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PHYSICS DIVISION PROGRESS REPORT

SHIELDING

E P Blizard J L Meem

The lid tank facility has been used in the submarine program primarily for solving design problems that were not amenable to calculation For the submarine intermediate reactor (SIR) the main interest was focused on secondary gamma ray production within the shield and experimental evidence proved that the large quantities of boron carbide originally called for were not necessary As a consequence considerable saving in time and money has been effected

For the submarine thermal reactor (STR) assistance was rendered in designing a plug to be installed in the shield so that control instruments would respond to the instantaneous reactor power instead of being affected by the decay gamma rays that are of course a function of the previous power history

Experiments dealing with air ducts through shields are being carried out expressly for the ANP Division of the General Electric Company and will be described in the next ANP quarterly progress report

The bulk shielding facility group is expending most of its effort on the measurement of gamma ray and neutron spectra and angular distributions The studies will be sufficiently complete to enable detailed calculation of the air scattering for aircraft divided shields Unfortunately the process of measurement and calculation appears to be too cumbersome for use in very many configurations

LID TANK FACILITY

C E Clifford

J D Flynn J M Miller
T V Blosser M C Marney
F N Watson M K Hullings
G T Chapman L S Abbott

Submarine Intermediate Reactor Mockup Tests
At the request of KAPL measurements were taken in the lid tank facility on mockups of various portions of the SIR shield to determine several iron water and boron carbide configurations that would satisfy the various shielding and engineering requirements The SIR shield is divided into three sections The primary shield is immediately adjacent to the reactor and is designed primarily to prevent activation and radiation damage of power plant components between the reactor and the secondary shield The secondary shield is a low temperature shield and is a simple combination of lead and either water or diesel oil The top plug is a removable section that fits on top of the reactor and must be free to rotate for fuel handling during shutdown The three sections are shown in Fig 1 Preliminary measurements on the primary shield have been given[1] and the entire SIR series of tests has been reported in detail [2]

To ensure a realistic mockup of the SIR shield a large beryllium slab was supplied by KAPL to simulate the reflector that precedes the shield The design of the primary shield was specified by consideration of the allowable neutron and gamma dose in the reactor compartment The predicted gamma dose was to be some fraction of the calculated dose resulting from the activated sodium coolant present in the compartment and the neutron level was set primarily by consideration of the induced activity of oxygen and impurities in the water that circulates between the reactor sodium water boiler and the steam turbines located beyond the shield The dose in the submarine shield was obtained from lid tank experiments and a calculation of a scale up factor by the G E group based on a comparison of the geometry and power of the lid tank facility source with that of the submarine reactor

After the final design of the primary shield was established measurements were made beyond the primary shield and a part of the secondary shield

[1] C E Clifford *et al* *Phys Div Quar Prog Rep Dec 20 1951* ORNL 1216 p 1

[2] C E Clifford *et al* ORNL CF 52 5 1 Parts 1 11

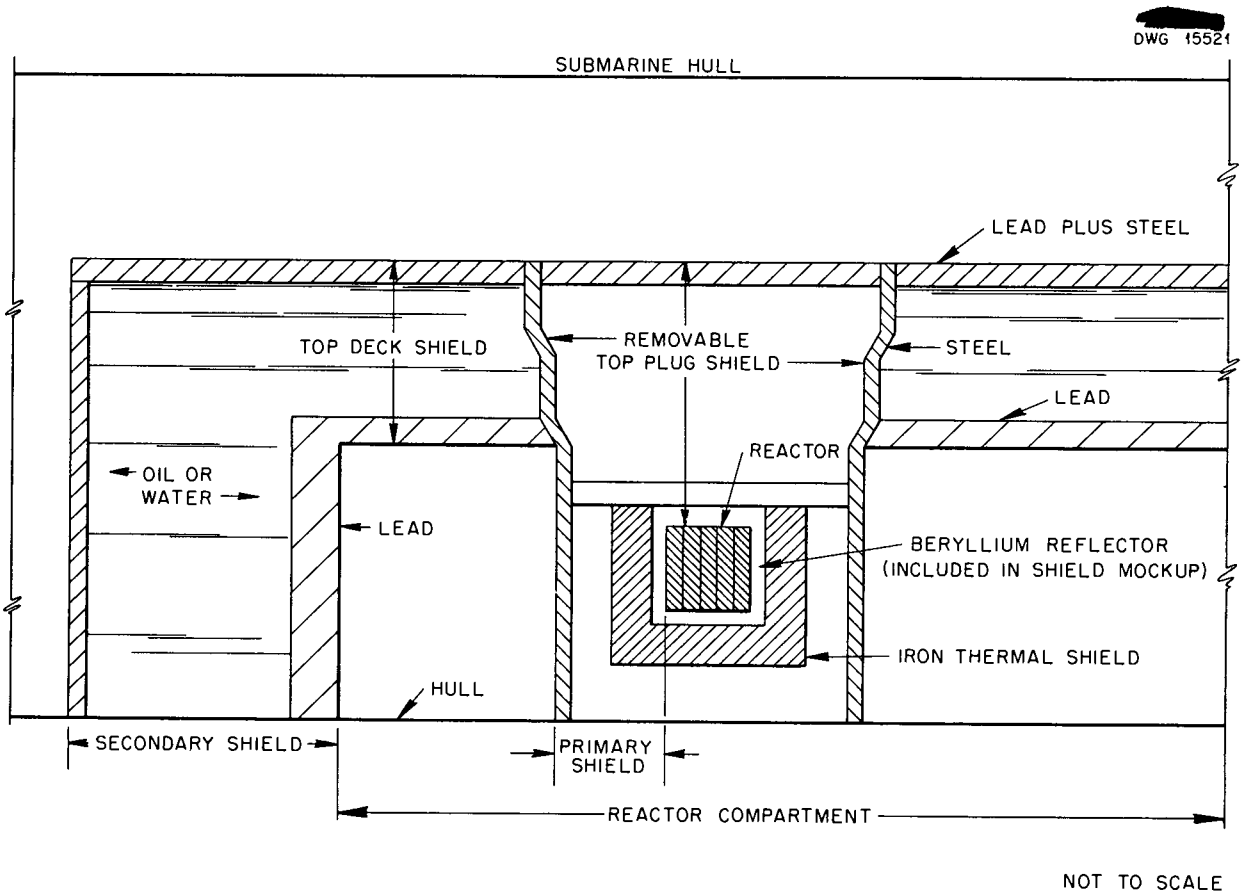

Fig 1 Schematic Drawing of SIR Shield Vertical Section

(iron lead, and water) Also neutron and gamma dosage distributions beyond the secondary shield were measured as a function of the water thickness in the primary shield in order to estimate the contribution to the total dose by capture gammas produced within the top deck shield The configurations were chosen to enhance the capture gamma production in the top deck by reducing the water layer in the primary shield stepwise to essentially zero thickness

Information obtained from the experiments on two earlier top plug mockups and further engineering study formed the basis for measurments on a final mockup in which the boron carbide layer was reduced in thickness and replaced with solid iron in the inner regions

The design of the removable top plug of the SIR shield necessarily incorporated rather massive structural members of solid steel that penetrated straight through the shield and thus allowed a leakage path for intermediate energy neutrons In order to determine the extent of the leakage problem a partial mockup of the worst case was installed in the lid tank facility The results of the test were not encouraging Only 13 in of perforation represented by the presence of a solid steel layer increased the emerging flux by an order of magnitude over that for the unperforated shield

Submarine Thermal Reactor Control Plug Mockup Measurements A short experiment has been completed in the lid tank facility in which measurements that were intended to aid in the design of control instrument plugs for the STR were made The plug was designed to increase the local thermal neutron flux in the water beyond the pressure shell This was accomplished by penetrating the 18 cm water reflector and the steel

and water thermal shield with an 8 in dia steel pipe that was filled with lead steel or air The measurements were compared with those of the unperforated shield

The thermal shield and plugs for the mockup were supplied by Westinghouse and the pressure shell was simulated by the use of seven 2 22 cm iron slabs Neutron measurements were taken in the water along the axis of the plug (Fig 2) and along a line perpendicular to and intersecting the plug axis (Fig 3)

Gamma measurements (Fig 4) were taken only beyond the air filled plug This was to aid in determining additional local heating in the pressure shell resulting from the penetration of gamma rays through the void in the thermal shield It is evident from the gamma measurements that neutron induced secondary gamma rays are predominant in determining the attenuation rate of the pressure shell since the apparent relaxation length is continually increasing and is longer than the usual 4 2 cm that would be observed in the absence of neutrons A cross section of the ion chamber used for the gamma measurements is given in Fig 5 The chamber was mounted vertically in the tank and the distance from the source z was measured to the center line of the chamber Therefore it was impossible to make measurements closer than 7 5 cm from the back of the shield

BULK SHIELDING REACTOR

J L Meem

R G Cochran	E B Johnson
M P Haydon	J K Leslie
K M Henry	F C Maienschein
L B Holland	G M McCammon
H E Hungerford	T N Roseberry

Shielding Experiments The experiments on the divided shield mockup are continuing The first part of the gamma ray spectral measurements has been reported by Maienschein[3] and is discussed in the ANP quarterly progress report[4] Upon conclusion of the gamma ray spectral measurements the fast neutron spectra will be measured with the spectrometer described below

A rough experiment to determine the air scattering of neutrons and gamma rays from the sides of the reactor shield into the sides of the crew shield has been performed The water in the pool was lowered to within a few feet of the top of the reactor, and neutron and gamma dosage measurements were made at a distance of about 15 ft from the reactor as the detectors were lowered into the water to simulate a variable thickness crew shield side wall The results of the experiment have been reported by Meem and Hungerford[5]

Fast Neutron Spectroscopy (R G Cochran) Considerable work has been done on the proton recoil neutron spectrometer at the bulk shielding facility Several parts of the electronic equipment have been redesigned especially the coincidence circuit The design changes in the coincidence circuit have increased the stability of the instrument considerably It is now possible to repeat a spectrum to within the statistical fluctuation expected from the counting rate as was indicated by the rerunning of the spectrum of the polonium beryllium source (PB 236) several times (Fig 6) Therefore the spectrometer is considered sufficiently stable to measure the neutron spectra needed in shielding design

Since the proton recoil neutron spectrometer is now functioning properly the spectra of several neutron sources have been measured Figure 7 shows the spectrum of a polonium boron source borrowed from the Health Physics Division Figure 8 shows the spectrum of a 1 curie radium boron source used for instrument calibration The yield from the source is small therefore the statistics are quite poor However the experiment indicated that a spectrum could be measured in at least an 80 r/hr gamma ray field Figure 9 shows the spectrum of the polonium beryllium source used to calibrate the bulk shielding facility fast neutron dosimeter The source has decayed through several half lives and at present is only of 1 curie strength Better statistics could have been obtained with longer counting periods but the interest in the spectra would not have justified the time required Consequently only a few hours were spent measuring each spectrum The

(3) F C Maienschein *Gamma Ray Spectral Measurements with the Divided Shield Mockup* ORNL CF 52 3 1 (March 3 1952)

(4) J L Meem *et al* *ANP Quar Prog Rep Mar 10 1952* ORNL 1227 p 73

(5) J L Meem and H E Hungerford *Air Scattering Experiments at the Bulk Shielding Facility (Preliminary Issue)* ORNL CF 52 7 37 (July 8 1952)

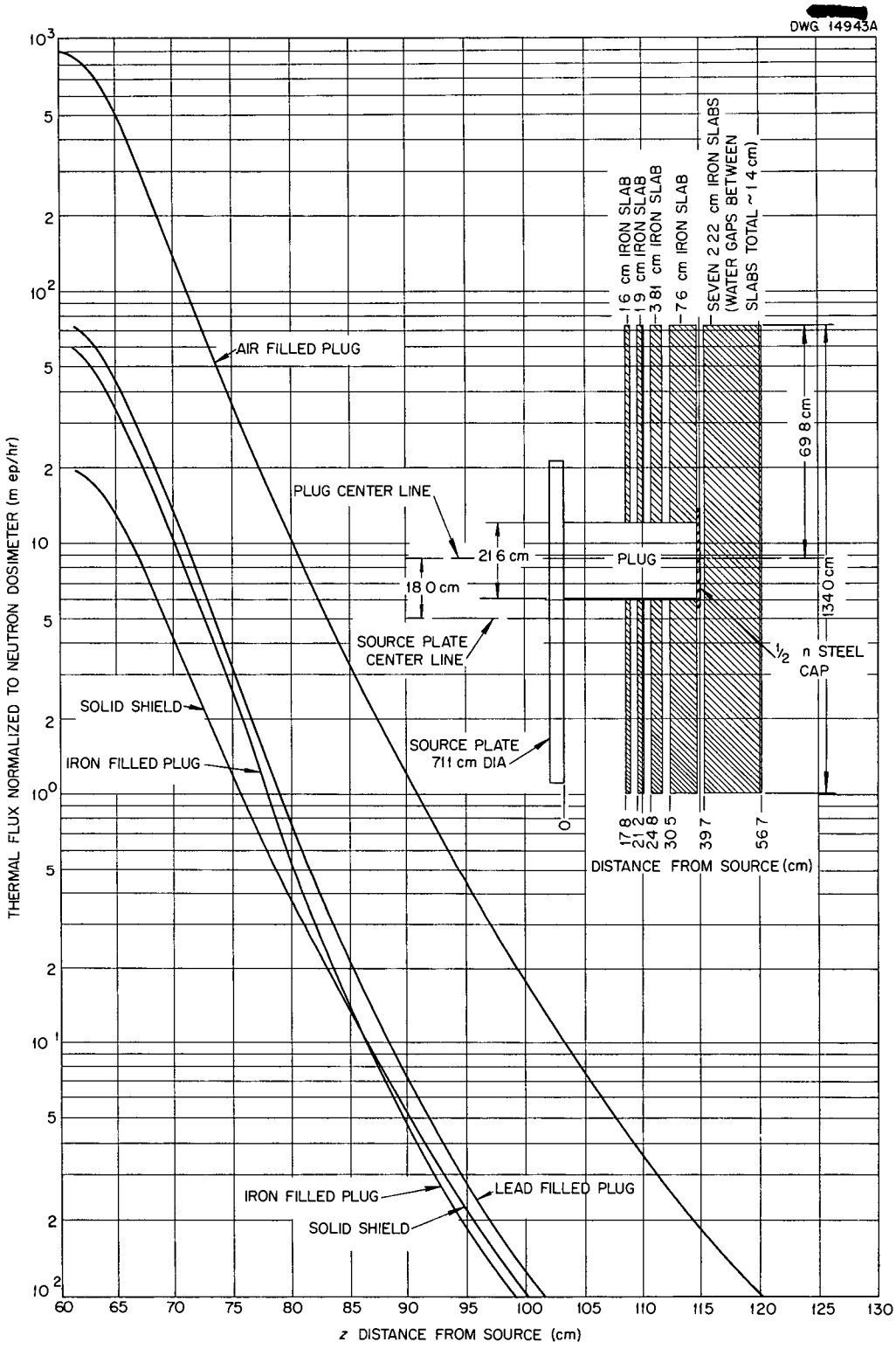

Fig 2 Westinghouse Control Plug Mockup Showing Neutron Distribution in Water Beyond Various 8 in dia Cylindrical Plugs

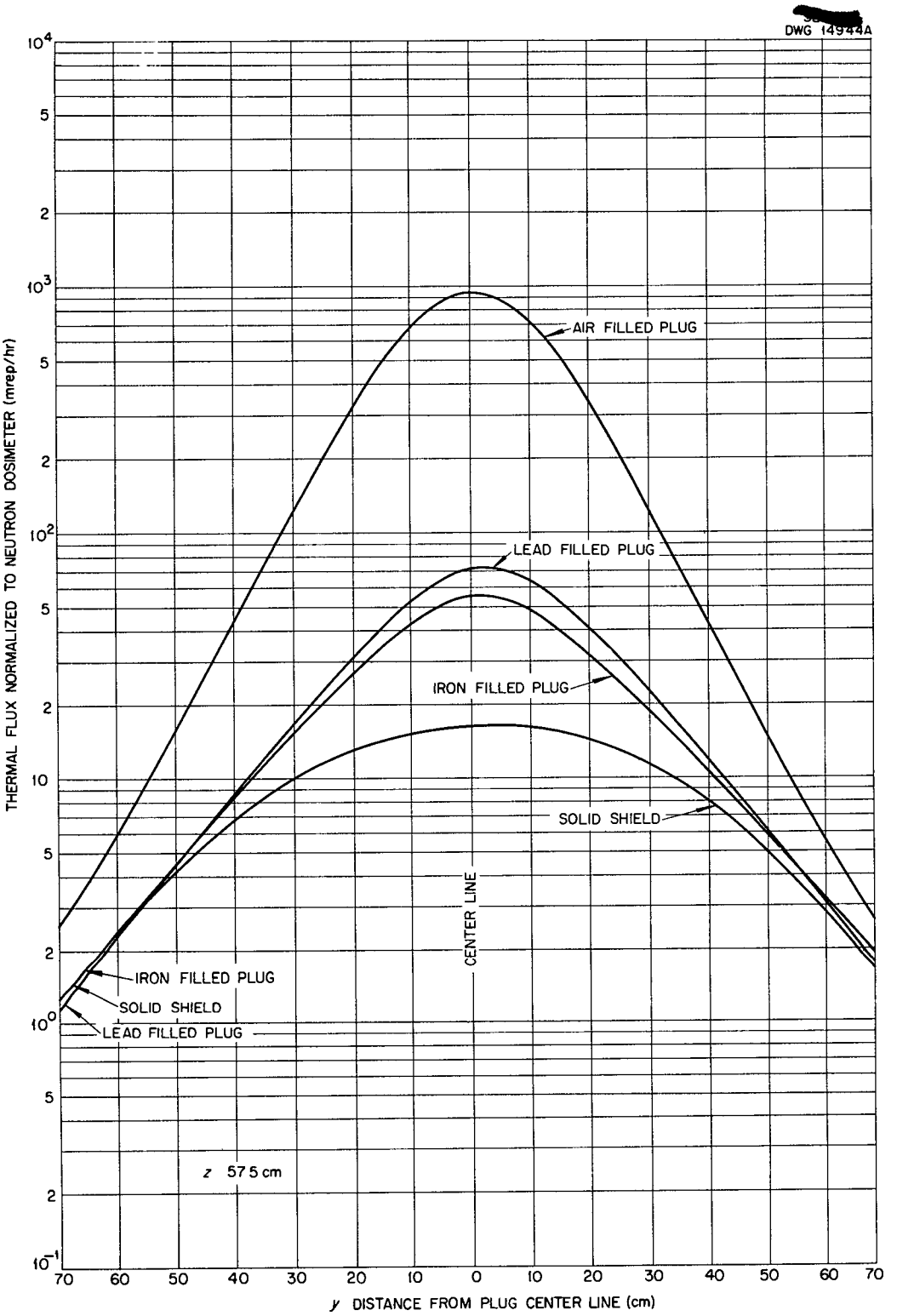

Fig 3 Westinghouse Control Plug Mockup Showing Neutron Horizontal Traverse Measurements in Water Beyond Various 8-in dia Cylindrical Plugs

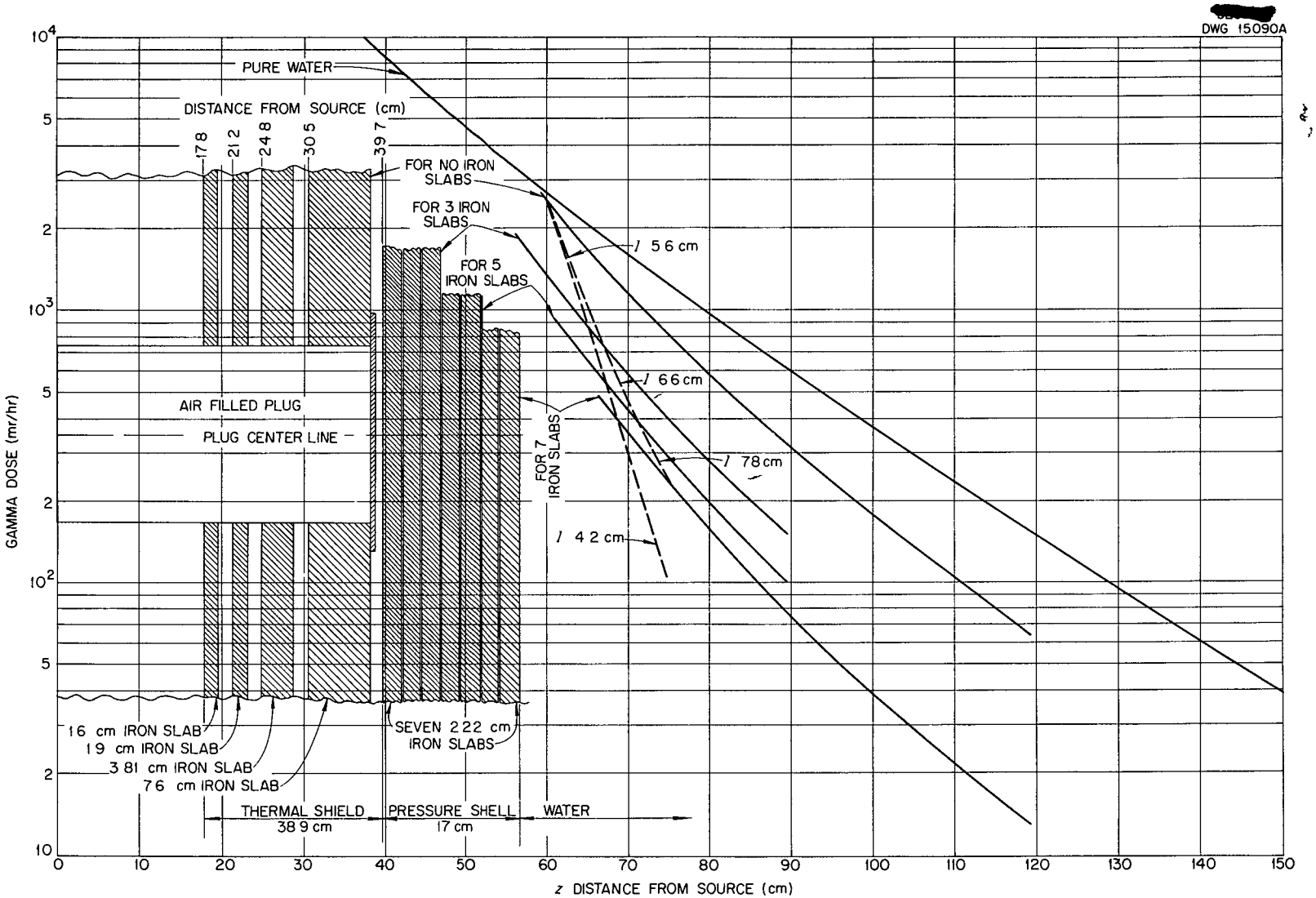

Fig 4 Gamma Absorption of Pressure Shell in Westinghouse Control Plug Mockup (Air filled Plug)

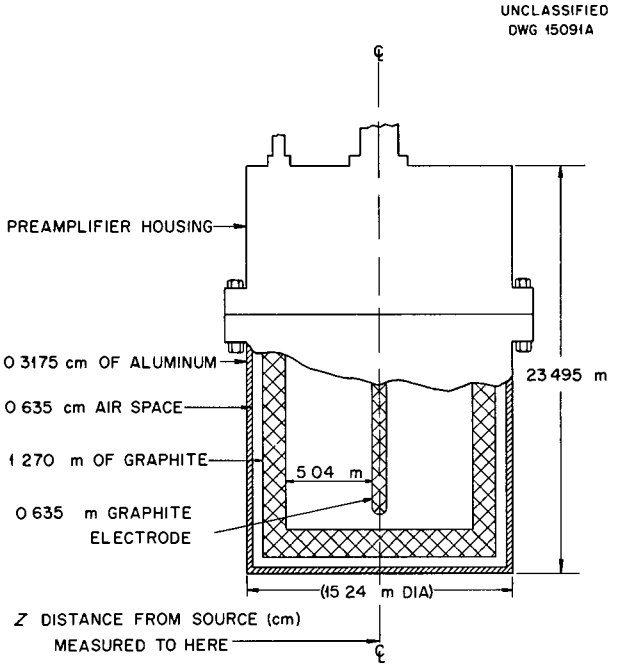

Fig 5 Cross Section of 10^{10} Ionization Chamber Side View (10^{10} is resistance ohms in series with chamber for signal generation)

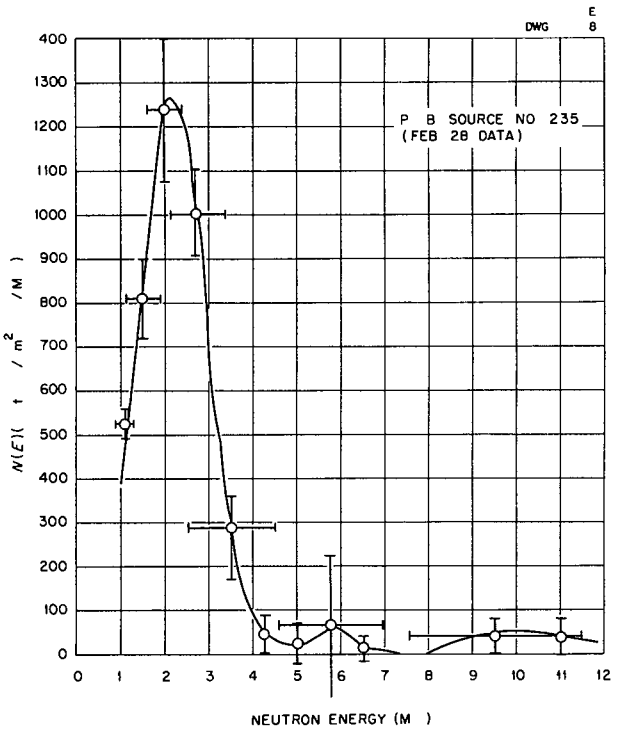

Fig 7 Polonium-Boron Spectrum

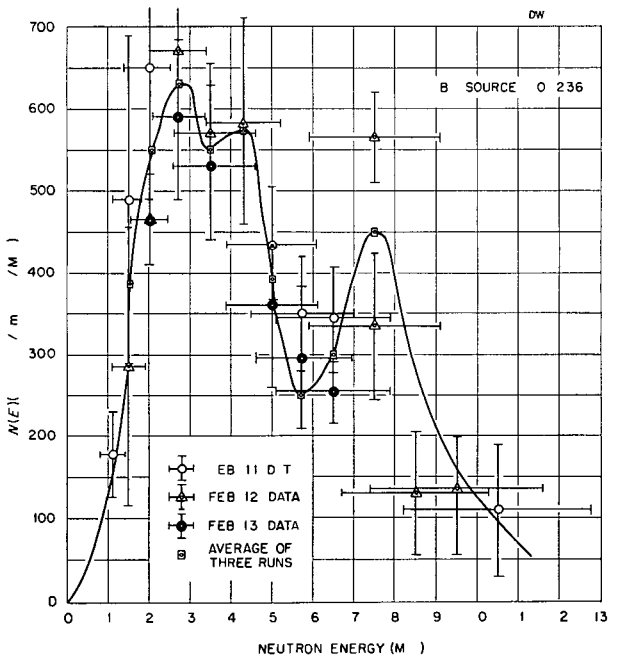

Fig 6 Polonium Beryllium Spectrum

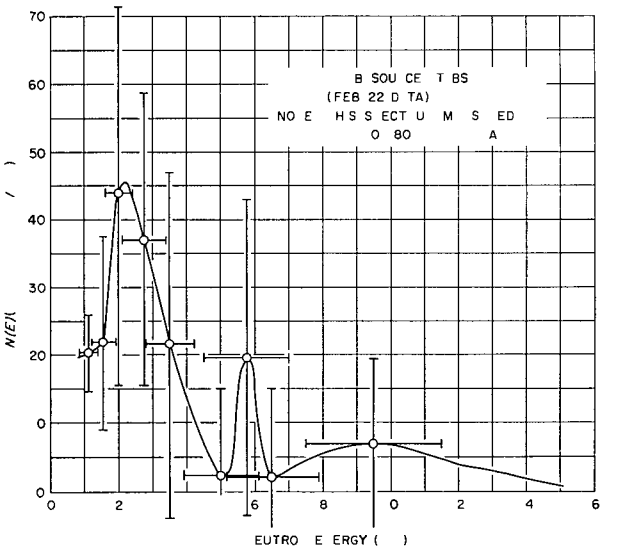

Fig 8 Radium Boron Spectrum

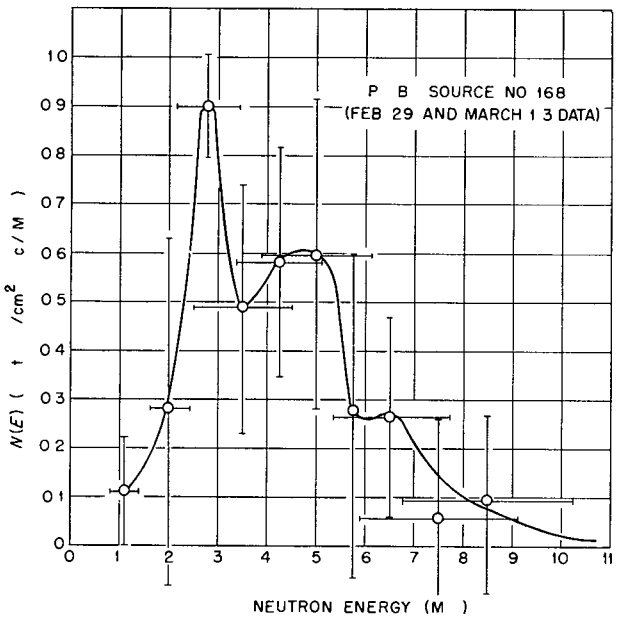

Fig 9 Polonium Beryllium Spectrum

$N(E)$ was calculated[6] for each point by using the hydrogen cross section and the fundamental constants of the counter

A three section counter has been designed to be used with the spectrometer and indications are that it will give a lower background without too much loss in sensitivity

To facilitate the recording of data during runs that continue over a long time interval an automatic data taking device has been developed that has provision for setting up any sequence of energy points desired with frequent background checks

After a discussion of He^3 counters with Los Alamos Scientific Laboratory personnel it was decided that the He^3 used should be purified to remove its tritium content The ORNL Isotopes Department performed the separation The He^3 is now pure to at least one part per million and will be put into the counter

[6] B R Gassick *General Principles of a Proton Recoil Fast Neutron Spectrometer* ORNL 1283 (Aug 14 1952)

BASIC REACTOR STUDIES

A D Callihan

The basic reactor program continues to be devoted to the experimental study of chain reacting assemblies of fissionable material The information obtained will provide a basis for the design of chemical processing plants and for the investigation of reactor characteristics

CRITICAL EXPERIMENTS

D F Cronin J W Morfitt[1]
J K Fox E R Rohrer

Uranium 235 The program of experiments to determine the critical conditions of the slightly enriched uranium that has been described previously[2] has continued A quantity of uranium oxide enriched to 5% U^{235} is mixed with successively larger amounts of glycerol tristearate in order to investigate the effect of moderation on critical conditions The mixtures are packed in aluminum boxes the largest being an 8 in cube that are stacked in a large tank and flooded with water So far the measurements have been extended to a hydrogen to U^{235} ratio of 320 The smallest mass of U^{235} made critical with the hydrogen content of the glycerol tristearate is 3 9 kg which occupies a cube about 17 in on an edge The critical mass without a water reflector is about 8 7 kg in a 22 in cube

In the part of the program intended to fix limiting dimensions of noncritical geometries no measurable neutron multiplication has yet been observed with the uranium mixture in a slab 42 by 42 by 8 in or in a column 12 by 12 by 48 inches

With increasing hydrogen content both the critical mass of a cube and the critical volume are decreasing The study will continue until the minimums have been evaluated

Uranium 233 A limited quantity of highly enriched U^{233} has been made available for an

[1] Y 12 personnel

[2] J W Morfitt J K Fox D F Cronin E R Rohrer and P E Wilkinson *Phys Div Quar Prog Rep Dec 20 1951* ORNL 1216 p 24

evaluation of some of its critical conditions The high specific activity of U^{233} necessitates a closed system for the transfer of solutions of uranyl nitrate Such a system consisting of a bank of storage cylinders and interchangeable cylindrical reactor vessels of various diameters has been designed and partly fabricated The reactor vessels are to be enclosed in a paraffin reflector

AIRCRAFT REACTOR STUDIES

E V Haake
D V P Williams
Dunlap Scott[3]
E L Zimmerman[4]
R C Keen[5]
W G Kennedy[6]

Direct Cycle Reactor The zero power mockup of the air cooled water moderated aircraft propulsion reactor being designed by G E was described in a previous report [2] The assembly consists of alternate layers of a methacrylate plastic to simulate water and an open grid of stainless steel sheets Disks of enriched uranium metal are placed between some of the steel sheets There is a beryllium jacket reflector with graphite on the ends The critical mass 38 kg of U^{235} and the core dimensions 51 in in diameter and 36 in long were reported earlier In the first experiment the plastic and stainless steel layers were horizontal In the second series the contents of some of the cells were rotated through 90 deg to make the structure essentially a series of open ended concentric square shells This arrangement more nearly simulates a later reactor design in which the moderator and coolant channels are alternate concentric annuli This change increased the critical mass slightly

Extensive measurements have been made on both of the assemblies The measurements include control rod calibrations temperature coefficients power and neutron flux distributions cadmium fraction distributions reactivity changes associated with various reflector substitutions and change in reactivity caused by separation of the core at its mid plane The results have been reported in detail [7 8]

Circulating Fuel Aircraft Reactor A preliminary experimental study of the circulating fuel aircraft reactor is to be made and the equipment is being assembled Beryllium oxide will serve as the reflector and moderator in the mockup and the fuel enriched UF_4 will be mixed with zirconium oxide, sodium fluoride and graphite to simulate the designed molten fluoride fuel The proposed program has been described more fully in another report [8]

(3) ANP Division

(4) Stable Isotope Research and Production Division

(5) Research participant

(6) Pratt and Whitney Aircraft Division of United Aircraft Corp

(7) E V Haake D V P Williams W G Kennedy and Dunlap Scott *ANP Quar Prog Rep Mar 10 1952* ORNL 1227 p 59

(8) R W Schroeder *ANP Quar Prog Rep June 10 1952* ORNL 1294 p 9

HIGH VOLTAGE PHYSICS

J L Fowler W M Good

The ratios of the fission cross sections of U^{234} and U^{236} to the cross section of U^{235} have been measured as a function of neutron energy from the thresholds to 4 0 Mev The cross sections are somewhat similar except for a shift of energy scales and show minimums and maximums well outside of statistical errors

The total neutron cross section of Li^6 has been determined with good resolution from 0 03 to 4 2 Mev The cross section goes through a 10 barn resonance at 258 ± 10 kev There is a broad minimum of about 1 3 barns between 1 and 2 Mev and then the cross section increases gradually to 2 1 barns at about 4 Mev

A rough theoretical estimate of the variation with neutron energy of the number of neutrons per fission of U^{235} ν^{235} has been made for the region 0 to 13 Mev The calculations indicate

that ν^{235} rises nonlinearly to a value of about 4 at 13 Mev

FISSION CROSS SECTIONS OF URANIUM 234 AND URANIUM 236 COMPARED WITH URANIUM 235

R W Lamphere

The fission cross sections of U^{234} and U^{236} have been compared with that of U^{235} from the threshold of the U^{236} to 4 Mev neutron energy The monoenergetic neutrons were obtained by bombarding the tritium gas target with protons from the 5 Mev Van de Graaff generator The gas target was designed by C Johnson of ORNL and is similar to one used at Los Alamos It contained tritium at 1 atm pressure and was 2 8 cm long Protons were introduced through a 0 2 mil aluminum window The fission chamber was of the parallel plate type and contained two thin uranium foils plated on 2 mil thick platinum disks placed back to back on the central plate of a three plate ionization chamber The central plate was kept at –300 v with respect to ground The spacing to the two outer collector plates was $^1/_8$ in and these plates were connected to the input grids of two amplifier channels and then to scalers and recorders The gas used in the chamber was 95% argon plus 5% carbon dioxide at 2 atm pressure A slight gas flow was maintained through the chamber to ensure purity The background counting rate was zero and there was no counting from alpha pile-up

For each of the isotopes the relative values of the cross section were obtained with comparatively thick foils (4 mg of uranium) in order to reduce the Van de Graaff time required to obtain the data The curves were then normalized by the use of thin foils on which the quantity of uranium was as accurately known as possible The spectroscopic analyses of the uranium samples are given in Table 1 The aluminum foils were prepared by a group at Y 12

The results of the measurements are given in Figs 10 and 11 The fission thresholds were found to be 0 37 and 0 69 Mev for U^{234} and U^{236} The rising portion of the U^{236} curve is in agreement with Nyer [1] although the point at 2 55 Mev differs markedly from the results reported here Two minimums well outside the statistical errors of the measurements are found in each curve Since the minimums occur at different neutron energies for the two isotopes it is almost certain that they are actually minimums in the U^{234} and U^{236} cross section curves rather than maximums in the U^{235} curve A more complete account of this research is being issued [2]

TABLE 1

SPECTROSCOPIC ANALYSIS OF URANIUM SAMPLES

SAMPLE	COMPOSITION	
	Uranium Isotope	Per Cent
U^{234}	U^{234}	89 34
	U^{235}	7 72
	U^{238}	2 89
U^{235}	U^{235}	99 92
	U^{234}	0 025
	U^{238}	0 05
U^{236}	U^{236}	95 51
	U^{235}	4 00
	U^{238}	0 43
	U^{234}	0 06

TOTAL CROSS SECTION OF LITHIUM 6

C H Johnson H B Willard
J K Bair

The total cross section of Li^6 has been measured with good energy resolution for neutron energies of 0 03 to 4 2 Mev and is shown in Fig 12 The measurements were made in a simple transmission experiment by using various neutron sources scatterers and detectors to cover the energy range In the energy region below 1 5 Mev neutrons were produced by bombarding a lithium

[1] W Nyer *The Neutron Induced Fission Cross Section of U^{236} as a Function of Energy* LA 1258 (May 26 1951)

[2] R W Lamphere *Fission Cross Section of Uranium 234 and Uranium 236 for Incident Neutron Energies up to 4 Mev* ORNL 1312 (July 15 1952)

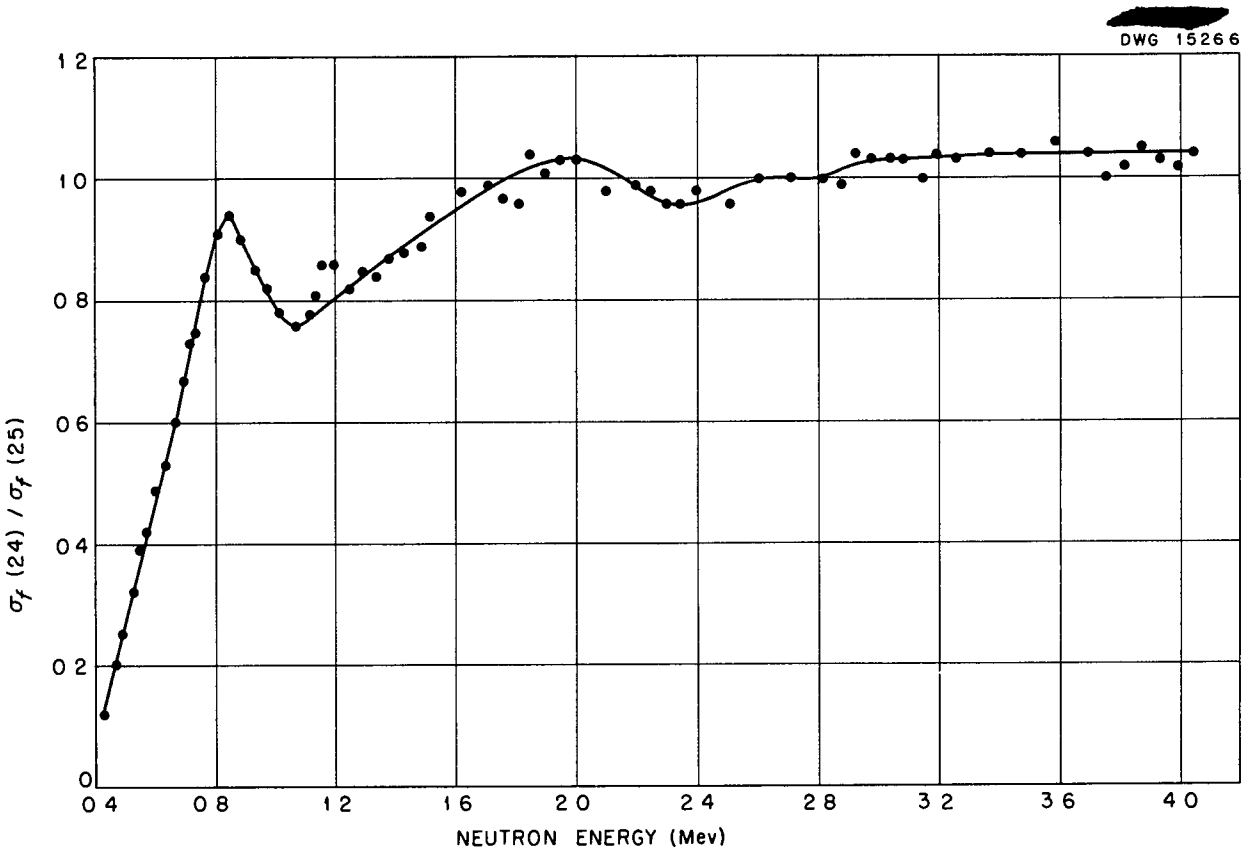

Fig 10 Fission Cross Section of Uranium 234 Relative to Uranium 235

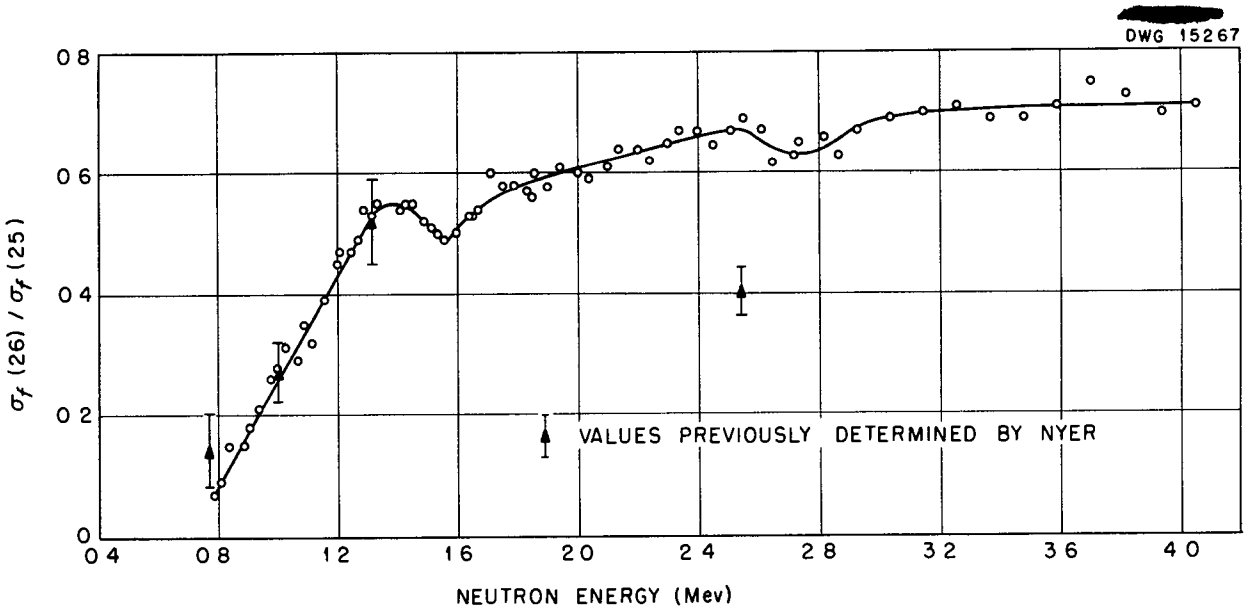

Fig 11 Fission Cross Section of Uranium 236 Relative to Uranium 235

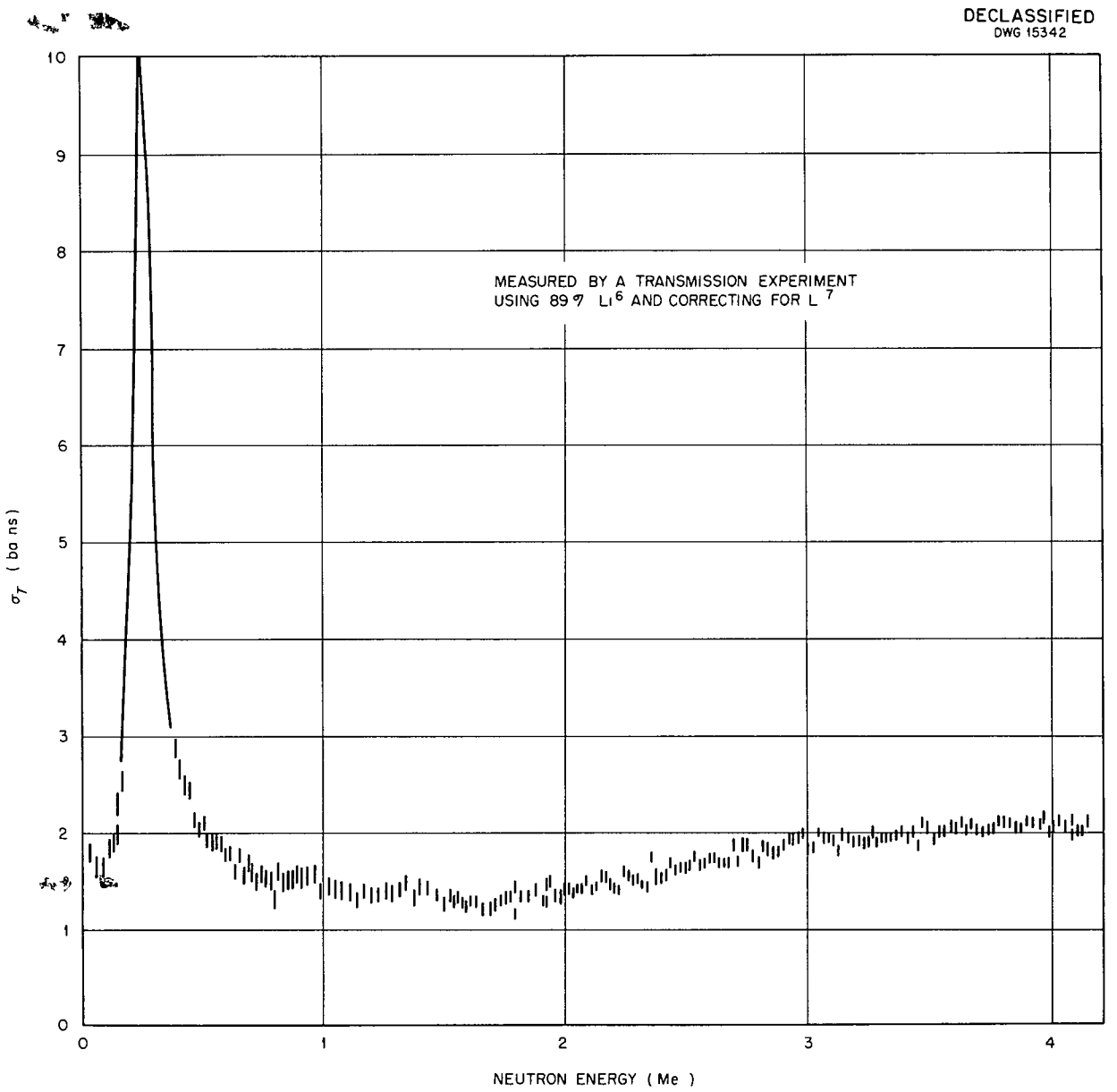

Fig 12 Total Cross Section of Lithium 6

target of about 15 kev stopping power with protons from the ORNL 5 5 Mev Van de Graaff generator Neutrons of greater than 1 5 Mev energy were obtained from the $H^3(p\ n)He^3$ reaction by using a zirconium tritium target[3] having a stopping power of 35 kev at threshold Because of the decrease in stopping power with energy the stopping power of the target was less than 20 kev for most of the measurements Data were taken in 10 to 20 kev intervals

Scattering samples were formed from lithium metal that was enriched to 89% Li^6 by the Isotopes Department at ORNL The lithium was cast into thin walled cylindrical stainless steel cans 3 cm in diameter

A boron trifluoride detector similar to that described by Seagondollar and Barschall[4] was placed at an angle of 97 deg to the proton beam and 30 cm from the neutron source for measurements in the neutron energy region from 35 to

[3] The Tritium Target was loaned by J W Bonner of Rice Institute

[4] L W Seagondollar and H H Barschall *Phys Rev* 72 439 (1947)

180 kev The neutron transmission of the lithium sample when placed 8 cm from the source was determined relative to the transmission of an identical empty can and the total cross section was found by assuming exponential attenuation of the neutron flux Background corrections were determined by interposing a paraffin shadow cone between the source and the detector In this scattering geometry 1 5% of the neutrons scattered by the sample would reach the detector if the scattering were isotropic therefore a correction of 1 5% was applied For neutron energies from 140 to 220 kev the same scattering geometry was used at 0 deg to the proton beam

For neutron energies of 180 to 1500 kev the detector was a propane filled proportional recoil counter 2 5 cm in diameter and 10 cm long placed with the axis coincident with that of the proton beam and with the center 30 cm from the neutron source Scatterers were placed halfway between the source and the detector in this geometry the in scattering correction applied for isotropic scattering was 1 2% Measured backgrounds were less than 1% and were neglected As the neutron energy was increased beyond 600 kev the amplifier bias setting was increased to discriminate against the low energy neutron group from the $Li^7(p\ n)Be^7$ reaction [5] In the vicinity of the resonance (Fig 13) a sample 2 2 cm in diameter was used for which an in scattering correction of 0 7% was applied

[5] V R Johnson M J Laubenstein nd H T Richards *Phys Rev* 77 413 (1950)

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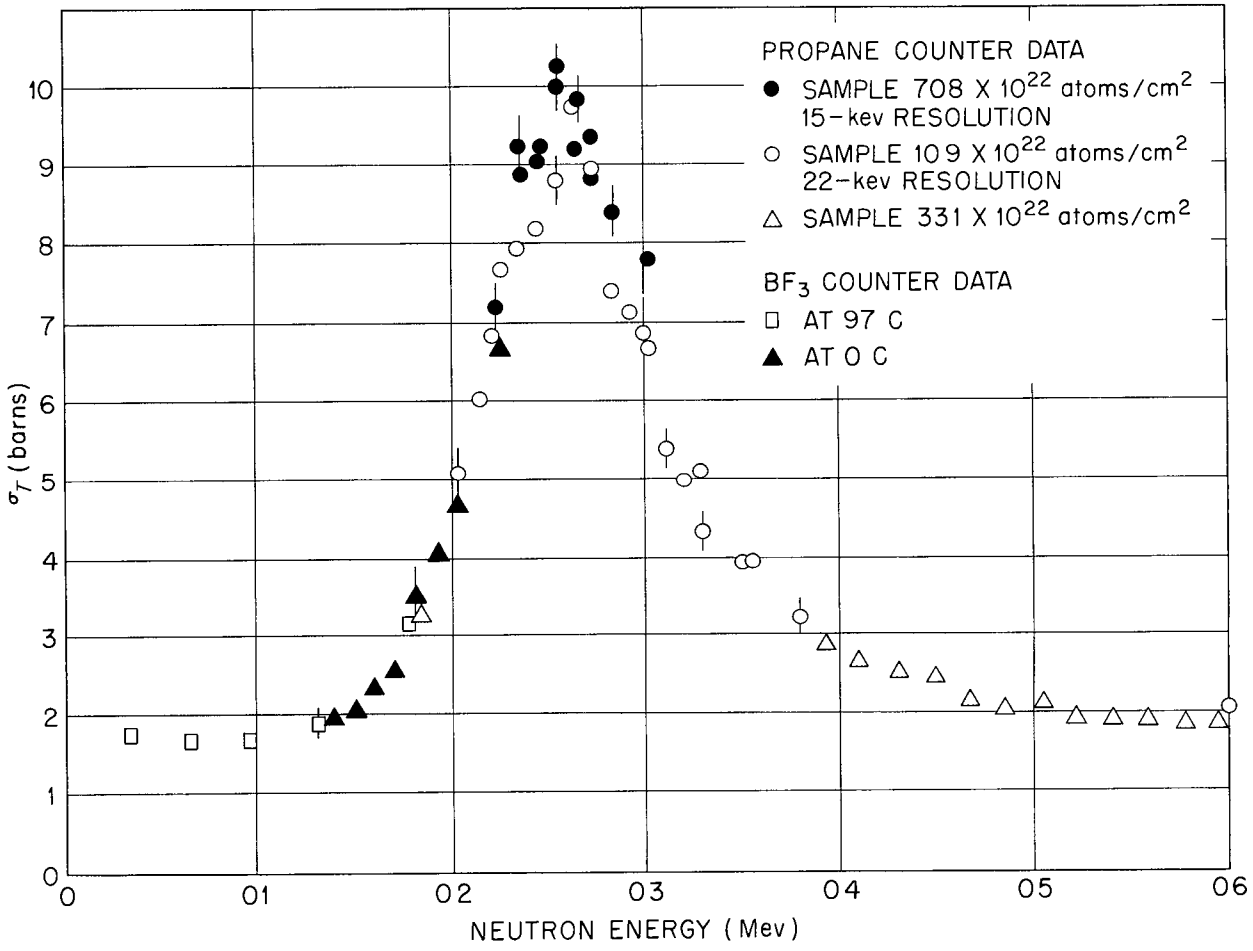

Fig 13 Total Cross Section of Lithium 6 Near the 258 kev Resonance

Measurements were extended beyond 1 5 Mev by using the T(p n) source and a cylindrical high pressure hydrogen chamber in the same geometry as that used for the propane counter This hydrogen counter was 2 5 cm in diameter and 15 cm long It had a central wire 20 mils in diameter and was operated as an electron collection chamber at 100 atm of hydrogen The chamber was filled with electrolytic hydrogen that had been further purified by passing over hot magnesium turnings for several hours In order to obtain a good signal to noise ratio the chamber was shock mounted the amplifier (model A 2) was operated with d c filaments and the amplifier rise and decay time constants were adjusted to 30 μsec Backgrounds were less than 1% and were therefore neglected

Cross sections were computed for the isotope Li^6 by using the published curves for normal lithium [6 7 8] Unfortunately a large error remains in the measurements because the composition of the samples was not accurately known Before preparing the Li^6 samples several cylinders of normal lithium were cast in a manner identical to that used for Li^6 The densities of the ordinary lithium samples were within 0 5% of the known density in each case whereas the densities of the three Li^6 samples prepared in the same manner were 6 5 0 6 and 8% greater than those expected if the two isotopes have the same crystalline structure At the present time only a spectral analysis of the Li^6 is available This type of analysis gives a measure of most metallic impurities except the alkali metals for which it gives rough estimates Using the spectral analysis including the estimate of alkalies the densities of the samples are still in error by 5 –2 5 and 6 2% It is likely that there is an impurity of lithium chloride Since the nature of the error is not known the cross section has been computed by assuming that the samples contained only lithium with the impurities mentioned The best estimate of the error involved if there is lithium chloride present is that the cross section shown in Fig 12 is 10% low at the resonance and 5% low off resonance

Figure 12 gives the resulting total cross section of Li^6 as a function of neutron energy The lengths of the vertical lines indicate standard statistical errors of the measurements A resonance was found with a maximum at 258 ± 10 kev which is in good agreement with the $Li^6(n\ \alpha)$ resonance that Blair and Holland[9] place at 250 kev

A theoretical analysis of the resonance is not yet complete Nevertheless it appears certain that the resonance results from p neutrons forming a state in Li^7 whose total angular momentum is $5/2$

ESTIMATE OF ν FOR URANIUM 235 AS A FUNCTION OF NEUTRON ENERGY

J L Fowler

The deduction that the prompt neutrons produced in fission come from the fission fragments rather than the compound nucleus [10 11] and the observation that the fragment kinetic energy is approximately independent of the excitation energy of the compound nucleus [12] make possible an estimate of the number of neutrons emitted per fission as a function of excitation energy of the compound nucleus A reasonable assumption is that the difference between the mass defect energy and the fragment kinetic energy exists as excitation energy of the fragments and that neutrons are boiled off according to the principles of the statistical theory [13]

For this purpose the many modes of fission of $U^{235} + n$ are simplified by considering only four

(6) C K Bockelman D W Miller R K Adair and H H Barschall *Phys Rev* 84 69 (1951)

(7) P H Stelson and W M Preston *Phys Rev* 84 162 (1951)

(8) Published curves extended to 3 4 Mev Preliminary measurements show that the cross section of normal lithium rises smoothly to 2 25 barnes at 4 2 Mev

(9) J M Blair and R E Holland *Argonne National Laboratory Quarterly Report July August and September 1950 Physics Division* ANL 4515 p 7

(10) R R Wilson *Phys Rev* 72 189 (1947)

(11) S De Benedetti J E Francis Jr W M Preston and T W Bonner *Phys Rev* 74 1645 (1948)

(12) S S Friedland *Phys Rev* 84 75 (1951)

(13) J M Blatt and V F Weisskopf *The Theory of Nuclear Reactions* NP 1587 (May 1 1950)

typical modes and ν is obtained by finding the weighted average of ν for these four modes of fission Since both the mass defect energy which is calculated from empirical mass tables [14] and the fragment kinetic energy are not accurately known their difference is adjusted so that $\nu = 2\ 53$ for thermal neutrons In this way the ν vs energy curve is normalized to the observed value at thermal energies The excitation energy was assumed to be divided between the fragments in the ratio of their masses

Figure 14 shows the results of the calculation of ν vs E_n up to 6 Mev together with one point at about 13 Mev The ν at 13 Mev is in agreement with the value of ~4 observed for 14 Mev neutrons [15] Since this estimate gives an appreciable increase of ν with energy an experiment has been devised and the apparatus is designed and is being built to measure ν vs energy in the 2 to 4 Mev energy region

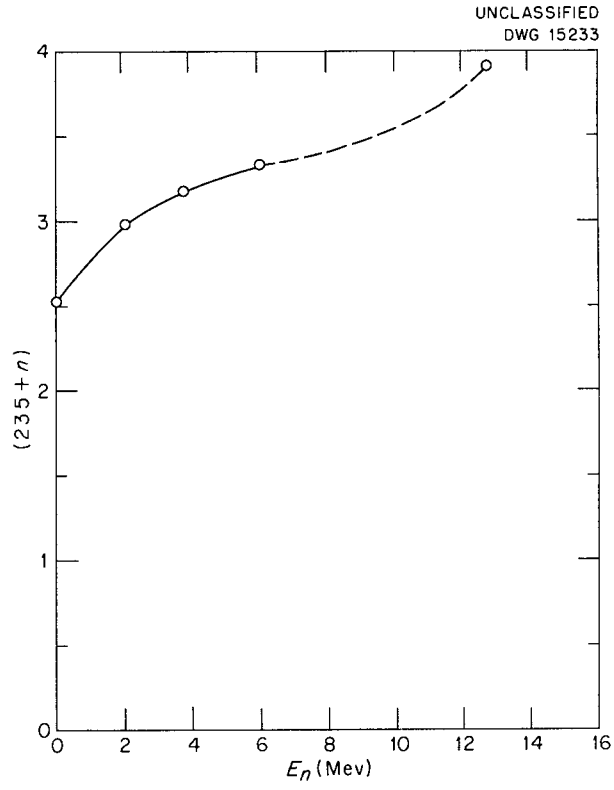

Fig 14 Theoretical Neutrons Per Fission as a Function of Neutron Energy for Uranium 235 Neutron Fission

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[14] N Metropolis and G G Rettweisner *Table of Atomic Masses* NP 1980 (March 1950)

[15] E R Graves *Conference on Classified Nuclear and Reactor Physics Oak Ridge National Laboratory September 10 11 12 1952* ORNL CF 52 9 9 p 36