UNCLASSIFIED

MonP-357

Subject Category: PHYSICS

0

UNITED STATES ATOMIC ENERGY COMMISSION

CRITICAL EXPERIMENTS ON A SMALL
REACTOR OF ENRICHED U^{235} WITH $Al-H_2O$
MODERATOR, AND D_2O , Be AND
 H_2O REFLECTORS

By
M. M. Mann
A. B. Martin

August 18, 1947

Clinton Laboratories
Oak Ridge, Tennessee

Technical Information Service, Oak Ridge, Tennessee

UNCLASSIFIED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Date Declassified: September 20, 1955.

This report was prepared as a scientific account of Government-sponsored work and is made available without review or examination by the Government. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights. The Commission assumes no liability with respect to the use of, or for damages resulting with respect to the use of any information, apparatus, method, or process disclosed in this report.

This report has been reproduced directly from the best available copy.

Issuance of this document does not constitute authority for declassification of classified material of the same or similar content and title by the same authors.

Printed in USA, Price 20 cents. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

GPO 987853

MonP-357

CRITICAL EXPERIMENTS ON A SMALL REACTOR OF ENRICHED U^{235} WITH $Al-H_2O$
MODERATOR, AND D_2O , Be AND H_2O REFLECTORS

Experiments by:

M. M. Mann
J. H. Buck
A. B. Martin
A. Longacre
S. E. Dismuke

Calculations by:

E. Greuling
B. Spinrad
A. V. Maskett

Written by:

M. M. Mann
A. B. Martin

August 18, 1947

Work performed under Contract No. W-35-058-Eng-71

CLINTON LABORATORIES
Oak Ridge, Tennessee

CRITICAL EXPERIMENTS ON A SMALL REACTOR OF ENRICHED U-235 WITH $\text{Al-H}_2\text{O}$
MODERATOR, AND D_2O , Be AND H_2O REFLECTORS

The problem of designing critical assemblies for the study of systems containing U-235 as fuel and H_2O as moderator arose in the fall of 1946. It was at this time that those interested in the design of the proposed high flux experimental pile for Clinton Laboratories finally decided to proceed with the system U-235 - H_2O with Be reflector.*

It also happened that during the early fall of 1946 the critical experiments group had spent some time in consideration of a program of experiments designed toward a systematic study of certain piles from both theoretical and experimental points of view. Thus, when it was requested that experiments be done to study the physics of the proposed high flux pile, it was suggested that a series of experiments be done, so that something of the general physics of small thermal piles might be learned. It was suggested further that calculations be made specifically for the experimental geometries.

With this in mind a simple set of geometries was planned in order to study the most easily calculable cases, with the hope that (1) more understandable data would be available for design of the high flux pile, and (2) that advanced pile theory would be furthered by comparison with experiment.

The following pages constitute a report of the experiments executed to date.

Experimental Facilities

These experiments were done in cells 6 and 7 of Bldg. 205, a portion of the former Pu separation pilot plant, where the earlier work on U- D_2O systems was done. Some fairly extensive changes have been made in the physical arrangement, though, and it is perhaps worthwhile to describe these briefly.

---

* See Weinberg et al MonP-206, MonP-272

In the first instance, a wall of concrete blocks has been erected between the pile room and the control room. This wall is of 2 ft. thickness up to a height of 8 ft. and of 1 ft. thickness from that point to within about 1 ft. of the ceiling, the gap being left for passage of control wires. A water window of 2 ft. thickness is placed in the wall to provide visual access to the pile and associated equipment. A factor of approximately 100 can be expected from this shield over and above the distance factor. Figure 1 will show the general features and dimensions of the present arrangement.

Secondly, a docrway has been cut through the 4 ft. concrete wall of cell 6 providing entrance from outside to the control room at ground level and avoiding the previous necessity of going down steps and up again to enter or leave the cells. Emergency exit is now much easier than before.

In the instrument field, new and faster monitrons have been added. There are now three (3) monitrons (ion chambers and associated circuits) in operation at all times, and all are connected to the control rod safety system. The time constants of the safety circuits are now of the order 0.2 to 0.5 seconds, depending on the sensitivity of the circuits.

Esterline-Angus recorders installed in the control room are connected to two of the three monitrons, providing the usual visual monitors for pile operation.

The usual array of counters, gamma and neutron, are in use and mechanical counter-recorders and loud speakers for these are mounted in the control room.

An important addition to the operating and safety systems is that of remote control of the neutron source of the pile. The mechanism for this feature contains interlocks that provide the following:

- (1) The pile cannot be started up unless the source is in its proper position.
- (2) The source may be removed when criticality is reached, and the pile may operate self-sustained.
- (3) Once the source has been removed, it cannot be re-inserted until the control rods have been put back into the pile.

For electrical details of the safety and control system, Figure 2 may be consulted.

Pile Geometries and Design

When an experimental study of the critical features of the high flux pile (H_2O moderator, Be reflector) was requested, no Be was available. The question then was whether it was possible to substitute, until Be became available, a reflector roughly equivalent to Be. To answer this with assurance a good knowledge of the constants for both Be and the substitute is of course necessary. This condition could be met moderately well in view of the fairly complete information in existence for D_2O and the less complete data available for Be. It was decided therefore that (1) D_2O is a reasonably good substitute for Be, and (2) since D_2O constants were better known than those of Be, it would be of interest to compare the two directly in experiment.

The next problem is that of the reactor, and the feature of most interest here is the effect of various quantities of Al. This question arises because of the construction of the fuel plates in the high flux pile, wherein the fuel is U-Al alloy, covered with Al and Al alloy. These plates are so closely spaced in the reactor that to a very good approximation the pile can be considered a homogeneous mixture of U, Al, and H_2O . It was clear then that a group of experiments with the volume ratio of Al to H_2O as the variable, keeping the concentration of U-235 constant, would be interesting and useful for two reasons, (1) engineering design of the high flux pile depends on allowable quantities of Al in the reactor, (2) the dependence of critical mass, and the age, on Al/ H_2O ratio is of both theoretical and practical interest.

The most probable values of these pertinent quantities, for the high flux pile, were, concentration of U-235 = 35.6 grams/liter of pile and Al/ H_2O (volume ratio) = 0.75. It seemed reasonable therefore to study systems with ratios in the region 0.30 to 0.90, approximately. It is of interest to observe here that now (June) the probable Al/ H_2O ratio in the high flux pile is about 0.64, as opposed to 0.75 quoted

above, and this seems to bear out the original feeling that a systematic group of experiments would be worthwhile.

The exact values of $\text{Al}/\text{H}_2\text{O}$ ratios used in the experiments to date are determined of course by materials and sizes available. Furthermore, the question of how best to construct an essentially homogeneous reactor in reasonably small integral parts, with variable quantities of Al, must be considered. One would like to avoid an experiment wherein the fuel is in solution and is contained in a single tank, in which various amounts of Al are inserted. The complexities of design and the dangers of an experiment of this sort are well known.

Thus, the term "reasonably small integral parts" implies that, (1) in the execution of an experiment one should not add fuel in amounts sufficient to cause a dangerous change in the multiplication factor, (2) the fuel should be placed in a number of separate containers, and (3) the quantity of fuel in each container must be small enough to satisfy condition (1) with appropriate safety factor.

Consideration of all these factors led finally to the selection of square aluminum tubes for fuel containers. A square tube satisfies the requirement for close packing and consequent good approximation to homogeneity of the reactor, and a reasonable size was found to be available, namely 1" x 1" with 1/16" wall thickness.

The lower limit of $\text{Al}/\text{H}_2\text{O}$ ratio is then set at 0.303 if only the Al of the tubes is considered. To increase this ratio, Al must be added, and this has been done in two ways. By the insertion of 1/8" (0.125") spacers between tubes a volume ratio of 0.65 is obtained. Then the placement of an Al strip of 1/16" x 3/4" cross-section inside the fuel tube will raise the ratio to 0.76, and finally a ratio of 0.88 is obtained if one substitutes a strip 1/8" x 3/4" inside the fuel tube.

The fuel is U-235 and in the form UO_2F_2 . When this is dissolved in H_2O , fuel and moderator form a homogeneous solution.

To summarize then, the pertinent quantities to be used in these experiments are as follows:

Concentration of U-235 = 35.6 grams/liter of reactor

Height of active portion = 70 cm

Size of individual fuel tube = 1" x 1" x 35" long

Content of fuel tube $\approx$ 20.3 grams ^{235}U /tube

Al/ H_2O volume ratios attainable = 0.88, 0.76, 0.65, and 0.303

The actual pile geometries investigated so far have been with one exception cylindrical, with reflector on the cylinder and no reflector on top or bottom. The exception occurs in the case of Be reflector, where a square cross-section was more feasible.

These geometries are fairly easily studied from the theoretical point of view, and offer a good basis for comparison of theory and experiment, particularly in the cases of critical mass and spatial neutron distributions.

To use D_2O as reflector, it is necessary to provide two (2) tanks, one for reactor and the other for reflector. This would not be necessary were it not for the fact that firm precautions must be observed in protection of D_2O from contamination by H_2O via air exchange.

The arrangement finally employed is shown in Fig. 3, and the procedure in operation is the following. The first obvious requirement is that the reflector be in contact with the reactor at all times, irrespective of the size of the active volume. To accomplish this, (1) the reactor tank has a full complement of tubes at all times, (2) some tubes contain fuel and the rest contain D_2O , and (3) to fill the peripheral gaps caused by the imperfect fit of square tubes in a round tank, D_2O is introduced into the reactor tank to a height of 70 cm.

It will be observed that this arrangement has the undesirable feature that in general the portion of reflector nearest the pile contains appreciable Al. It turns out, however, that one can take account of this point in the theoretical calculations by considering the three regions separately and further discussion will be found later in this report.

The outer tank, containing the main body of D_2O reflector, is the same vessel which was used in the earlier work. It has been modified by the insertion of a false bottom approximately 70 cm below the overflow pipe, thus providing reflector along the active height of the reactor.

In all experiments the thickness of D_2O reflector has been 50 cm or greater.

All of the above statements relating to the D_2O experiment apply equally well to the arrangement and procedure used in the case of the H_2O reflector. The experiments in which H_2O was employed as reflector were carried out for two reasons: (1) the results should provide information regarding the effect of the water which will be present on top and bottom of the high flux pile, and (2) the study of a pile in which both the moderator and the reflector are the same substance is of considerable interest to theoreticians.

When Be was used for reflector, it turned out that with the square arrangement noted above the experiment was a bit "cleaner" in that it was possible to do away with the irregular region between reactor and reflector. This will be evident from Fig. 4.

The Be is in the form of 2" x 2" x 8" bricks, and the lay out, entailing considerable intricate brick laying, was designed so that if the critical size came close to either a nine (9) or eleven (11) fuel tube square, then a minimum of tubes containing D_2O would be necessary. It turned out that the Be-reflected pile became critical just four fuel tubes short of a nine tube square and the reactor was built out to completely fill this square geometry, the excess k being taken up by the insertion of a number of .030" diameter gold wires, distributed uniformly throughout the reactor. Plate I is a photograph looking down on the beryllium assembly.

The procedure then in all cases, in building up a pile, is that first the reactor volume is almost filled with D_2O tubes. Usually a relatively small number of fuel tubes, a quantity known definitely to be safe, is put in at the start.

Then to increase the fuel, a D_2O tube is removed and replaced by a fuel tube. At appropriate intervals, depending on the nearness to criticality, the control rods are withdrawn slowly one by one and the multiplication is observed via counting rates of the BF_3 counters. The reciprocal counting rate is plotted against mass of U-235 so that the nearness to criticality may be estimated in the usual way. These operations are repeated until criticality is reached.

Neutron distributions are measured by the use of Indium foils. The foil holders for use in the reactor tank are $1/8$ " Al strips, which are identical to, and replace, the $1/8$ " spacer strips mentioned earlier. Indium foils are placed in slots ($1" \times 9/16" \times .050"$) located 35 cm. from the bottom of the foil holder strips. A special holder device to suspend foils at known positions in the outer reflector tank was designed for the H_2O experiment. In the Be experiment a space of $1/16$ " between bricks was provided in one row of the assembly, in order to insert plexiglass foil holders similar to the Al strips described above. Vertical distributions were taken by the use of an Al strip having foil slots spaced at intervals of 5 cm.

Results and Discussion

Experiments which have been done to date consist of the following:

D_2O Reflector

1. Al/H_2O volume ratio = 0.88
  - a. Critical mass
  - b. Neutron Distributions, radial and vertical
  - c. Value of control rods, cavities, etc. in terms of fuel.
2. Al/H_2O ratio 0.76
  - a. Critical mass
  - b. Neutron distributions

Be Reflector

1. Al/H_2O ratio = 0.76
  - a. Critical mass
  - b. Neutron distributions
  - c. Value of Control rod.

H_2O Reflector

1. Al/H_2O ratio = 0.76
  - a. Critical Mass.
2. Al/H_2O ratio = 0.66

- a. Critical Mass
- b. Neutron distributions.

TABLE I
CRITICAL MASSES IN Kg. OF U-235

Reflector	Vol. Ratio Al/H ₂ O	Observed		Calculated	
		Gross	Corrected (for empty control rod ports, etc.)	2-group 2 region	3 region
D ₂ O	.88	2.48	2.40	2.10	2.64
D ₂ O	.76	2.23	2.15		2.43
Be	.76	1.54	1.42	1.54*	
H ₂ O	.76	3.29	3.22		3.34
H ₂ O	.66	2.82	2.72		3.04

The calculations of critical masses (by Greuling, Spinrad and Maskett) for D₂O reflector were made in two different ways. First, two group, two region calculations were made, and these yielded low figures. Then two group, three region calculations were made, the third region being that of the reflector adjacent to the reactor and containing appreciable Al. These calculations yielded figures in better agreement with experiment, but a bit higher than observed values.

For the Be reflector, a two group, two region calculation turned out to be in excellent agreement with experiment. The last column in Table I gives the calculated values.

The situation in spatial neutron distributions is somewhat different. Figure 5 and 6 contain both experimental and theoretical radial distributions. These distributions were measured at a height of 35 cm above the bottom of the pile.

---

* Where critical K = .988 x k of pile without poison

It will be noted that in general the observed densities of both thermal and epi-thermal neutrons in the reflector are somewhat greater than expected from a two group calculation. Data for the D_2O reflector are not at all complete, extending only a few centimeters into the reflector region, but for the Be reflector more detailed comparison is possible. The rise in thermal neutron density just outside the reactor is quite pronounced, the maximum experimental value being ~40% higher than the minimum, whereas this ratio - on a two group picture - is ~15%.

One might be tempted to conclude that Be exhibits advantages - as a reflector - which were unsuspected, but it seems probable that the experiment merely emphasizes known short-comings of a two group theory. A three group calculation has been made by Greuling and results are shown in Figure 6. The source or sources of the remaining discrepancy between theory and experiment are not yet clear. Age measurements in Be are now in progress at Argonne and the results should be helpful in the interpretation of these critical experiments. Figures 7 and 8 contain neutron distributions observed with H_2O reflector. Figure 7 is a linear plot showing a typical distribution in the reactor and adjacent reflector regions. A semi-logarithmic plot extending further into the reflector is shown in Figure 8. Rather good general agreement is noted with the results obtained at Los Alamos on a sub-critical assembly, see LA-241. It will be noted that the maximum in thermal neutron flux just outside the reactor is about 85% of that at the center of the reactor.

Calculations are not yet complete for H_2O reflector and no attempt will be made here to discuss diffusion, slowing down and other phenomena. It is expected that a report dealing with these items for all reflector cases will be issued soon.

Vertical neutron distributions have been studied also, and typical results will be found in Figure 9. It will be recalled that no reflector is present at top or bottom of the experimental pile, and the solid lines are cosine curves fitted to points near the center by least squares method. The slight lateral shift of the data from center is apparently due to the presence of a portion of a control rod in the top of the pile, or to the right in Figure 8. It is clear that the extrapolation distances for thermal and epi-thermal neutrons are the same, within

the experimental limits. A few rough measurements of the value of control rods have been made. These rods are of square cross-section, $3/4$ " on a side, composed of Cd sheet 0.020" thickness, covered with stainless steel 0.020" thick. The ports for these rods are merely empty square Al tubes similar to the fuel tubes, and Figures 3 and 4 show the disposition of control rods in the piles. In Fig. 3, the D_2O case, the center rod is found to be ≈ 220 grams of U-235, or approximately 11 fuel tubes and $\sim 1.7\%$ $\delta k/k$. The peripheral rods are ≈ 100 grams U-235 and $\sim 0.8\%$ $\delta k/k$.

In Fig. 4, the Be case, the rod near center is found ≈ 160 grams of U-235 or approximately 8 fuel tubes, and approximately 1.3% in $\delta k/k$.

The peripheral control rod ports, Fig. 3, amounting to cavities in the pile, are found to be equivalent to ~ 9 grams U-235 each, and a cavity - (empty tube) - approximately half way from the center to periphery ≈ 18 grams. On this basis the center cavity ≈ 35 grams.

Experiments are continuing on these and other arrangements of related interest.

Acknowledgements

A large amount of cooperative effort has gone into the general preparation for these experiments, and it is a pleasure to record that Mr. Weintritt and his design group, Messrs. Klemiski, Chadwell and Sibert and their shop groups are responsible for a well integrated job.

Messrs. Chrisney and Elliott of the Chemistry Division contributed long and careful effort in the preparation of the fuel solutions.

12

SECTION THROUGH ASSEMBLY & CONTROL ROOMS
FIGURE 1

CONTROL SYSTEM FOR CRITICAL EXPERIMENTS
SCHEMATIC & WIRING DIAGRAM

—FIGURE 2—

ASSEMBLY FOR
 D_2O REFLECTOR
FIG. 3

ASSEMBLY FOR
BERYLLIUM REFLECTOR

FIG. 4

—Fig. 5—

—Fig.6— 17

FIG. 7
RADIAL NEUTRON DISTRIBUTIONS
H₂O REFLECTOR

AL/H₂O (VOL) = 0.65

Fig. 9

Fig. 10