The determination of reactor parameters of the Montana State College sub-critical assembly
by Tushar Kumar Chowdhury

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Physics
Montana State University

Abstract:
This thesis is a report of the research, in which the infinite multiplication factor of the Montana State College natural uranium, water moderated subcritical assembly has been obtained both theoretically and experimentally. Theoretically the infinite multiplication factor has been calculated from the four-factor formula to which the simple diffusion theory has been applied. Experimentally the thermal utilization has been determined by the foil-activation method; two-mil-thick Indium foil has been used. The theoretically calculated value of the thermal utilization is (0.774) whereas the experimentally determined value is 0.780. The material and the geometrical bucklings have been determined experimentally with the scintillation counter and from these the infinite multiplication factor has been calculated to be (0.911). The simple diffusion theory yields (0.960) as the value of the infinite multiplication factor. Finally the effective multiplication factor has been found to be (0.814) and the subcritical multiplication is (5.38).

THE DETERMINATION OF REACTOR PARAMETERS OF THE MONTANA STATE COLLEGE SUB-CRITICAL ASSEMBLY

by

Tushar K. Chowdhury

A THESIS

Submitted to the Graduate Faculty

in

partial fulfillment of the requirements

for the degree of

Master of Science in Physics

at

Montana State College

Approved:

Head, Major Department

Chairman, Examining Committee

Dean, Graduate Division

Bozeman, Montana
May, 1961

ACKNOWLEDGMENT

This investigation was undertaken at the suggestion of Dr. Kurt Rothschild of the Department of Physics, Montana State College. I wish to express my sincere thanks and appreciation to him for his advice and constructive criticism throughout the course of this study. I also wish to acknowledge the typing help from Mrs. Charles Myrick and J. R. Desai.

TABLE OF CONTENTS

TABLE OF FIGURES

Abstract

This thesis is a report of the research, in which the infinite multiplication factor of the Montana State College natural uranium, water moderated subcritical assembly has been obtained both theoretically and experimentally. Theoretically the infinite multiplication factor has been calculated from the four-factor formula to which the simple diffusion theory has been applied. Experimentally the thermal utilization has been determined by the foil-activation method; two-mil-thick Indium foil has been used. The theoretically calculated value of the thermal utilization is (0.774) whereas the experimentally determined value is 0.780. The material and the geometrical bucklings have been determined experimentally with the scintillation counter and from these the infinite multiplication factor has been calculated to be (0.911). The simple diffusion theory yields (0.960) as the value of the infinite multiplication factor. Finally the effective multiplication factor has been found to be (0.814) and the subcritical multiplication is (5.38).

INTRODUCTION

Plutonium emits alpha-particles which interact with a light element such as beryllium to produce neutrons of 5 Mev or higher energy. The sub-critical reactor at Montana State College employs this type of poly-energetic Pu-Be source of neutrons. Such fast neutrons lose most of their kinetic energies as a result of elastic scattering with the nuclei of the material, called moderator, in which the source is embedded. After a number of scattering collisions, the energy of a neutron is reduced to $\sim$0.025 ev, which corresponds to the average kinetic energy of the atoms and molecules of the moderator. This energy is called thermal energy and the neutrons possessing it are called thermal neutrons. Neutrons with energies above thermal value (0.025 ev) are epithermal neutrons.

Uranium-nuclei (specifically U^{235}) have high interaction probability (i.e. high fission cross-section) for the thermal neutrons. The U^{235} nucleus absorbs a neutron and the resulting compound nucleus is so unstable that it either returns to the ground state by emission of a gamma-ray or breaks up into two parts emitting on the average 2.5 ± 0.1 neutrons of high energy (approximately 2 Mev). These fast neutrons are then slowed down in the moderator to thermal neutrons which then produce fission of some other U-nuclei. Thus the chain reaction continues.

In the Montana State College reactor, natural uranium (0.71 per cent U^{235}) and ordinary distilled water are the respective fuel and moderator.

The gamma-rays produced in interaction of neutron with nuclei induce some photofission and thereby help to maintain the chain reaction. However, their contribution to the chain-reacting system is less than one per cent (1).

Two essentially distinct physical phenomena are associated with the uranium-fission chain reaction. One covers the individual nuclear processes such as fission, neutron capture and neutron scattering; these are quantum-mechanical in character, and their theory is non-classical. The second one, which is the process of diffusion and leakage of neutrons, is of fundamental importance in a nuclear chain reaction. This process is classical. Insofar as the theory of neutron diffusion is concerned, the mathematical study of chain reactions is an application of classical, not quantum-mechanical technique.

In a heterogeneous thermal reactor, fission in the uranium lump produces fast neutrons. These neutrons then diffuse in accordance with the laws of diffusion theory until they are finally captured in the moderator, or in the uranium, or until they escape from the boundary.

If a reactor has exactly the critical size, each neutron produced by fission will, on the average, give rise to exactly one new fission, and the neutron density will remain constant. The ratio of the number of neutrons in one generation to that in the preceding generation is called the reproduction factor or the criticality factor "k" and for an exactly critical assembly, $k = 1$.

Critical reactors are designed in such a way that "k" can be made slightly larger than one. The reactor can then be made super-critical ($k>1$), just critical ($k=1$), or subcritical ($k<1$) by means of control rods. Since the Montana State College reactor can never become critical, it is called a subcritical reactor.

In this paper all calculations for the determination of the reactor parameters are based on classical theories. Here "one-group theory" is applied, i.e. it is assumed that all neutrons are generated, diffused, and absorbed at a single energy which corresponds to energy in the thermal region.

All theoretical calculations are made for the steady state.

DESCRIPTION OF THE SUBCRITICAL ASSEMBLY

Form and Composition: The assembly contains about 2300 kg of natural uranium in the form of ring-shaped cylindrical slugs clad with Al-Si alloy (density 2.79 gm/cm^3) immersed in about 500 gallons of distilled water. The fuel elements are distributed heterogeneously in the central part of the reactor, i.e., the reactor core. The horizontal cross-section of such distribution of the fuel tubes is shown in Figure 1 below.

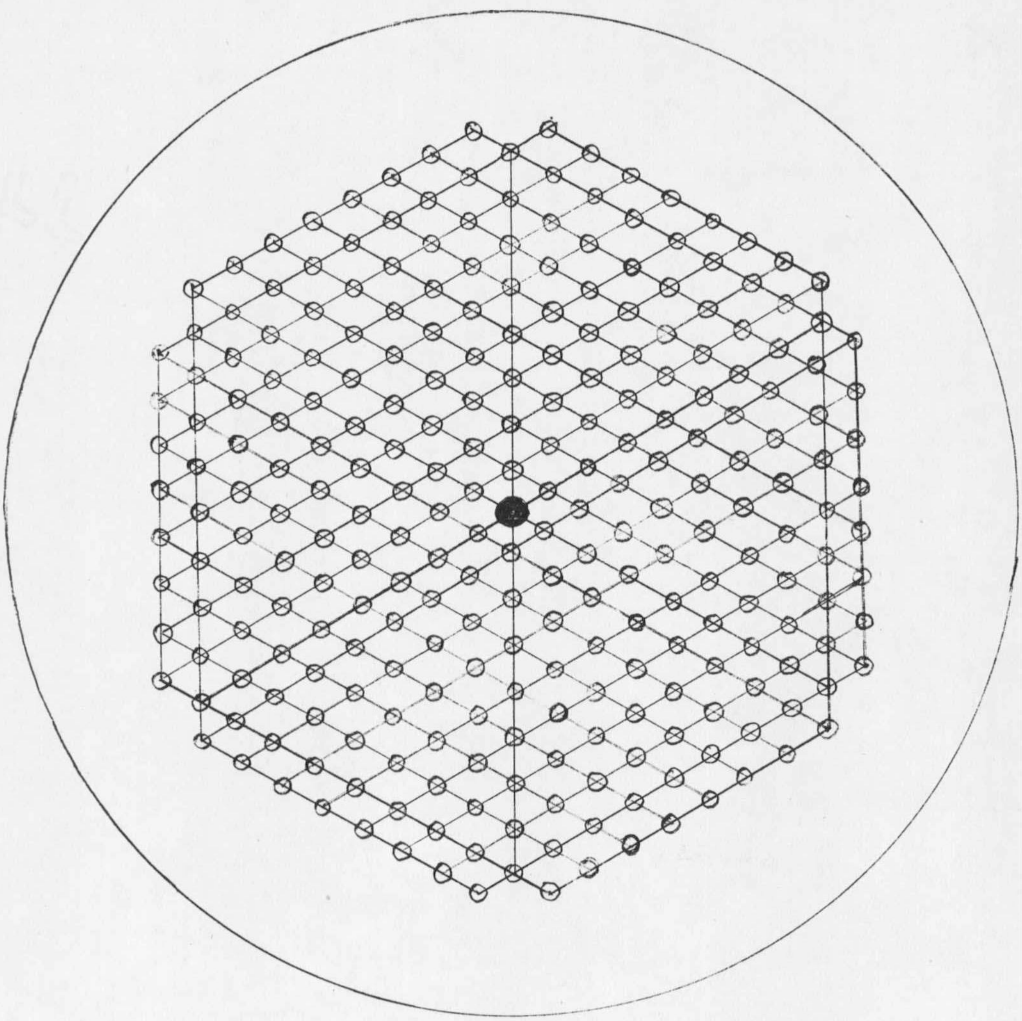

Figure 1. Horizontal Cross Section of the Assembly

The vertical section of the assembly is shown in Figure 2. This assembly contains 264 aluminum tubes each holding 5 uranium slugs. The average dimensions of a slug are given below:

Outside diameter of the aluminum-clad slug, D_1 = 2.90 cm.

Inside diameter of the aluminum-clad slug, D_2 = 0.98 cm.

Length = 20.56 cm

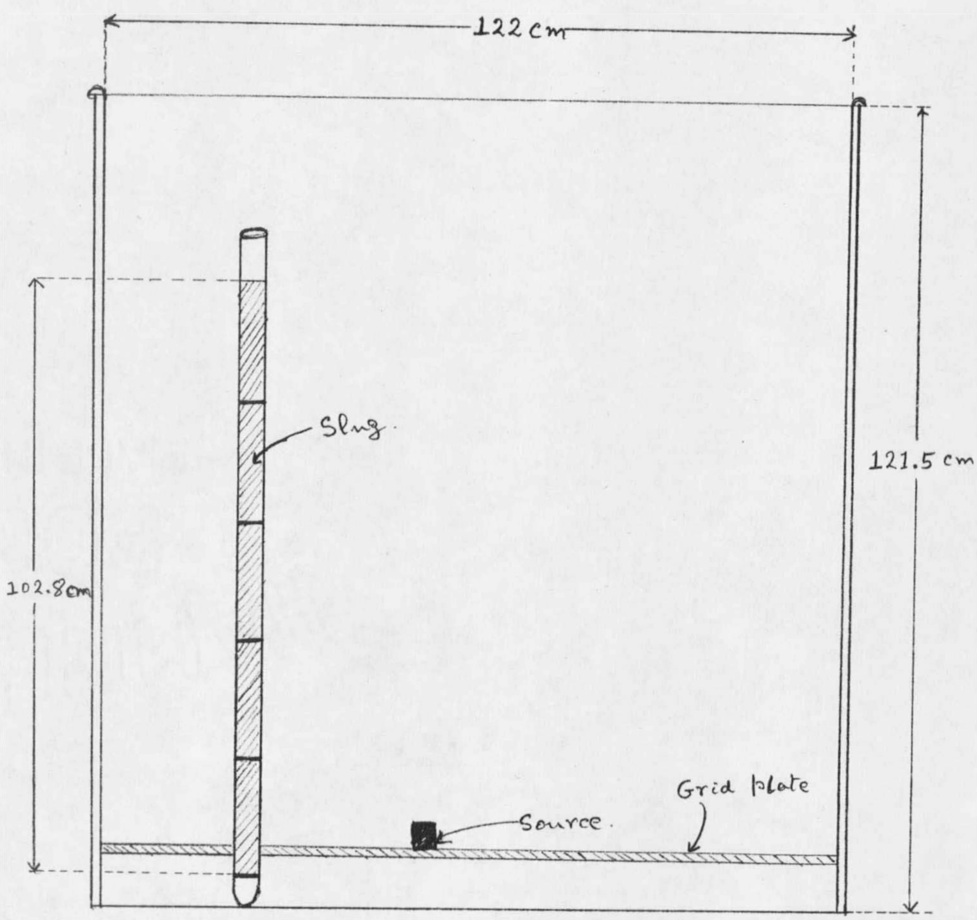

Figure 2. Vertical Section of the Assembly