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A TEST OF NEUTRON MULTIPLICATION BY SLIGHTLY ENRICHED URANIUM

Part II

Dixon Callihan

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A TEST OF NEUTRON MULTIPLICATION by SLIGHTLY ENRICHED URANIUM

Part II

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ABSTRACT

An experiment has shown approximately 20000 lb of liquid UF_6 enriched to 2% in U-235, homogeneously mixed with 7 mol percent HF and contained in four cylinders 30" in diameter and 80" long, to be sub-critical In this mass of UF_6 are 123 kg U-235 In the absence of an aqueous neutron reflector the source neutrons were not significantly multiplied, with a reflector the apparent multiplication was as great as two although no quantitative significance can be attached to the value The experimental results are in agreement with multigroup Fermi age calculations which give a value for k_∞ of about 0 3 Conservative limits are set for certain process operations which are free from nuclear hazards The conclusions are not applicable to small element lattices in a moderating medium

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I INTRODUCTION

The continuing expansion of facilities for the separation of the uranium isotopes has necessitated further consideration of the conditions under which uranium only slightly enriched in U-235 can be made critical In order to specify methods of storing and shipping these materials it is desirable to know batch sizes, geometric parameters, etc , which can be imposed to insure nuclear safety or, in the absence of knowledge of actual critical conditions, to be assured that otherwise practical quantities present no hazard Of particular interest at this time is a system of two or more individually subcritical masses of UF_6 with a U-235 enrichment of 2% containing only small amounts of internal hydrogen including the case where the entire system may be immersed in water In earlier experiments of this series[1] it was shown that 3600 kg of 2% enriched UF_6 in a column 30" in diameter and approximately 8' high with essentially no internal hydrogen produced no significant neutron multiplication even when surrounded by an effectively infinite hydrogeneous reflector This result was used to design a shipping container Uncertainties in the scattering and energy degradation of fast neutrons by fluorine, in the fast fission effect in U-238, and in extrapolation of the earlier measurements to larger masses and somewhat higher hydrogen contents dictated an experimental rather than an analytical approach to the present problem A measurement, made in the ORNL Critical Experiments Laboratory, of the neutron multiplication by 9108 kg (2×10^4 lb) of UF_6 at 2% U-235 enrichment is reported here

II EXPERIMENTAL MATERIALS, APPARATUS AND METHOD

The UF_6 was contained in four drums, designated as "One Ton Cylinders, Type A", made of steel and measuring 30" diameter x 81-1/2" long, outside, with 13/32" thick walls, minimum The ends were dished and the drums had minimal inside dimensions of 29-3/16" x 64-1/2" They were equipped with appropriate valves and connections One of the cylinders used in these experiments had a 1/2" diameter re-entrant tube along the axis which was a convenient location for thermocouple junctions and a neutron source

The cylinders were filled with liquid UF_6 and about 7 mol % of HF was added Prior to and during the experiments the temperature of the cylinders was kept sufficiently high to maintain the UF_6 as a liquid, thereby preserving, to some extent, the homogeniety of the uranium and the hydrogen A description of the contents of each cylinder is given in Table I

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1 Callihan, D et al, "A Test of Neutron Multiplication by Slightly Enriched Uranium" K-740, March 29, 1951

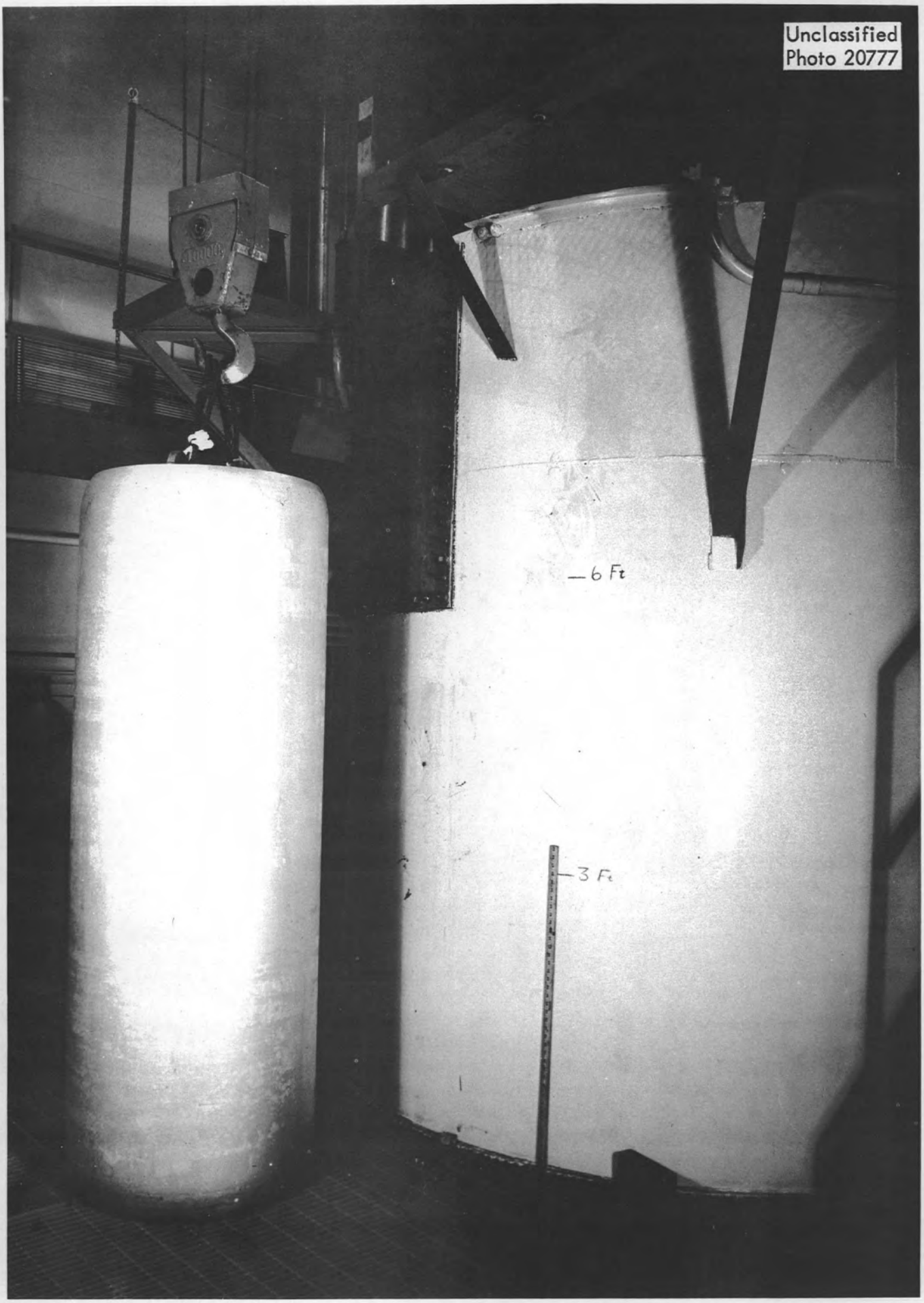
TABLE I

UF_6 Used in Multiplication Test

Cylinder No	D-31	D-39	D-43	D-44	Total or Average
Weight of UF_6, lbs	5024	4965	5025	5023	20037
" " UF_6, kg	2284	2257	2284	2283	9108
Weight of U, kg	1544	1526	1544	1544	6158
U-235 enrichment, %	2 002 2 003	2 005 2 010	1 978 1 977	1 985 1 989	1 993
Weight of U-235, kg	30 9	30 6	30 5	30 7	122 7
Weight of HF added, lbs	21 3	20 6	21 2	20 8	83 9
" " " " kg	9 68	9 36	9 64	9 45	38 13
HF in liquid UF_6 wht % (Laboratory Analysis)	0 457 0 457	0 361 0 380 0 358	0 437 0 469	0 401 0 418	0 417
H U-235 Atomic Ratio (from HF added)					3 70
" " " (from Laboratory Analysis)					3 70

The water, providing an effectively infinite neutron reflector, was kept at 67 ± 1°C It accumulated a few thousand parts per million of impurities, mostly iron, during the experiment because of corrosion of the steel cylinders

A large steel tank, 9' in diameter and 9-1/2' high, had been installed in the Laboratory to serve as a container for reflector water in experiments of this type The bottom of this tank is 1" thick and is adequately supported on the upper level of a large room to permit loading all four cylinders into it The Laboratory bridge crane could be operated from the control room allowing remote assembly of the cylinders The tank is connected through a pump and a 1-1/4" solenoid valve to a temperature controlled water supply of a few thousand gallons In parallel with this line is another, 3" in diameter and returning directly to the storage tank, containing a normally open spring operated diaphragm valve This valve may be opened by manual control or by instrument signal at a predetermined radiation level and is one component of the safety system, allowing the water to drain by gravity to the supply tank A large sheet of cadmium, magnetically supported in a position such that it could fall adjacent to one of the cylinders, was another safety feature A Po-Be source of about 10^6 neutrons/sec was located at the center of the first cylinder loaded in the tank One of the UF_6 cylinders is shown beside the water tank in the figure



UF_6 Cylinder (left) and Reflector Water Tank

The radiation detection instrumentation was conventional, consisting of five boron lined proportional counters with attendant scalars and several BF_3 ion chambers and γ-sensitive detectors connected to strip recorders The temperature of the water bath necessitated locating the detectors outside the tank and the resulting shielding by the water reduced the counting rates significantly Three of the proportional counters, 1, 2 and 3, were located immediately below the reflector water tank and two were beside it about 3' above the bottom Somewhat less confidence is placed in the results from the latter group since the addition of the UF_6 filled cylinders to the tank changed the shielding of the source The errors in the counting rates, the poor source-neutron multiplying medium-detector geometry, and the neutron scattering materials in the set-up make neutron multiplication measurements uncertain

In the procedure the neutron counts made with one cylinder in the tank, with and without the water reflector, were taken as "backgrounds" and subsequent counting rates were measured with two, three and four cylinders, respectively, loaded in contact*, both bare and immersed in water The loading pattern was that resulting from the following sequence The first cylinder was positioned somewhat off center of the tank and the second was placed in contact with it The third was located in contact with the first two as was, subsequently, the fourth In a second arrangement the above pattern was preserved with the edge-to-edge spacing increased to approximately 2"

III RESULTS AND CONCLUSIONS

Unreflected

The counters located below the tank and yielding results less susceptible to spurious neutron absorptions and reflections showed no significant multiplication of source neutrons as the loading was increased from one to four cylinders although it is estimated that a multiplication, at the 95% confidence level, of 1 05 could have been detected Data from the counters at the side of the tank are less certain It is concluded that the increase in the loading from 31 kg U-235 to 123 kg did not increase the source neutron multiplication and that the final array was far from critical

Water Reflected

With the array of cylinders immersed in water the counter statistics were somewhat poorer with an estimated limit of detectable multiplication of 1 14, with 95% confidence, by the counters below the tank The variable thickness of water between the source and the two side counters makes the results from them suspect The counting rates

*Although the cylinders were nominally in contact the edge-to-edge separation ranged between zero and 1 75" because of irregularities in the cylinder walls and in their end structures which caused them to tilt

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measured on all instruments after successive cylinder additions are listed in Table II

TABLE II

Neutron Counting Rates and Multiplications
With Successively Increased Loading

Water Reflected

Counter No	1		2		3		4		5	
Number of Cylinders	Rate c/min	M	Rate c/min	M	Rate c/min	M	Rate c/min	M	Rate c/min	M
1	94 6	1 00	61 8	1 00	102 5	1 00	53 7	1 00	29 8	1 00
2	139 0	1 47	64 0	1 04	87 5	0 85	57 0	1 06	24 5	0 82
3	137 5	1 45	104 8	1 69	73 8	0 72	66 0	1 23	31 5	1 06
4	135 5	1 43	127 2	2 06	121 0	1 18	59 0	1 08	25 8	0 87
4s*	113 0	1 19	99 0	1 60	104 0	1 02	32 9	0 61	14 7	0 49

* In this test the cylinders were separated about 2" edge-to-edge

It is concluded from these results, therefore, that the system of four cylinders of UF_6, enriched to 2% in U-235, containing 7 wht % HF and a total 123 kg U-235 (an H U-235 atomic ratio of 3 7) was far from critical In the absence of water reflector there was no statistically significant source neutron multiplication With water surrounding the cylinders there is some multiplication indicated by those detectors yielding results in which there is greatest confidence It is to be emphasized that uncertainties in apparent neutron multiplications as low as these, especially when observed with variable neutron absorbers and reflectors, are so great that no evaluation of reactivity can be made It is highly probable, however, that the systems were far from critical and conservatively establish upper limits for the specification of nuclear safety in certain process operations The results of the experiments are not inconsistant with those of calculations, based on 32 lethergy groups, which gave a value of k_∞ of about 0 3 in an infinite mass of UF_6 at 2% U-235 enrichment and containing 7 mol percent HF homogeneously dispersed None of these conclusions apply to small element lattices of the uranium in hydrogeneous materials

IV ACKNOWLEDGEMENT

The UF_6-HF mixtures used in these experiments were prepared and analyzed by the K-25 Process and Laboratory Divisions respectively

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