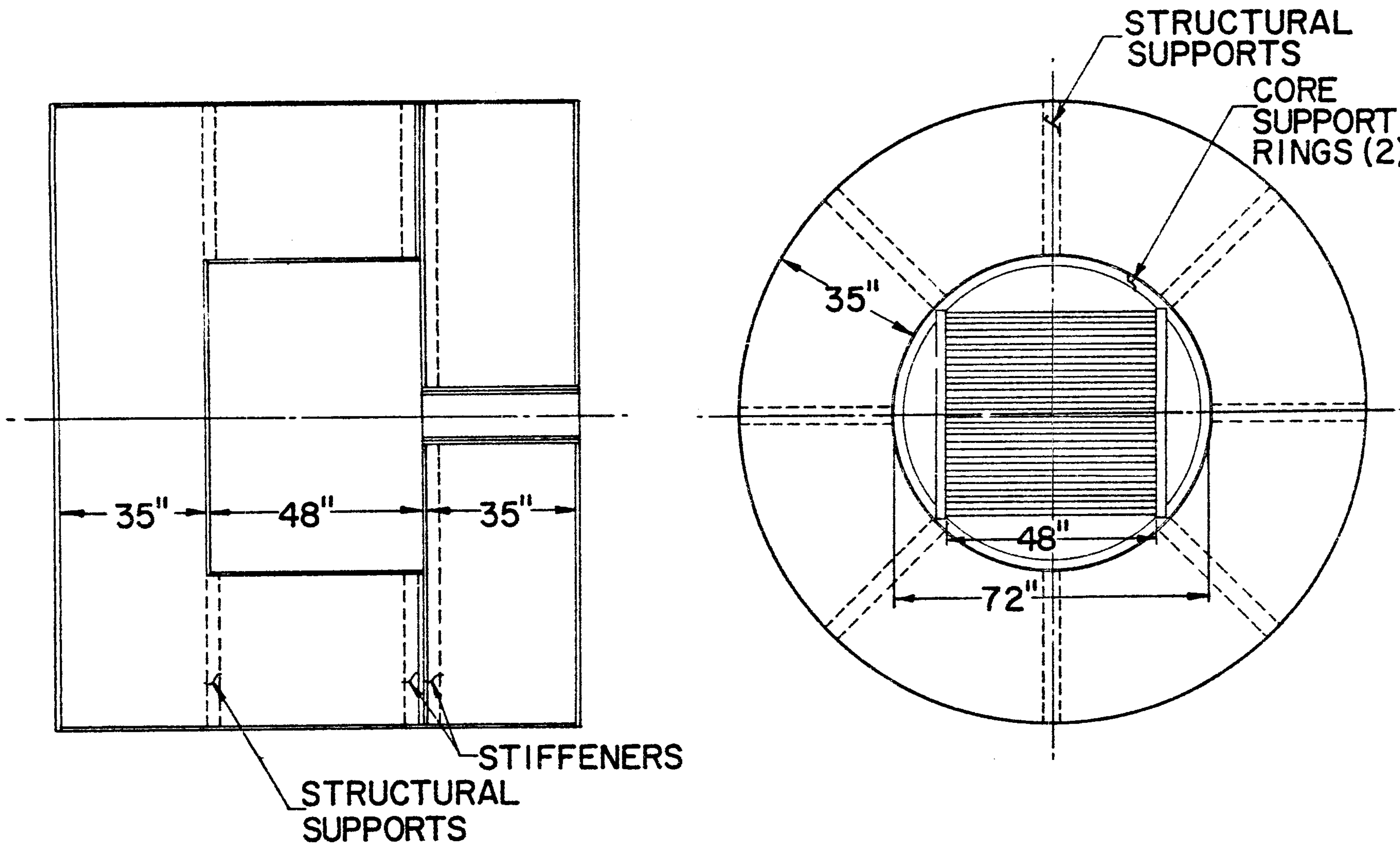


Fig. 2 Cavity reactor layout

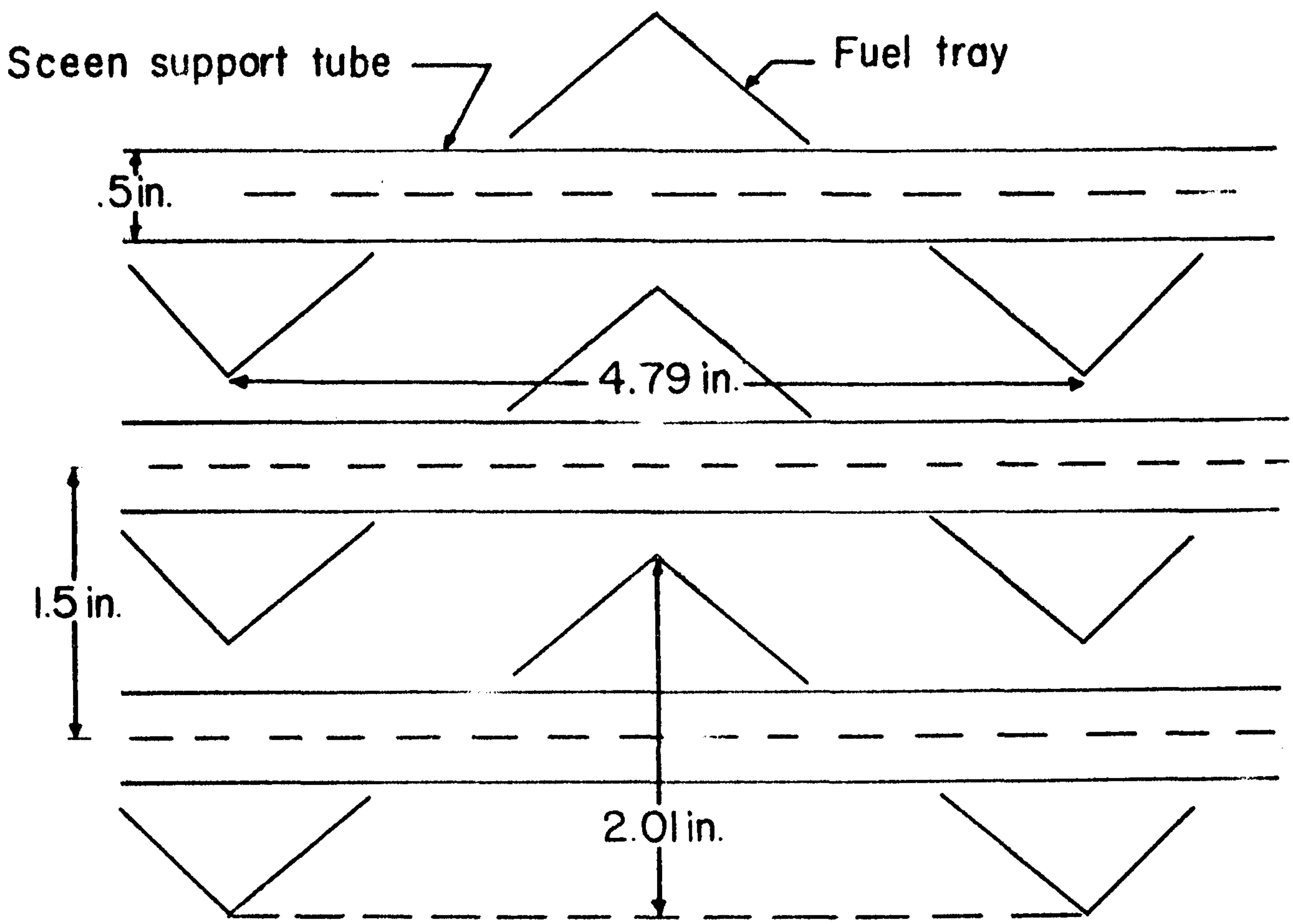
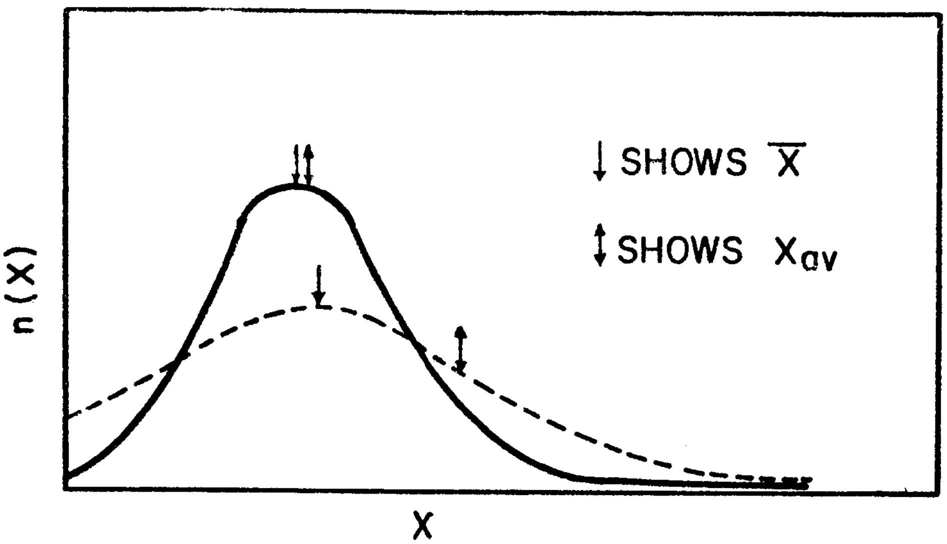


Fig. 3 Aluminum fuel tray arrangement



$\overline{X}$ is most probable nuclear path length

X_{ave} is the average nuclear path length

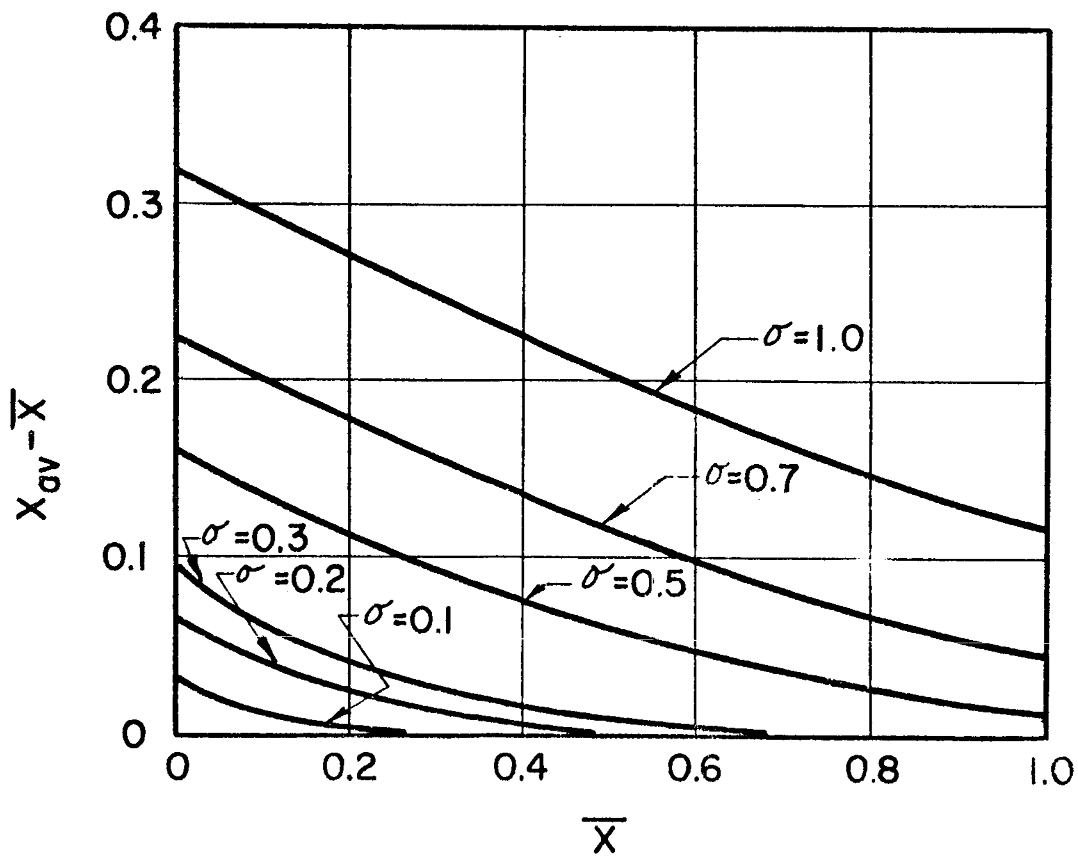


Fig. 4 Effect of gas density vs. foil density in terms of nuclear path length distribution

important to use only low cross section materials, particularly at the outside boundary of the fuel (the tank walls). Aluminum was chosen as the structural container and hot air as the heating medium circulating in a quarter inch annulus at the outside of the tank. The UF_6 was transferred into or out of the tank through 0.305 in. I.D. monel lines that were within the hot air ducts. The hot air ducts and UF_6 transfer lines extended about 20 ft to standard UF_6 transfer and storage bottles. This system is illustrated in Figures 5, 6 and 7. The operating conditions are shown in Figure 8 for the two basic configurations measured, a reflector of all D_2O and one with a 4 in. thick slab of beryllium located 6.7 cm from the cavity wall.

OPERATING EXPERIENCE

Initial transfer rates of UF_6 to the core tank were as high as 2 lb/hr, but slowed to less than half of this as the bottles became near empty. Reverse transfer into the bottles from the tank was as rapid as 5 lb/hr initially, but slowed to very low rates as the tank became empty. Each inventory of fuel was obtained by evacuating the transfer lines using only the pumping action of a cold trap, and then weighing the cold trap and the UF_6 bottles.

The approach to criticality was made with the usual incremental increases in fuel loading, making certain that the total vaporization temperature-pressure conditions were equaled or exceeded. Typical reactivity effects of tank temperature, once criticality had been achieved are shown in Figure 9. As indicated, the reactivity rose slowly while heating after vaporization temperature was reached and continued to increase slowly after the heater and blower were turned off while the wall temperature decreased. When the blower was turned on the reactivity increased rapidly producing a reactivity spike and then decreased with continued cooldown. It was suspected that the reactivity spike was due to an initial condensation on the inner surface wall. A similar measurement is shown in Figure 10 with two reactivity spikes on cooldown. The first is postulated to be due to the initial condensation on the flat end of the tank where the cold air impinges and the second due to the cooling of the outer radial wall. No explanation is given for the very slow reactivity rise during the operation when all of the fuel should be vaporized.

Throughout all operations, the hot air stream was monitored at its exit from the tank by an alpha detector and then filtered. Uranium leaks were not detected; though short lived radon daughter products were observed.

EXPERIMENTAL RESULTS AND CONCLUSIONS

As previously mentioned, a mockup of the UF_6 experiment was performed prior to performing the gas experiment. There were differences in aluminum structure inside the fuel region between the mockup experiment and the UF_6 experiment, and the UF_6 contained fluorine which was not simulated in the mockup. Measurements were made of the worth of fluorine, using Teflon and carbon, and the worth

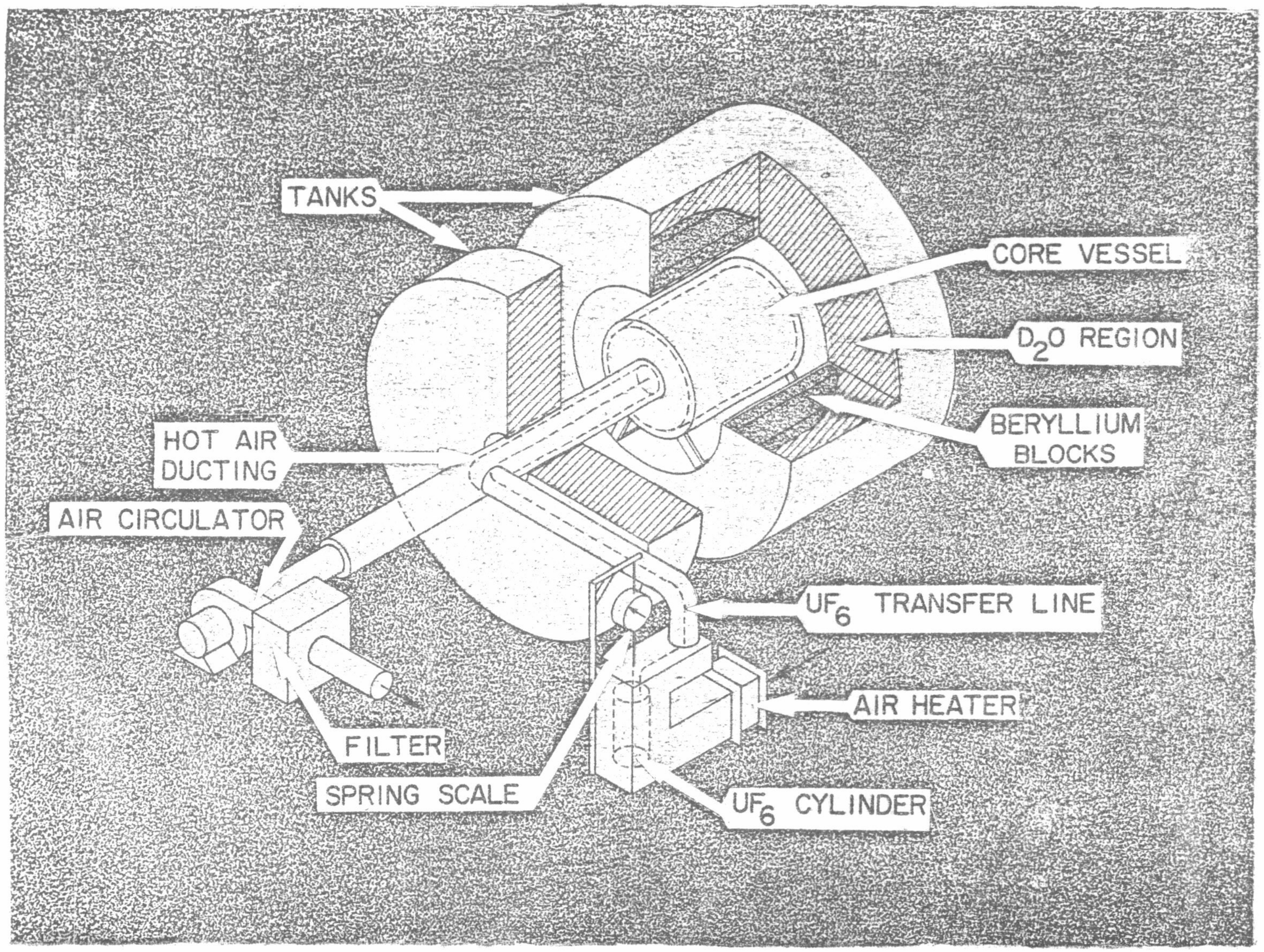


Fig. 5 General arrangement of cavity reactor showing heating equipment and UF_6 transfer system

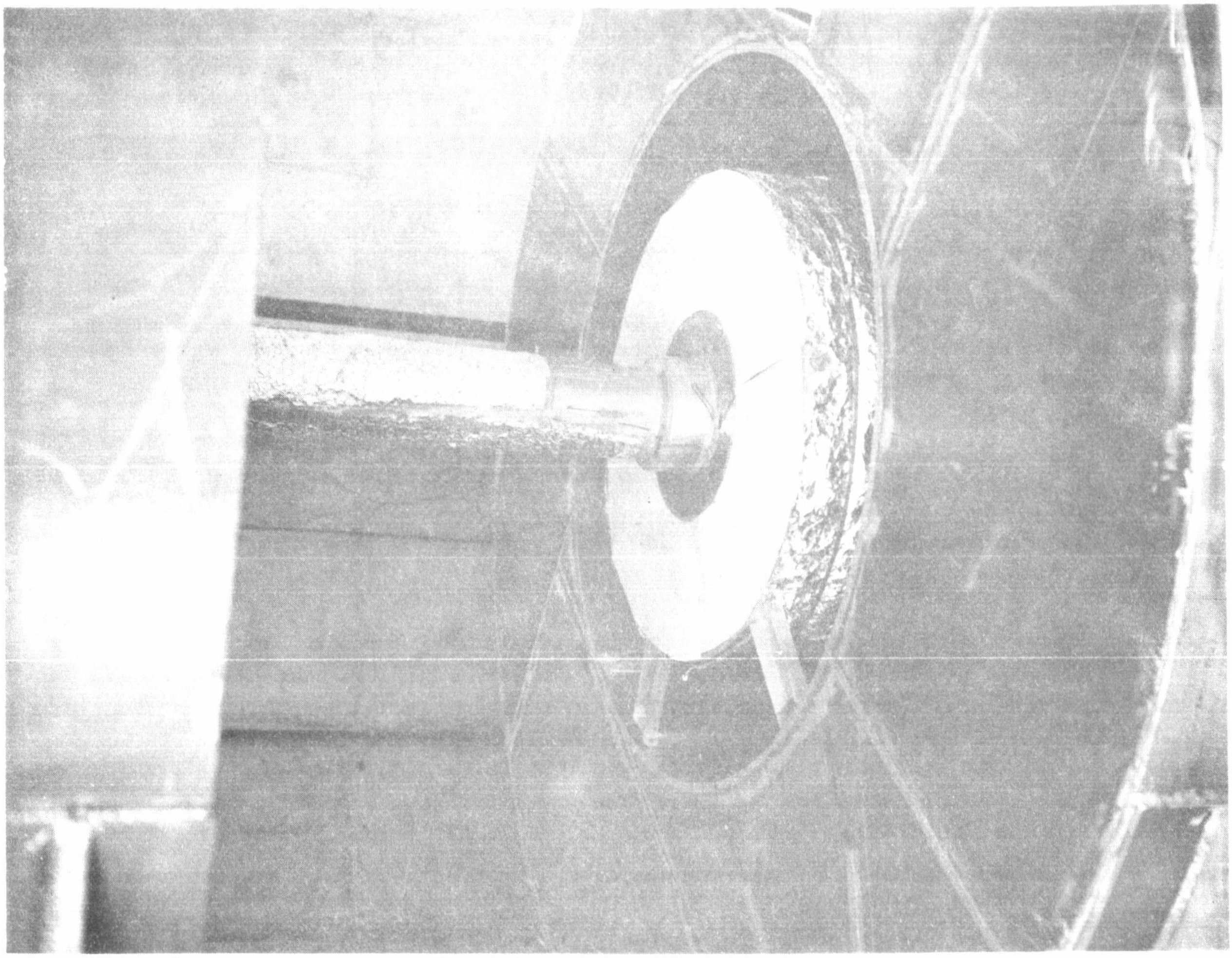


Fig. 6 Reactor core tank and heating duct

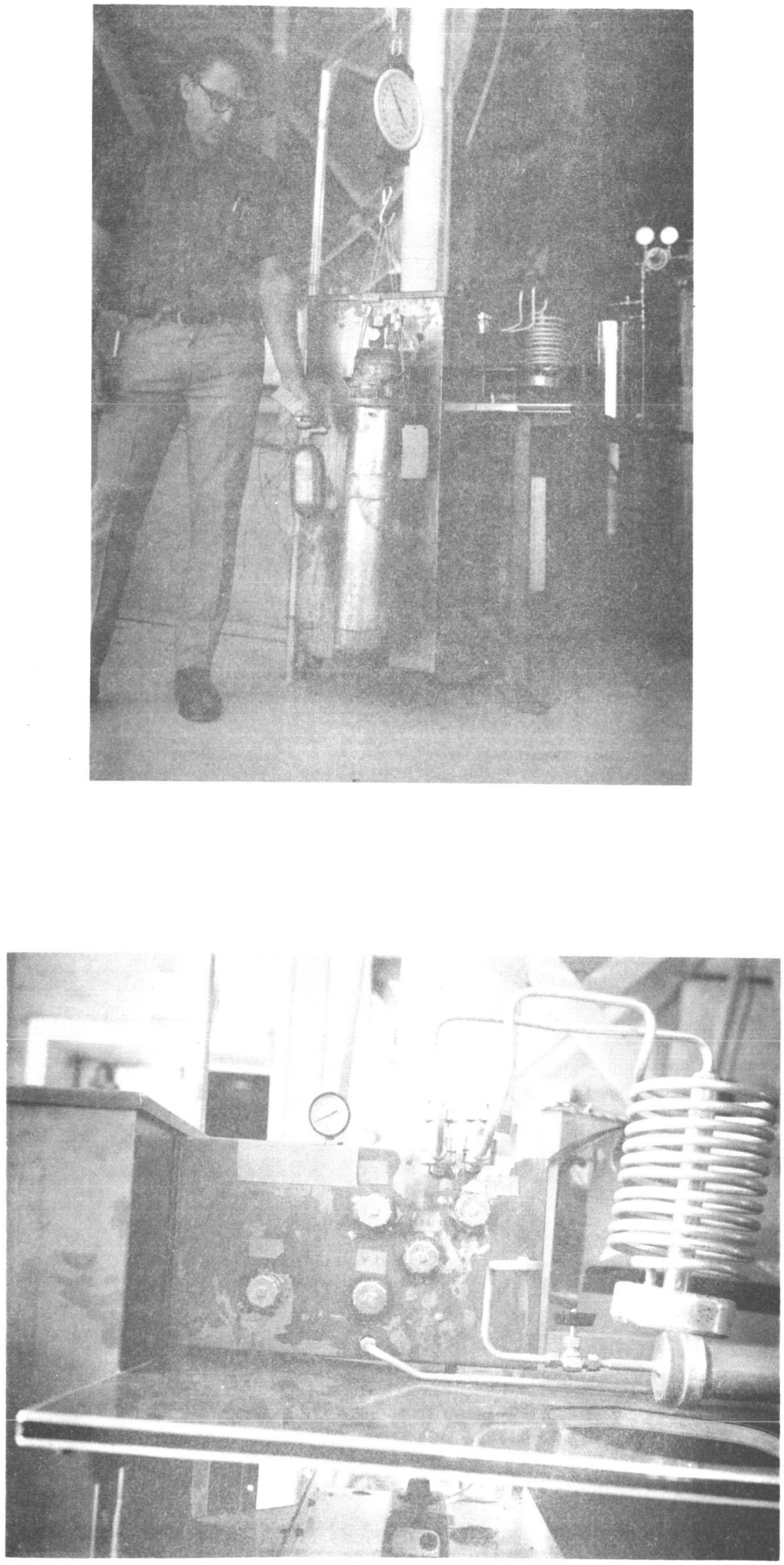


Fig. 7 Gas transfer equipment

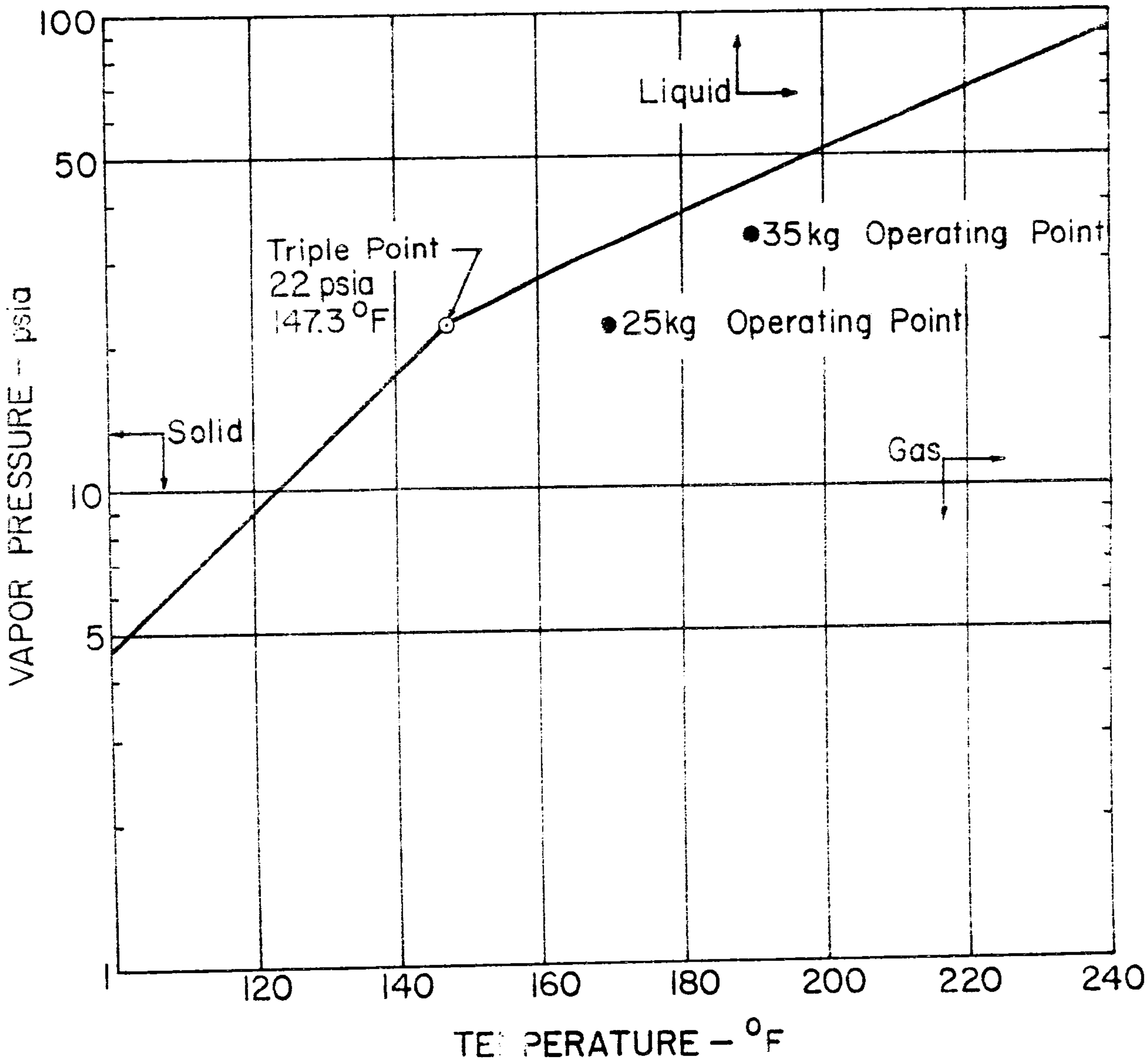


Fig. 8 Physical characteristics of UF_6

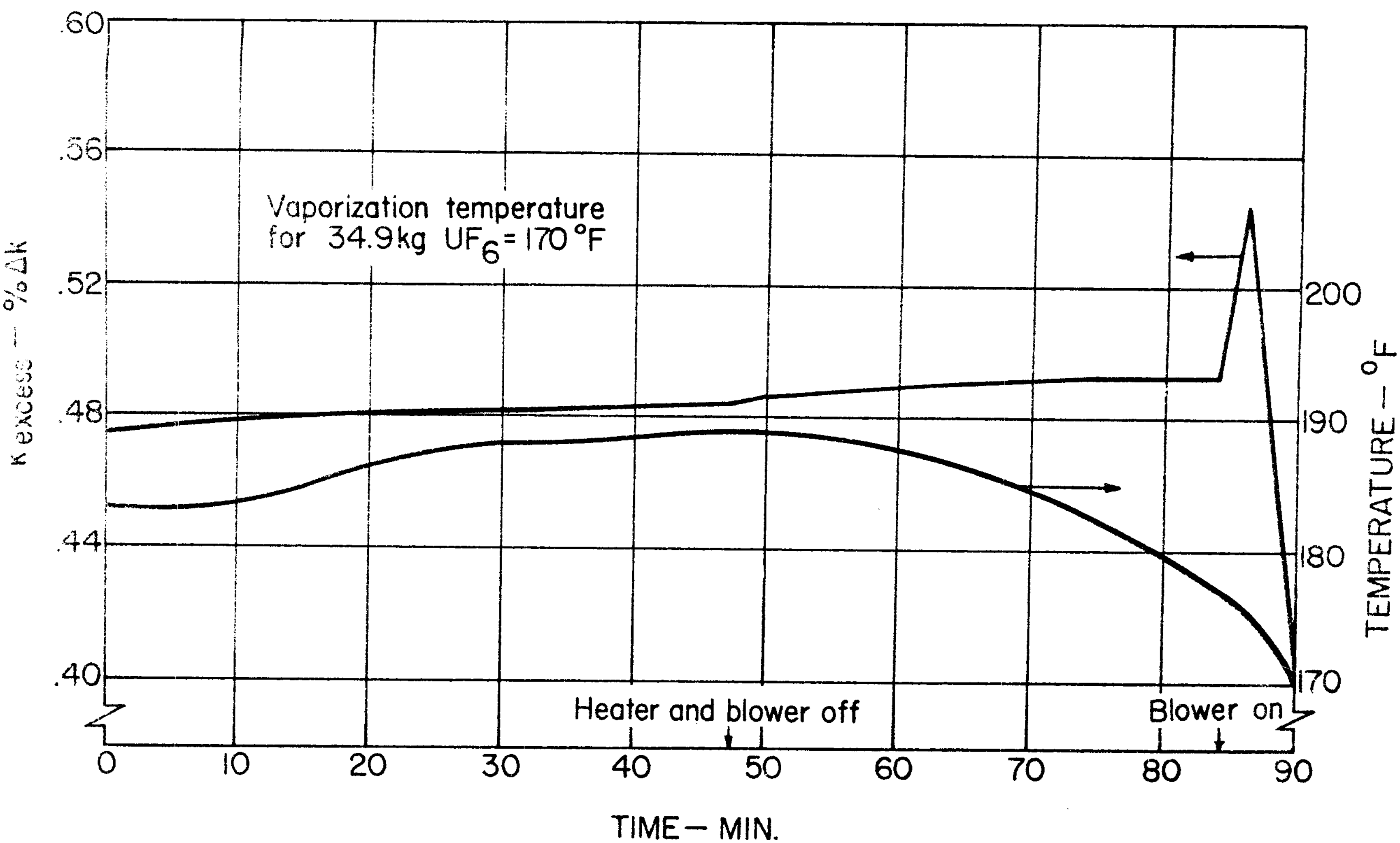


Fig. 9 UF_6 temperature effect on reactivity

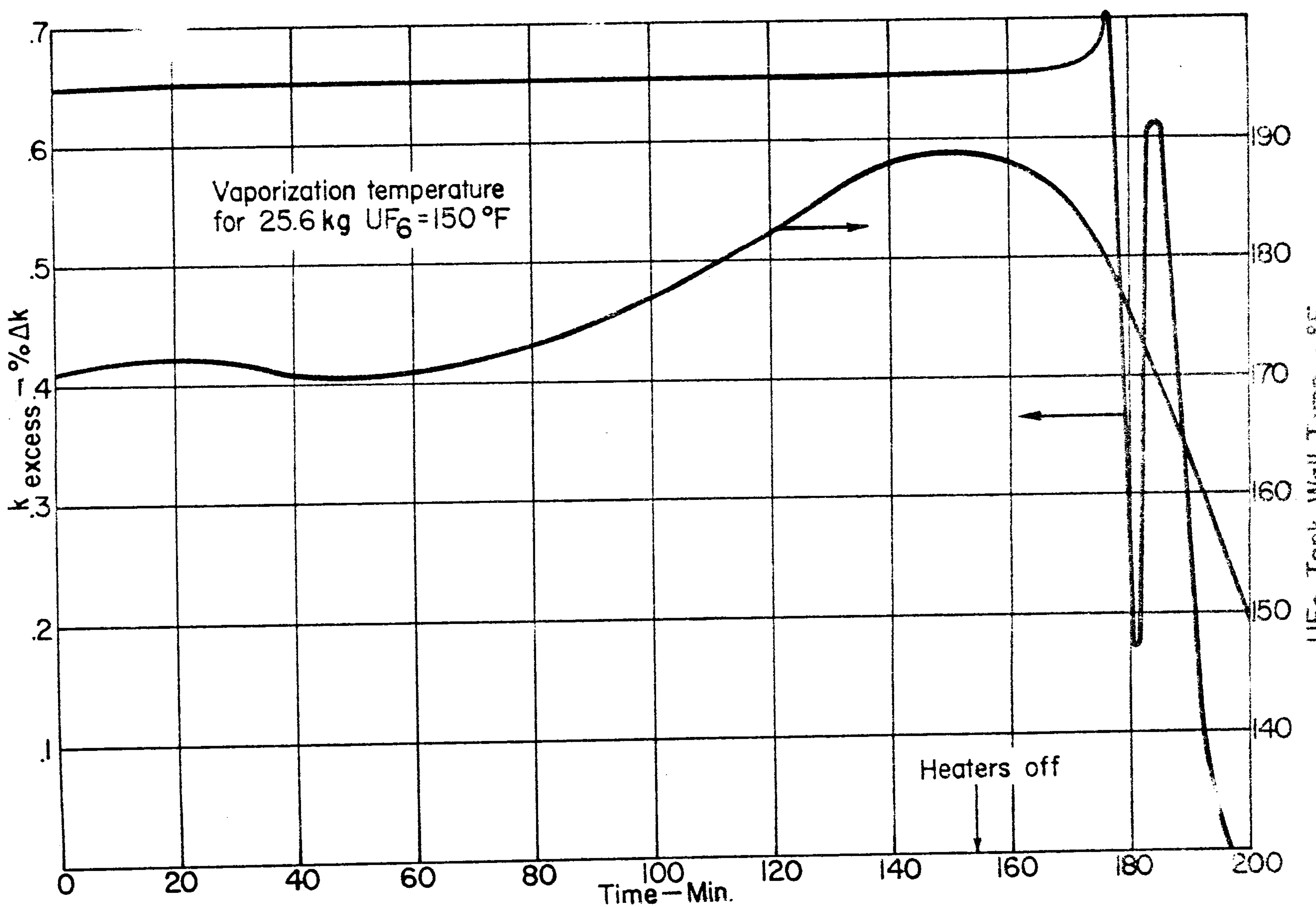


Fig. 10 UF_6 temperature effect on reactivity of aluminum in order to correct for these differences between the experiments. The aluminum material at the edge of the fuel region was duplicated almost exactly in the gas and mockup experiments. The resulting comparison of experimental results is shown in Table 1.

A new core mockup has been assembled and is illustrated in Figure 11. This fuel support structure features fuel boxes 3 in. square by 4 ft long which are supported within an aluminum support structure. Figure 12 shows the fuel arrangement and illustrates the method in which zero interaction fuel paths are minimized. This assembly achieved criticality on October 25 with a mockup of the gaseous experiment. The fuel loading corrected for differences in aluminum within the fuel region with this assembly is within 5 % of the gaseous experiment and indicates that this arrangement is superior to the original arrangement. It is concluded that this mockup provides an adequate representation of the gas core and can be used to study variations in materials and geometry that are extremely difficult with the gas core. It is further concluded that a correction of the order of 9% should be applied to prior results to correct for fuel heterogeneity. The work planned for the near future is to evaluate the complete effect of structural materials and the hydrogen coolant.

TABLE 1

Comparison of Critical Loading Results

	MOCKUP	UF_6	UF_6/MOCKUP
Critical mass (kg of uranium)	24.8	22.8	.92
Fuel worth at critical ($\Delta k/k/\Delta m/m$ of U-235)	0.155	0.179	1.15
Power ratio from edge of fuel to center of core	2.86	2.47	.86
Uranium cadmium ratios			
Center of core	6.6	6.9	1.05
Edge of fuel	15.2	15.2	1.00
Cavity wall	19.2	20.5	1.07
Gold foil cadmium ratios			
Center of core	1.18	1.2[illegible]	1.03
Edge of fuel	1.53	1.47	.96
Cavity wall	1.63	1.69	1.04

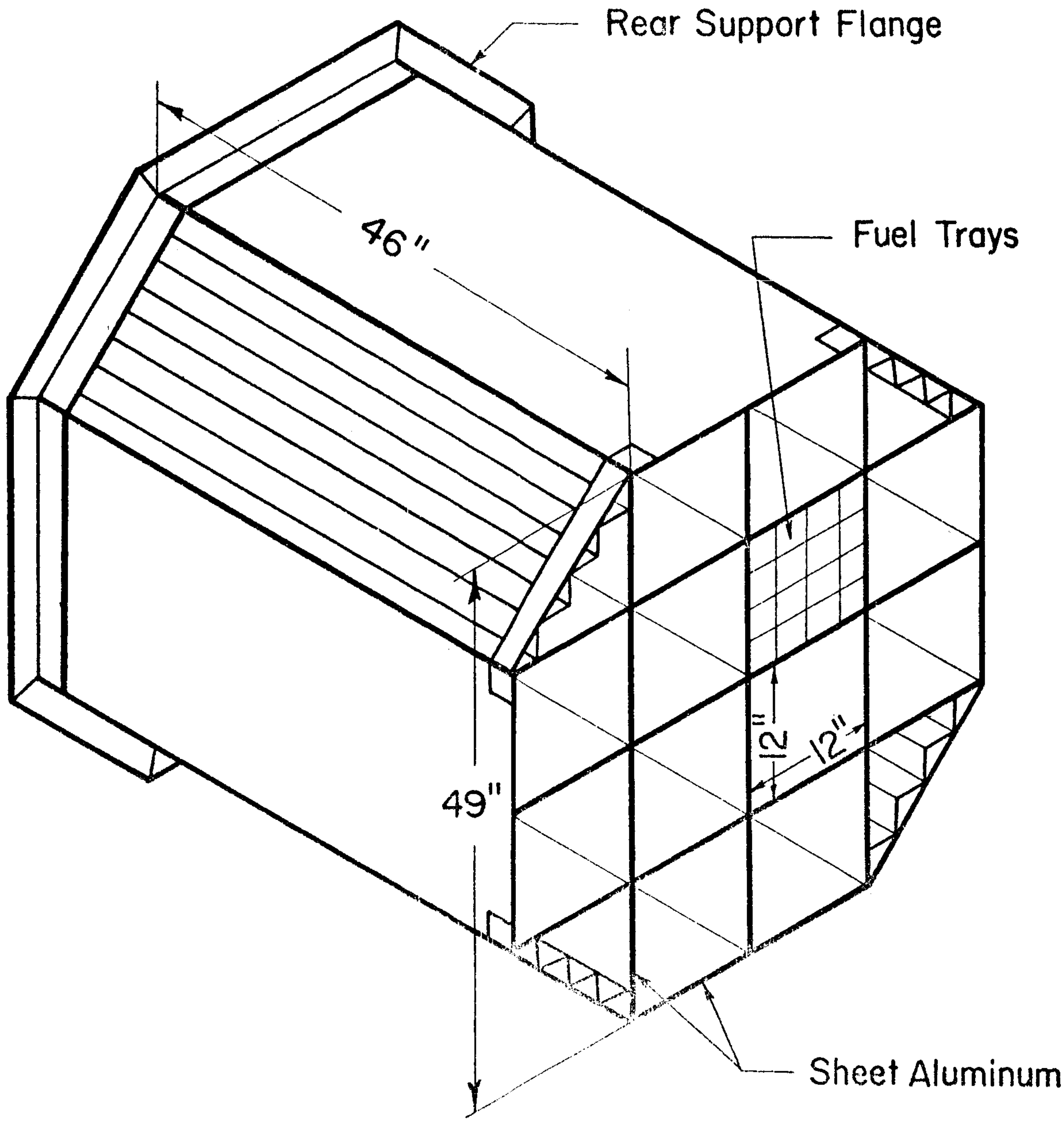


Fig. 11 Cavity reactor fuel support structure

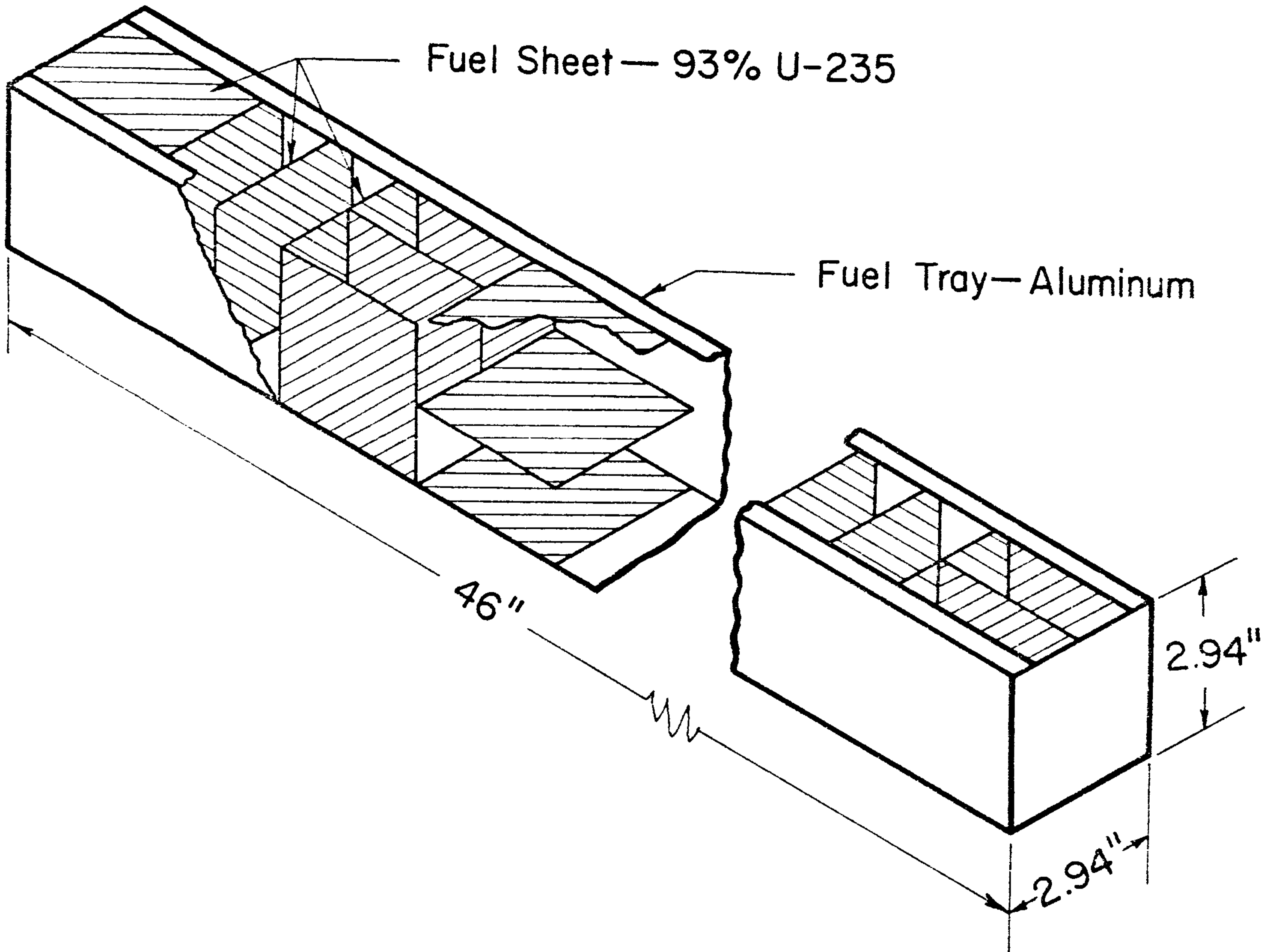


Fig. 12 Cavity reactor fuel element

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