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SUBJECT: ABSOLUTE MEASUREMENT OF ETA BY THE MANGANESE BATH TECHNIQUE

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FROM: G. deSaussure and R. L. Macklin

ABSTRACT

This is a short description of an experiment, now in progress, to measure η of U^{233}, and an estimate of the various errors involved in the experiment. It seems that a value for η can be obtained with a precision of 1% or better.

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DISCLAIMER

An experiment is in progress to measure the absolute value of eta of U^{233} by a manganese bath technique. It is hoped to obtain the absolute value of η with an accuracy of 1% or better. Below is a short description of the method and an estimate of the errors involved.

Any suggestions to improve the experiment, the calculation of the corrections or for inclusion of more corrections will be welcomed.

Description of the Method and of the Apparatus

The apparatus consists mainly of a 60-in.-long collimator, one end of which is against the Bulk Shielding Reactor, the other end in the middle of a 42-in. I.D. sphere filled with a 100 gm/liter $MnSO_4$ solution in water. By measuring the ratio of the activation of the manganese in the bath when a U^{233} sample is in the center of the sphere to the manganese activation when there is no sample, a value is obtained for η. A sketch of the experiment is attached. Engineering designs have been printed under Q-2027.

The method consists of measuring the ratios R_i of the specific activity of the manganese bath to the activity of the manganese monitor foil for the four following situations:

1. The sample is placed in the center of the manganese bath with the uranium foil facing the beam. (See detail of sample on Fig. 1.)

2. The sample is placed in the center of the bath with the cadmium foil facing the beam.

3. No sample in the center of the bath.

4. A cadmium foil is placed in the center of the bath, in the sample position.

Eta is then obtained, except for small corrections, by the following ratio:

$$(1) \qquad \eta_{\text{sub Cd}} = \frac{R_1 - R_2}{R_3 - R_4}$$

Nine corrections to Eq. (1) have been considered, they are discussed below.

Corrections

1. Self-Multiplication

For each thermal neutron absorbed in uranium, η fission neutrons are produced, before those neutrons escape the uranium foil they may produce further fast fissions, the apparent increase of η can be estimated as:

$$(2) \qquad 1 + (\eta_{\text{fast}} - 1)\, \Sigma_a^{\text{fast}} \cdot 2s(1 + e^{-\Sigma s}) \simeq 1.03 \pm .002$$

where

$\Sigma_a^{\text{fast}} = .11\ \text{cm}^{-1}$ is the macroscopic absorption cross section of uranium for fission neutrons,

$\eta_{\text{fast}} = 2.76$ is the number of secondary neutrons produced by a fast fission,

$\Sigma = 28.14\ \text{cm}^{-1}$ is the macroscopic absorption cross section of uranium for sub-Cd neutrons,

s = .025 in. is the thickness of one uranium foil.

In Eq. (2) those neutrons produced by fast fissions in one side of the sample due to fission neutrons originating in the other side have been neglected, the solid angle under which one side sees the other, being small. The numerical value given for Eq. (2) and its error were computed by L. Dresner with a more refined calculation.

2. Transmission

Some fraction of the "thermal" neutron beam traverses the three .025-in.-thick uranium foils and is subsequently absorbed in the .020-in. cadmium foil. Those neutrons will not produce η secondaries. The apparent decrease of η can be estimated as

$$1 - e^{-3\Sigma s} = .9953 \pm .0005 \tag{3}$$

where the symbols have the same meaning as above; the 10% uncertainty in the calculation of the transmission is based upon an estimate of the uncertainty in the thickness of the foils, the cross sections, etc.

3. Scattering

Some thermal neutrons may be scattered out of the uranium sample before being absorbed. Most of those "scattered-out neutrons" will come from the first .025-in. foil. The apparent decrease of η caused by this effect can be estimated as:

$$1 - (\eta - 1)\frac{\Sigma_s}{2}\int_0^s e^{-\Sigma_a x}\left\{E_2\left[\Sigma_a x\right] + E_2\left[\Sigma_a(s - x)\right]\right\} dx = .9976 \pm .0012 \tag{4}$$

where

Σ_s = .48 cm^{-1} is the macroscopic scattering cross-section of uranium,

$E_2(x)$ = is a function tabulated by Case, deHoffmann and Placzek (p. 17 and 155, Introduction to the Theory of Neutron Diffusion, Vol I, 1953.)

In Eq. (4) the scattering is assumed isotropic. The 50% error estimated in this evaluation of the scattering correction accounts for the isotropic scattering assumption and the neglect of the scattering effect for those neutrons transmitted through the first .025-in. uranium foil.

4. Resonance Absorption in $MnSO_4$

Implicit in this method for measuring η is the assumption that fission neutrons and thermal neutrons will activate the manganese in the manganese bath in the same way. This is not quite true since the ratio of absorption in manganese to absorption in the other constitutents of the bath is not the same at thermal energies and at resonance energies. The apparent decrease of η due to this effect can be estimated as:

$$(5) \qquad 1 - \frac{\Sigma^H \left(\frac{I^{Mn}}{\sigma^{Mn}} - \frac{I^H}{\sigma^H} \right) + \Sigma^S \left(\frac{I^{Mn}}{\sigma^{Mn}} - \frac{I^S}{\sigma^S} \right)}{\Sigma_s} = .9947 \pm .0005$$

where

Σ^H = .0221 cm^{-1} is the macroscopic thermal absorption cross section of hydrogen in the manganese bath,

Σ^S = .0002 cm^{-1} is the macroscopic thermal absorption cross section of sulphur in the manganese bath,

Σ_s = 1.53 cm^{-1} is the macroscopic scattering cross section of the manganese bath,

$\frac{I^{Mn}}{\sigma^{Mn}}$ = .81 ± .08 is the ratio of the resonance absorption I^{Mn} = 10.8 b to the thermal cross section σ^{Mn} = 13.3 b for manganese,

$\frac{I^{H}}{\sigma^{H}}$ = .44 ± .005 and $\frac{I^{S}}{\sigma^{S}}$ = 1.1 ± .1 are the same ratios for hydrogen and sulphur respectively.

5. Parasitic Absorption

The fraction of neutrons absorbed in structural materials is not the same for thermal neutrons and fission neutrons. The fraction of thermal neutrons absorbed in the magnesium wall upon which they are impinging can be estimated as:

$$\frac{\Sigma_a^{Mg}\, t}{\Sigma_a L} = (2.0 \pm .2)\ 10^{-3} \qquad (6)$$

where

Σ_a^{Mg} = .0019 ± .0001 cm^{-1} is the macroscopic absorption cross section of the magnesium wall (measured at the pile oscillator),

t = .030 in. is the thickness of the magnesium wall,

Σ_a = .0276 cm^{-1} is the macroscopic absorption cross section of the manganese bath,

L = 2.577 cm, its diffusion length.

The fraction of fission neutrons absorbed in the magnesium wall after they have slowed down to thermal energy can be estimated as:

(7) $$\Sigma_a^{Mg}\, t \cdot 4\pi\, a_1^2\, \phi = (1.7 \pm .9)\, 10^{-4}$$

where

a_1 = 3 in. is the radius of the magnesium sphere,

$4\pi\, a_1^2\, \phi$ = 1.16 is the total flux per fission neutron (here calculated by formula 5.5a3.2 p. 103 of MT-12* assuming a point fission source in the center of the sphere.)

The parasitic absorption, since it is not the same for fission and thermal neutrons produces an apparent increase of η by the amount

(8) $$\frac{1 - 1.7 \times 10^{-4}}{1 - 2 \times 10^{-3}} = 1.0018 \pm .0002$$

6. Indirect Multiplication

Some fission neutrons, after slowing down in the manganese bath may still be captured in the fissionable sample and produce further multiplication. This effect will cause an apparent increase in η estimated as:

(9) $$1 + 4\pi\, a_1^2\, \phi \left(\frac{D_a}{4a_1}\right)^2 \left\{\frac{1}{2}\left(\frac{1}{2}\,\eta - 1\right) + (\eta - 1)\,\frac{h}{a_1}\right\} \simeq 1.009 \pm .001$$

where

$D_a \simeq$ 1.5 in. is the diameter of the sample discs,

$h \simeq$ 1 in. is the length of the sample (separation between front foil and back foil).

The other symbols are defined under Eq. (7).

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*"Elementary Approximations in the Theory of Neutron Diffusion," by P. R. Wallace, and J. LeCaine.

Since the outside faces of the samples are covered, one with cadmium, the other with uranium, and since they are symmetrical, for each neutron impinging upon those faces, $\frac{1}{2}\eta$ new fission neutrons will be produced. The inside faces of the sample are weighted by a solid angle factor of the order of $\frac{b}{a_1}$. The calculation above is very preliminary and could be much improved. The uncertainty of 10% given in Eq. (9) was estimated on the basis of the internal consistency between various more sophisticated calculations of this effect performed by A. M. Perry, P. Kasten, E. Halbert, S. Jaye and others, on a similar geometry.

7. Fast Leakage

Because of the finite radius of the manganese bath some fission neutrons will leak out. This will cause an apparent reduction of η estimated as:

$$1 - P_{nc}(R - a_1) - P_G(R - a_1) \simeq .992 \pm .002 \tag{10}$$

where

R = 21 in. is the radius of the sphere containing the manganese bath,

P_{nc} = is the probability for a fission neutron to escape on its first flight path and,

P_G = the escape probability for a collided neutron.

The estimate above is the average of various preliminary code calculations performed by A. M. Perry, P. Kasten, E. Halbert, S. Jaye, et al.

8. Duct Streaming

Some fast neutrons may leak out of the manganese bath through the

collimator. The apparent decrease in η due to this effect is

$$(11) \qquad 1 - \frac{1}{16}\left(\frac{D}{R}\right)^2 = .9998 \pm .0003$$

where

D = 1.25 in. is the diameter of the collimator,

R = 21 in. is the radius in the outside sphere.

9. Impurities

a. Isotopic Impurities

Neutrons absorbed in U^{235} and U^{234} tend to reduce the apparent value of η. The effect can be estimated as:

$$1 - \frac{\eta^{23} - \eta^{25}}{\eta^{23}} \frac{\sigma_a^{25} N^{25}}{\sigma_a^{23} N^{23}} \frac{\sigma_a^{24} N^{24}}{\sigma_a^{23} N^{23}} \simeq 1 - .11 \frac{N^{25}}{N^{23}} - .17 \frac{N^{24}}{N^{23}}$$

The effect of other uranium isotopes is negligible since their microscopic cross sections are small compared to σ_a^{23}.

b. Chemical Impurities

Neutrons absorbed in non-fissionable material contribute to an apparent reduction of η estimated as:

$$1 - \Sigma_a \frac{233}{A} \frac{\sigma^A}{\sigma^{23}} \frac{\rho^A}{\rho^{23}} = 1 - .4\, \Sigma_a\, \mu^A \frac{\sigma^A}{A}$$

where

$\mu^A = \frac{\rho^A}{\rho^{23}}$ and σ^A is, in barns, the thermal absorption cross section of element A of atomic weight A.

Gd, for instance, has $\frac{\sigma^A}{A}$ = 300 b, thus 8 ppm of Gd in the U^{233} foil would decrease η by .1%.

Specifications on the chemical purity of the uranium foils have been set so as to allow the decrease of η due to absorption of neutrons in chemical impurities to be calculated with a precision of .1%.

The corrections listed above have been very roughly estimated, a more accurate calculation is possible in most cases. Even so they amount to a $1.019 \pm .004$ total correction. (The error quoted is the square root of the sum of the squares of the errors.)

The description of the counting technique has been left out of this note. This item is not found to involve unavoidable uncertainties greater than those in the corrections considered above.

A. M. Perry will compute the ratio $\eta_{\text{sub Cd}}/\eta_{2200\ \text{m/sec}}$. This ratio can probably be calculated with a precision of .5% even considering the lack of information on the neutron spectrum a few inches away from a reactor face.

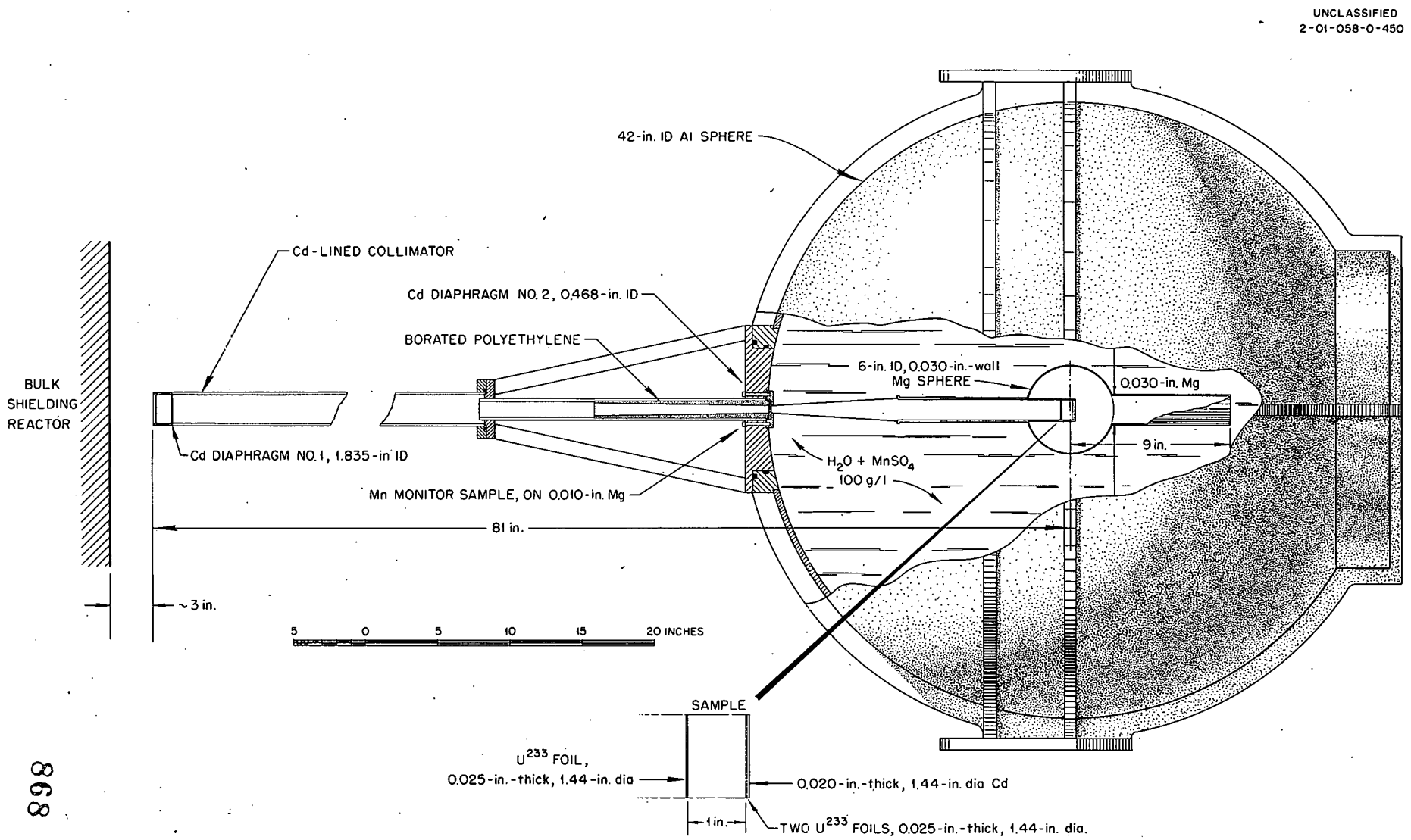

Fig. 1. Experimental Arrangement for Measurement of Eta of U^{233}.

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