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CRITICAL MASS CALCULATION

FOR

APPR-1 CRITICAL EXPERIMENT

by

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I. INTRODUCTION

In order to check previous calculations, and to provide a tool for future analytical work on APPR type reactors, a calculation to predict the critical mass of the APPR critical experiment[1] has been performed. The particular cases investigated were for the cold, unpoisoned critical assembly, with and without the stainless steel end boxes. The inclusion of the end boxes changed the axial reflector from water to 60% water and 40% stainless steel. An infinite radial reflector was assumed at all times. The critical mass was found to be 8.68 ± .02 Kg of U^{235} in both cases.

II. GENERAL METHOD

The basic two group method for cylindrical geometry, described in WAPD-RM-167[2] was used, with modifications to allow absorption and fissioning in the fast group. The modified diffusion equations for the core were written as:

$$D_f \nabla^2 \phi_f - \Sigma_f \phi_f + (1-P^{th}) K_f \Sigma_f \phi_f + K_s \Sigma_s \phi_s = 0$$

$$D_s \nabla^2 \phi_s - \Sigma_s \phi_s + P^{th} \Sigma_f \phi_f = 0$$

A self-shielding factor was included to account for the thermal flux depression in the uranium foil. The effect of flux hardening within the fuel was investigated, using a multigroup model and was found to be insignificant.

The critical mass was computed first using an infinite radial reflector, and an assumed axial reflector savings. From this calculation a radial reflector savings was determined and used to solve the axially reflected case. A new axial reflector savings found by this second calculation was used to solve the radial case again, and the procedure was repeated until the same critical mass was calculated for both the axially and radially reflected cases.

Before considering the APPR critical assembly, an attempt was made to check a stainless steel-water critical experiment performed at Argonne National Laboratory[3]. A critical mass of 7.8 Kg was calculated, compared to the experimental value of 8.087 Kg. This agreement was considered good for the method of calculation, and may be fortuitous in light of the fact that the Argonne critical experiment seemed to have a large percent of epithermal fissions, and the geometry of the assembly made the assumption of homogeneity erroneous.

III. THE EVALUATION OF CONSTANTS

The core of the APPR critical assembly was assumed to be a homogeneous cylinder of radius 28.19 cm and 55.89 cm high, with 79.6 volume percent of water and 20.4 volume percent of stainless steel[1]. The addition of fuel caused a negligible change in these concentrations. Nuclear constants were evaluated at 68° F., and determined from cross sections data found in AECU-2040, BNL-250 and the Reactor Handbook Vol. 1. The methods of finding group constants were generally the same as in ORNL-1613,[4] although with some variations. Included here are only those constants whose method of determination was different from that in ORNL-1613.

A. FERMI-AGE

The Fermi-Age in water, of 31.4 cm was used. For the core and stainless steel-water end reflector, data were taken from NACA-RM/E54H04[5], adjusted to the age of fission neutrons to thermal energy. (See Fig. 1). Inelastic scattering in iron is accounted for automatically by using experimental values of the age in iron-water mixtures.

B. FAST DIFFUSION LENGTH

$$D_f = \frac{\int_{u=0}^{u=19.8} \frac{\phi(u)}{3\left[V^{SS}\Sigma_{tr}^{SS} + V^{H_2O}\Sigma_{tr}^{H_2O}\right]}\, du}{\int_{u=0}^{u=19.8} \phi(u)\, du}$$

Where $\phi_p(u)$ is calculated as a proton moderated flux. (See Fig. 2).

C. RESONANCE ESCAPE PROBABILITY

$$P^{th} = \exp\left[-\int_{u=10}^{u=19.8} \frac{\left(V^{U}\Sigma_a^{U} + V^{SS}\Sigma_a^{SS}\right)}{\bar{\xi}\left(V^{H}\Sigma_s^{H} + V^{U}\Sigma_a^{U} + V^{SS}\Sigma_a^{SS}\right)}\, du\right]$$

Since essentially all moderation was achieved by water, the assumption $\bar{\xi} \simeq \xi^{H} = 1$ was made.

D. FAST MULTIPLICATION

$$K_f = \frac{\nu \int_{u=10}^{u=19.8} V^{U}\Sigma_f^{U}\, \phi(u)\, du}{\int_{u=10}^{u=19.8} \left(V^{U}\Sigma_a^{U} + V^{SS}\Sigma_a^{SS}\right) \phi(u)\, du}$$

To find P^{th} and K_f, numerical integration was employed using lethargy increments of $u = .2$. Cross sections for U^{235} and U^{238} were found in BNL-250. Stainless steel was assumed to have a $\frac{1}{V}$ absorption cross section. The scattering cross section of hydrogen in water was taken from RH Vol. 1[6]. The fast neutron flux from lethargy 10 to lethargy 19.8 was considered to be constant, as found from the calculation of a proton moderated fission neutron source.

The values of the constants are listed in Table I.

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TABLE I

CONSTANTS USED AT 8.68 Kg

CONSTANT	CORE	H_2O REFLECTOR	REFLECTOR W/END BOX
D_f	1.21 cm	1.37 cm	1.11 cm
τ	36 cm^2	31.4 cm^2	40.5 cm^2
Σ_f	.0336 cm^{-1}	.0436 cm^{-1}	.0274 cm^{-1}
K_f	1.270	-	-
P^{th}	.803	-	-
D_s	.1805 cm	.1588 cm	.2082 cm
L_s^2	1.194 cm^2	8.12 cm^2	2.10
Σ_s	.1512 cm^{-1}	.01955	.0991
K_s	1.253	-	-

Note: Subscripts f and s refer to the fast and thermal group.

IV. RESULTS

The results of these calculations give an estimated critical mass of 8.68 Kg, somewhat larger than those predicted in ORNL-1613[4], and Supplement 1[7], for the cold, clean APPR-1 core. The value used for K_f in this calculation is smaller than those plotted in ORNL-1613, due to the inclusion of a $\frac{1}{V}$ stainless steel absorption cross section in the determination of K_f. There may be some question as to the validity of the assumption that $\bar{\xi} \simeq \xi^H = 1$ in the calculation of P^{th}, but it was felt that the error introduced by this assumption would be small.

Included are radial and axial plots of the fast and thermal flux (Figs. 3 & 4), indicating the normal peak in the thermal flux in the reflector.

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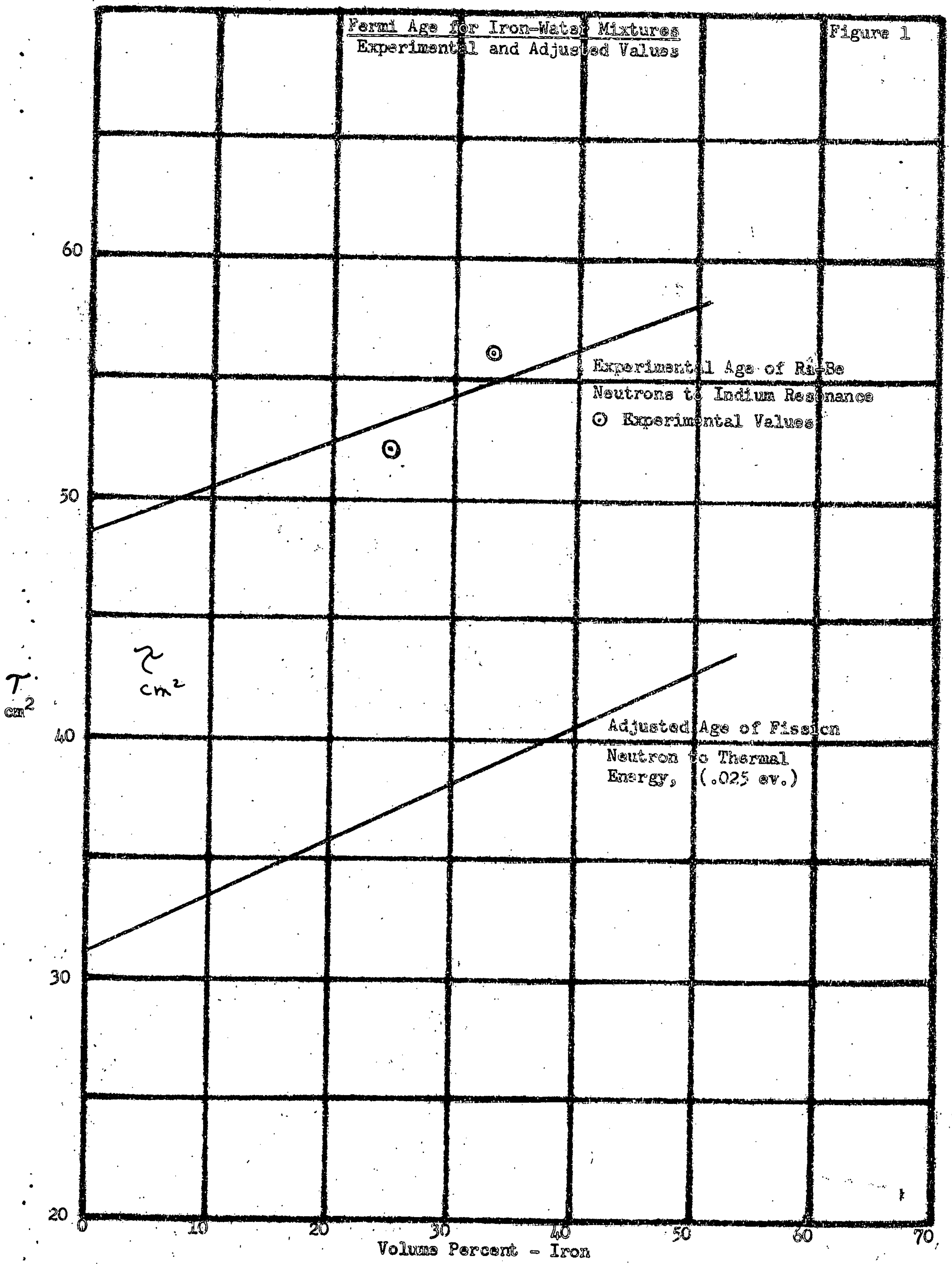
Fermi Age for Iron-Water Mixtures
Experimental and Adjusted Values
Figure 1
Experimental Age of Ra-Be
Neutrons to Indium Resonance
⊙ Experimental Values
Adjusted Age of Fission
Neutron to Thermal
Energy, (.025 ev.)
τ
cm²
20
30
40
50
60
0
10
20
30
40
50
60
70
Volume Percent - Iron

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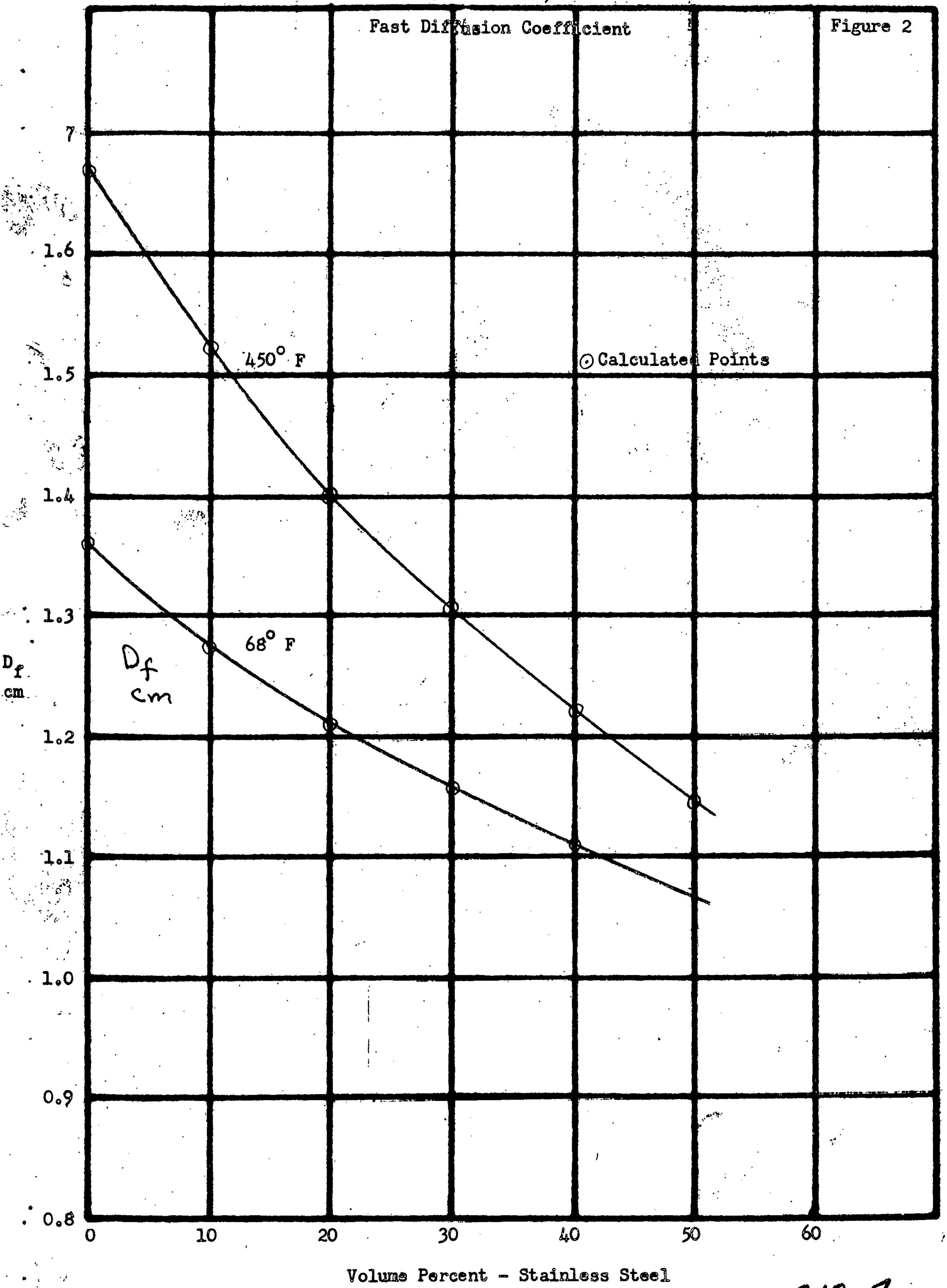
Fast Diffusion Coefficient
Figure 2
450° F
68° F
Calculated Points
D_f
cm
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
7
0
10
20
30
40
50
60
Volume Percent - Stainless Steel

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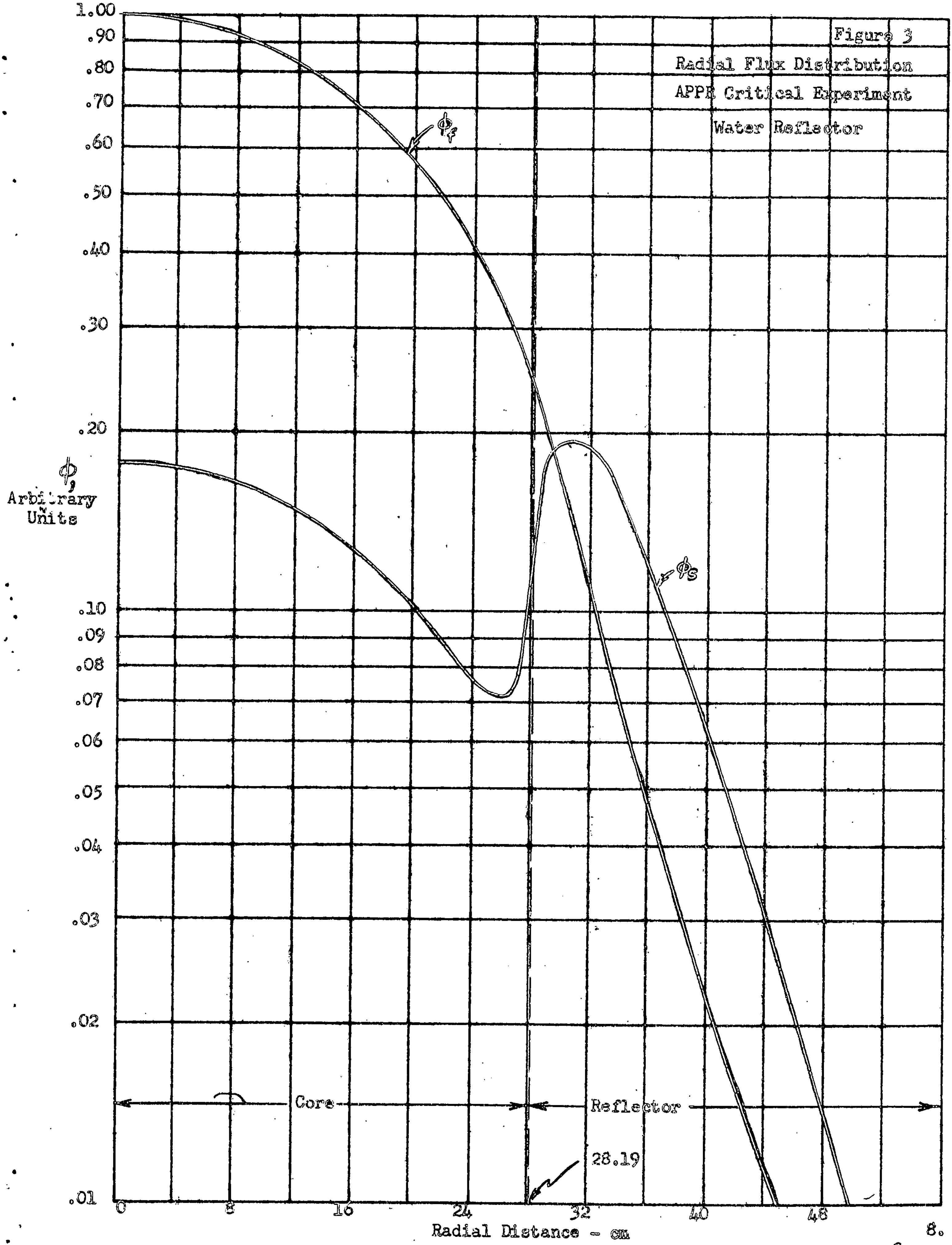
Figure 3
Radial Flux Distribution
APPR Critical Experiment
Water Reflector
φ, Arbitrary Units
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
ϕ_f
ϕ_s
Core
Reflector
28.19
0
8
16
24
32
40
48
Radial Distance - cm

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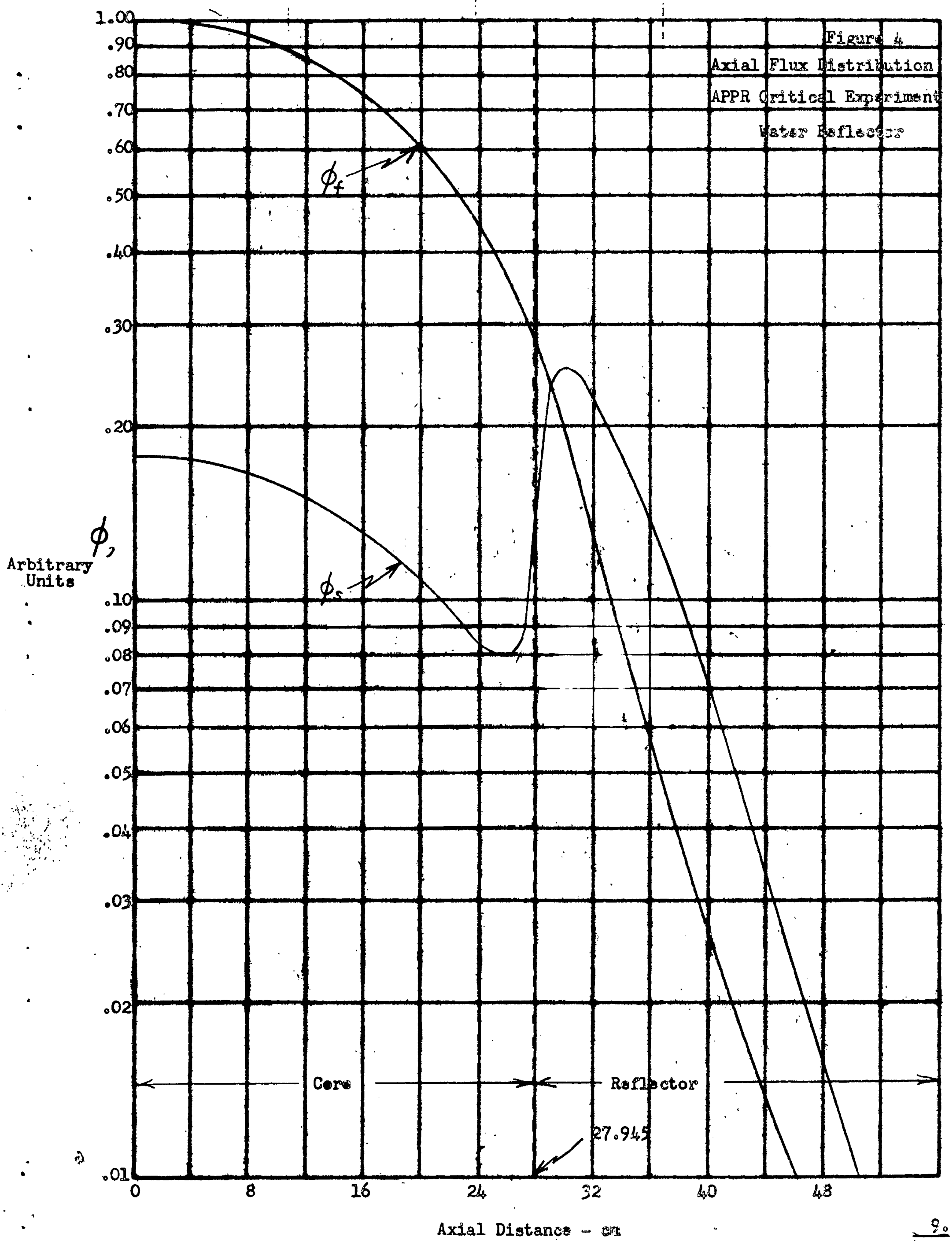

Figure 4
Axial Flux Distribution
APPR Critical Experiment
Water Reflector
ϕ_f
ϕ_s
ϕ,
Arbitrary Units
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
Core
Reflector
27.945
0
8
16
24
32
40
48
Axial Distance - cm

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