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TECHNICAL ACTIVITIES REPORT

for

May 1953

PHYSICS UNIT - APPLIED RESEARCH SUB-SECTION

by

J. E. Faulkner, D. E. Davenport and G. E. Duvall

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48

DECLASSIFIEDEXPERIMENTAL PHYSICS - J. E. FaulknerI. Xenon Generator - J. W. Finnigan, R. E. Peterson, J. W. Culvahouse,
H. W. LefevreA. General Design and Construction

Money has been made available for the xenon project this month. Project engineers are now scheduling the design and fabrication of equipment and shielding. It appears at this time that plant forces can begin fabrication in six weeks. The separation line will be disassembled for removal to 100-DR Area within the next month.

B. Experimental

A final test run was made this month with the enriched generator exposed for four hours in the test pile operating at 100 watts. Operating parameters for this separation were essentially the same as for the previous run described in last month's report, HW-27921. It was felt that a more vigorous heating of Trap #1 would release more xenon and improve separation efficiency. This was accomplished by heating Trap #1 to a temperature of 500°C for half an hour. Upon collection of the xenon sample and coincidence counting, the activity was found to be 1.16×10^7 d/s as compared with a one hundred percent calculated yield of 3.14×10^7 d/s activity. The yield was thus 37% of the calculated amount produced in the generator. This represents an improvement of 7% in separation efficiency over the previous run which may be attributed to better release of the xenon from the charcoal traps.

C. Xenon Assay by Counting Techniques

A 5/32 inch thick by 1-1/2 inch diameter anthracene crystal and a photomultiplier tube replaced the beta proportional counter for coincidence counting of the xenon sample. The anthracene crystal gives a light pulse which is proportional to the particle energy loss in the crystal. This allows energy discrimination by means of pulse height discrimination. By measuring the maximum energy of the Xe^{135} 0.9 Mev betas after they had passed through the glass sample bulb, the thickness of the glass was determined. This thickness was great enough to completely absorb the Xe^{133} contaminated beta and the Xe^{135} internal conversion electron, so it was established that no error in counting was produced by either of these effects. The gamma sensitivity of the crystal is inherently low and since the gamma energies are all lower than the betas, it was easily possible to discriminate against gammas in the beta counter.

The pulse rise time from anthracene is about 3×10^{-8} sec so no trouble was caused by a time spread of true coincidences and a much better resolving time was achieved than could be obtained with the gas proportional counter. The coincidence counting part of the final xenon sample analysis

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is thus on a much firmer footing with regard to errors than it has been.

Three counting samples were obtained by volume fractioning of the total sample. One sample--1/10 of the total--was delivered into a special bulb for checking the sensitivity of the Shonka gamma ion chamber for Xe^{135} . The sensitivity agreed within a factor of two with a value based on a radium to Xe^{135} conversion calculation. It may be necessary to modify the current measurement system to obtain small current differences to the desired accuracy.

A report has been issued in conjunction with J. R. Triplett on the results of the test pile reactivity measurements on two plutonium samples, HW-27851.

Figure 1 is an experimental determination of the relative response of two anthracene crystals to betas and gammas from the Cs^{137} decay. The beta maximum energy is 0.51 Mev and the gamma energy is 0.66 Mev. The gamma is internally converted in about 6% of the decays to give an 0.63 Mev electron. The peaks at the high energy end of the beta spectra is due to detection of this electron. The differences in the two beta curves are due to different photomultiplier gain and geometry differences. The gamma response for the thin crystal is only 6% of the beta response. The correction for gamma counting in the beta crystal can thus be obtained to sufficient accuracy by using an aluminum absorber to cut out the betas.

The photoelectric gamma absorption cross section for anthracene is quite low due to the low Z of its constituents (mainly carbon and hydrogen). The pulses produced by gammas in anthracene result from compton processes in the crystal with the largest pulses resulting from 180° scattering. This is shown in the curves relative position of the conversion electron pulses and the upper limit of the gamma response curves.

II. Cl^{12} Cross Section - J. W. Culvahouse, R. E. Peterson

The LiI sample, cobalt sample and a cobalt aluminum wire irradiated at MTR arrived at Hanford this month.

The LiI ampoule was removed from its aluminum can and is ready to be transferred to 222-T Building. There the tritium will be removed and counted, if possible, and the lithium will be extracted in a form suitable for mass spectrometer analysis.

The cobalt and its aluminum wrapper were removed from their ampoule and put in solution with concentrated hydrochloric acid. J. Meinhard of the Chemistry Unit made a spectrophotometer analysis of the amount of cobalt present in the solution. His measurements gave a value of $494 \mu\text{g} \pm 10 \mu\text{g}$. The weighed amount before irradiation was $487 \mu\text{g} \pm 5 \mu\text{g}$. These results show that very little cobalt had been lost or gained. The latter figure will be used in

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HW-28283

subsequent calculations.

A total of fifteen counting samples was made by the Chemistry Unit. Five of these were made up identical with the Bureau of Standards Co^{60} sources, and this activity was made roughly equal to 10^6 d.p.s. which was near the activity of one by the standards. The other ten sources were made by evaporating a suitable amount of activity on a microscope slide in such a manner that they would be suitable for absolute counting. The amount of Co^{59} in all of the counting samples is known to be better than two per cent.

The first five samples have been compared with the Bureau of Standards source both with a Shonka chamber and a scintillation counter. Preliminary measurements give 4.72×10^5 d.p.s. $\pm 1\%$ relative to the Bureau of Standards source, which has a probable error of 2% in the original $\rho - \lambda$ coincidence counting and a further one or two per cent error caused by six years of decay with a half life that is known to only two or three per cent. Because of these additional errors, it is believed that our coincidence counting will give more precise results. The total error in Co^{60} activity per gram of Co^{59} is expected to be no worse than 3%.

The cobalt aluminum wire will be scanned to give the average flux distribution along the hole which contains the Cl^{12} , LiI and cobalt samples. This makes it possible to normalize the LiI and cobalt, and later the Cl^{12} and cobalt to a common flux.

When the data from the cobalt wire and the lithium burnout have been obtained, the resonance activation of cobalt for the particular flux spectrum obtained at the sample position can be calculated. This will be used to correct the activity of the cobalt with the Cl^{12} samples to the value for a $\frac{1}{V}$ absorber. In this way thermal flux will be measured.

III. Critical Mass Problems - D. D. Lanning

Document HW-28036, concerning proposed changes in certain process vessels in the 231 Building, has been issued. This report recommends possible vessel design which will be subcritical with large concentrations of plutonium for vessels PR-3, S-1 and SR-1.

A trip was made this month to talk with design engineers in the Vitro Corporation at New York. Criticality hazards were studied in the design stage of certain process equipment for the Purex Separations Plant. Recommendations were made for certain changes in distances between same vessels, and calculations were made to estimate the criticality hazard of supports and piping around the vessels. The methods used for the calculations were outlined and discussed with an engineer from Vitro so that further criticality questions can be answered by him with a final check of the design to be made by a Critical Mass group.

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FIGURE 1

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IV. Neutron Beam Catcher Design - W. P. Stinson

In a ratio determined by the amount of liquid paraffin required to saturate the powdered boric acid, 2,330 pounds of paraffin and boric acid were mixed together. This ratio came out to be 57% by weight boric acid and 43% paraffin. This was cast in small waste cartons and the average weight of the loaded cartons was 48-1/2 pounds. These were stacked to form a cube and holes were bored so that neutron and gamma flux measurements can be made every 3 inches in a horizontal plane through the center of the neutron beam. Plugs were made to fit in the holes not occupied by the detectors.

The neutron flux will be measured with a small BF_3 enclosed in 1/2 inch of paraffin and the gamma flux will be measured with a NaI crystal mounted on a photomultiplier tube.

V. Neutron Diffraction Spectrometer - B. R. Leonard, Jr., S. M. Hauser

The recent installation of the improved collimator and shielding assembly for the neutron spectrometer has allowed an improvement in the positioning of the spectrometer. The spectrometer is now mounted in a position to allow a motion of the detector arm of from plus 30 degrees on one side of the direct neutron beam to plus 100 degrees on the other side. Such an installation is of great importance in the elimination of systematic errors in cross-section determinations. For a given crystal plane, data can now be taken at equal nominal angles on each side of zero angle thereby minimizing the uncertainty in the determination of zero angle. The alignment of the diffracting crystal plane with the detector is also subject to some uncertainty. If crystal planes of the same planar spacing but different orientations in the crystal slab (e.g., $\text{Be } 10\bar{1}1$, $10\bar{1}\bar{1}$) are both used on each side of the central beam, then systematic errors due to misalignment and unsymmetrical lane diffraction are observable and can therefore be corrected. The reduction of such errors to the order of 0.01 degrees seems quite feasible.

In the process of aligning the spectrometer, an attempt was made to use the instrument for the study of a powder pattern from a polycrystalline material (graphite). This spectrometer was constructed to perform this experiment in the following manner: A monochromating crystal is mounted on a second axis to reflect some particular neutron wave length. The detector arm, which has no controlled motion about this second crystal axis, is now set and locked in position to detect the monochromatic beam from the second crystal. The powder sample is then mounted on the first axis in the primary neutron beam and the arm containing the monochromating crystal and detector is isolated about the first axis to study the diffraction of the particular wave length neutrons selected by the second crystal. It was soon discovered that the background counting rate was several times that expected in the lane maxima from the graphite powder. The limited time available for this experimentation did not allow a determination of the source of this background, but it is likely due either to neutrons incoherently scattered from both powder and monochromating crystals or is a general background due to air scattering and backscattering

DECLASSIFIED

-8-

HW-28283

from the neutron beam catcher. Neither of these factors could be overcome in this installation as this spectrometer requires that the powder sample diffract in the primary polychromatic neutron beam and the beam facility requires that the primary beam traverse a large air path and be caught in the laboratory rather than in the collimator shielding. The results of this experiment, though not conclusive, show that it is unlikely that such experimentation is feasible with this facility, at least without extensive modification.

The fission chamber has been remounted on the spectrometer and preliminary work has been completed to perform the accurate measurement of the ratio of fission cross sections of Pu^{239} and U^{235} on receipt from KAPL of the foils to be used in this experiment. It is of interest to note that the intensity obtained in a monochromatic neutron beam has been increased by a factor of about three over that previously obtained. This increase is believed due to the elimination of an obstructing plug behind the neutron beam collimator and the elimination of paraffin in the construction of the collimator. Some of the paraffin originally surrounding the collimating tubes had melted into the tubes and has now been replaced with selectron.

A previous remark that the ratio of net counting rate to background could be improved in the region above a few tenths of an electron volt neutron energy by using an appropriate cadmium filter in the diffracted beam has been verified. The ratio of net counting rate to background for the limiting case of a light plutonium fission foil has been improved from about 2:1 without filter to about 7:1 with filter at 1.0 e.v. with no decrease in net counting rate. This result follows from the fact that most of the detectable background is due to the relatively large amount of diffusely scattered thermal neutrons. The use of this technique, along with the observed intensity increase, should make possible the extension of data to several e.v. in a fission cross-section experiment.

VI. Beta Spectrometer - L. R. Boyd

A complete analysis of the data obtained from $\text{Ru}^{106}\text{-Rh}^{106}$ source was made this month. Figure 3 shows the results of the analysis. Beta components with end point energies of 3.55, 2.4 and 0.7 Mev are indicated. Figure 2 shows the momentum intensity distribution for the three components which were calculated from the Kurie plots. The areas under the curves give relative total intensities of the 3.55, 2.4 and 0.7 Mev components as 1, 0.28 and 0.08 respectively.

The latest published information reports beta components of 3.55, 3.05 and 2.4 Mev, and minor fractions of lower energy. An expanded plot of the data from the high energy end of the spectrum was made to ascertain that nothing such as the 3.05 Mev component was overlooked. The plot in the upper right of Figure 3 gives the results. Each point has the uncertainty indicated. The slope of the curve is changed as much as possible in the direction which would accentuate any deviation from linearity of the data, but this yields nothing.

Another interesting feature of the data just obtained is the 0.7 Mev component.

DECLASSIFIED

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-9-

HW-28283

One of the possible sources of this activity is Ru^{103} which has a reported half life of 40 days. Rh^{106} has a 1-year half life. If the half life values are correct, the 0.7 Mev would be entirely negligible in this 2-year old sample.

The spectrum is being rerun for verification.

John E. Faulkner

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FIGURE 2

Momentum Plots of Beta Activity
Components of Rn^{102} and Ru^{103}

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2813

EXPONENTIAL PILE PHYSICS - D. E. Davenport**DECLASSIFIED**Hollow Slug Program - W. B. Farrand

The initial experiment in this program calls for an exponential experiment with solid slugs 1.660" in diameter. The metal is now canned and ready for insertion in the 7-1/2" exponential pile. The central water-containing tubes have arrived, and work has started in welding end caps. The two water tube sizes are 0.8" and 1.1"

Instrumentation - W. B. Farrand, E. Z. Block

Resolving times of many of the instruments of the Exponential Pile Group have been measured and show rather a wide range of values. The resolving times of four Potter scalars and P-12 amplifiers have been determined using a Hewlett-Packard pulse generator and synchronization pulses from the same instrument. Both pulses are square waves 1 microsecond wide and 0.2 volts in height. The resolving times vary from 1.75 microseconds to 5.5 micro seconds for 1 microsecond pulses. Previously, these instruments had been assumed to have a 7.6 microsecond resolving time. Resolving times for the four Geiger tubes in use have also been determined. Their range of values are from 108 microseconds to 180 microseconds. In the past, they have all been assumed to have a 130 microsecond recovery time.

Blackness - W. B. Farrand

An investigation of blackness corrections as outlined by R. W. Woodruff, HW-27737 has been undertaken. The correction factor for 5.5 milgold foils, which have been used in these measurements, has been calculated. Further measurement of blackness by the same technique used in the past but with thicker gold foils will be made to check the validity of these correction factors.

A survey of materials was made to determine which material might offer a totally black, thin foil. Dysprosium is a possible material, but is available only in oxide form. Prices range from \$200 to \$1000 per gram. Further investigation is being carried out concerning availability of dysprosium oxide.

A check of the blackness value determined by the foil method will be given by the blackness values derived from the layer measurements presently being carried out in the exponential piles.

Exponential Pile Measurements with Small Slug Size - E. D. Clayton, R. C. Lloyd

The measurements in the 6-3/16" and 7-1/2" lattice with the 0.926" diameter slugs have now been completed. The wet buckling in the 6-3/16" lattice is now given as $98.2 \times 10^{-6} \text{ cm}^{-2}$. An earlier value of $98 \times 10^{-6} \text{ cm}^{-2}$ was reported which was based on an estimated background. A value of $66.4 \times 10^{-6} \text{ cm}^{-2}$ has been obtained for the wet buckling in the 7-1/2" lattice. The buckling values with the small slugs are summarized in the following table.

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BUCKLING
(Slug Diameter 0.926 Inch)

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<u>Lattice Spacing</u>	<u>Dry</u>	<u>Wet</u>
6-3/16"	$115.0 \times 10^{-6} \text{ cm}^{-2}$	$98.2 \times 10^{-6} \text{ cm}^{-2}$
7-1/2"	$95.3 \times 10^{-6} \text{ cm}^{-2}$	$66.4 \times 10^{-6} \text{ cm}^{-2}$

For comparison with the standard slug size results, these values may be plotted vs. the graphite/uranium mass ratio per unit of cell volume. This is accomplished in Figure 4. In the small slug size, the mass of U per unit of cell length is approximately one half of the standard slug size. From the curves, it is noticed that the buckling is reduced by only 5.7 microbucks in the dry lattice with a 7-1/2" spacing when the uranium per unit of cell volume is reduced by approximately one half. This does not appear unreasonable since if the standard slug size dry buckling curve is extrapolated to the corresponding graphite/uranium ratio (a lattice spacing of about 10.6"), a value of around 90-100 microbucks should result. On the basis of the measured values, however, this extrapolation is quite uncertain as is evident from the buckling curve.

In the wet lattice, the curves do not match at all for the same graphite to uranium ratio. For the small slug size, the curve appears to be shifted upward some 25 microbucks. The maximum may also be shifted, but with only two points this cannot be determined. It should be pointed out that the water to uranium ratio is 11% higher for the standard slug size, but this difference will produce only a small effect. In view of these results, it will be of special interest to measure lattice spacings of 5-3/8" and smaller with the 0.926" slugs to see if the maximum in the curve is also shifted.

A series of calculations is now being made in which the buckling and other lattice constants are being calculated for all of the lattice measured to date with the standard and 0.926" slug size. These calculations are being carried out with an equivalent uranium density (to account for end caps) and also for the solid slug density. From these calculations, it is hoped that a value for $\Sigma \eta$ can be obtained which will be mutually consistent for the different lattices measured. The results will be reported upon completion of the calculations and the comparison with the experimental values.

During the latter two weeks of May, the exponential piles have been made available for blackness measurements which will be reported on by the Theoretical Physics Group. R. K. Cole has been taking these measurements.

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Buckling vs Graphite/Uranium Ratio for Standard and Small Slug Size

A Small Slug Size (.926")

7 1/2

Small Slug Size

Lattice Spacing in inches

6 3/16

8 3/8

8

7 1/2

Standard Slug Size

Buckling $\times 10^6 \text{ cm}^2$

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FIG 4- Graphite to Uranium Ratio

THEORETICAL PHYSICS - G. E. Duvall

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I. Critical Lattice Experiments

A. Mockup in Exponential Pile - R. K. Cole

These experiments are being carried out as planned and should be completed by June 1.

B. Time Behavior of a Pile with Reflector - G. M. Muller

The following computation was made using time-dependent two-group theory under the assumption of no delayed neutrons. An active graphite-moderated core 270 cm x 360 cm x 40 cm is reflected on its 270 cm x 360 cm faces by 270 cm x 360 cm x ∞ cm graphite reflectors. The constants assumed for the core and reflector are as follows:

	<u>Core</u>	<u>Reflector</u>
Thermal life time	1.3×10^{-3} sec	1.2×10^{-2} sec
Slowing down time	1.5×10^{-4} sec	1.5×10^{-4} sec
L^2	291.0 cm ²	2642.0 cm ²
τ	365.0 cm ²	365.0 cm ²

It is required to find the value of k prompt in the core which will produce a given positive period for the reactor. The results are given below.

<u>Period</u> (seconds)	<u>k prompt</u>
∞	1.767
1	1.769
0.1	1.807
0.01	2.138

II. Lattice Theory

A. Measurement of Thermal Neutron Current Density - R. W. Woodruff

Thermal neutron current densities are directly measurable with discs made of a material which is a $1/v$ absorber, which are thick enough to absorb all incident thermal neutrons. Such a disc must therefore have a very large absorption cross section if its thickness is not to be excessive. If the surface area is small compared to the surface of a sphere generated by the transport mean free path of the adjacent material, then the effect of the disc on the quantity being measured will also be small.

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-16-

HW-28283

The only two materials available at present which would be at all suitable for this type of measurement are Eu_2O_3 and Dy_2O_3 . The former is objectionable because an isotope of long life is formed by activation; therefore the disc would be of limited service. The latter is also objectionable because of its smaller absorption cross section which necessitates a larger disc, thus increasing the effect of the disc on the quantity to be measured.

B. Parameter Survey for 7-1/2" and 6-3/16" Lattices with Small Slugs -
E. J. Seppi, H. Neumann

Recently the Exponential Piles Sub-Unit has measured the bucklings, wet and dry, in the 7-1/2" and 6-3/16" lattices using 0.926" diameter slugs in 1.218" (outside diameter) process tubes. For purposes of comparison, parameter surveys for these assemblies have been carried out, using methods and formulae from HW-21374 and HW-22400 (both by G. E. Duvall). The results of this survey are quite obviously wrong, especially for the wet piles.

Since it is felt that the principal difficulty lies in the uranium utilization formula, this formula is being revised so as to account for the neutron utilization more accurately, including the effects of slug end caps. The resultant formula will be only slightly harder to apply than those formulae presently used, and it will be quite similar in structure.

C. Neutron Economy - E. J. Seppi

The fate of neutrons produced in the C and K Piles has been calculated using conventional lattice theory. The results are reported in HW-27993.

D. Diffusion Length in P-10 Lattices - H. Neumann

Consider an infinite reactor driven by an infinitely long line source of pure thermal neutrons. Located in a square lattice array about the source, there are infinitely long purely absorbing columns, parallel to the line source. If the asymptotic relaxation length of the neutron density in such a reactor is identified with the reactor thermal diffusion length, a small source calculation presents the following relationship among absorbing column blackness $\mathcal{B}$, reactor inverse diffusion length $\mathcal{H}$, moderator parameter and lattice dimensions:

$$\frac{1}{\mathcal{B}} = \frac{a}{2D_0\rho_0^2} \left[\frac{1}{\mathcal{H}^2 - \lambda^2} + \frac{1}{\lambda^2} - \frac{\rho_0 K_1(\lambda\rho_0)}{\lambda} - \frac{\rho_0^2}{2} K_0(\lambda a) \right] + \frac{\lambda a K_1(\lambda a)}{2};$$

a is the radius of the absorbing column, ρ_0 is the cell equivalent radius ($= \sqrt{\frac{1}{\pi}}$ x lattice spacing), λ is the moderator inverse diffusion length, and D_0 is the moderator diffusion coefficient.

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This formula was investigated in the following fashion: The Exponential Piles Sub-Unit has measured the reactor thermal diffusion length in several P-10 exponential piles. These several measured values were identified with values of λ^{-1} , and ρ was computed for each assembly. The results are:

<u>Lattice</u>	<u>$1/\lambda$ wet</u>	<u>ρ wet</u>	<u>$1/\lambda$ dry</u>	<u>ρ dry</u>
8-3/8"	16.11 cm	0.454	15.26 cm	0.518
8"	15.10 cm	0.474	14.56 cm	0.517
7-1/2"	14.3 cm	0.459		
7"	13.27 cm	0.463	12.51 cm	0.529
<u>Average</u>		0.463		0.521
<u>Standard Deviation</u>		0.007		0.019

The following graphite parameters and lattice dimensions were assumed.

$$\lambda^{-1} = 53.45 \text{ cm} \quad D_0 = 0.89 \text{ cm} \quad a = 2.196 \text{ cm}$$

The accuracy of the calculations is as follows:

An uncertainty in the measurement of λ^{-1} of ± 0.1 cm would lead to an uncertainty in ρ of about ∓ 0.007 .

An error in the value of λ^{-1} of ± 1 cm would imply an error in ρ of about ∓ 0.021 .

The absence of a systematic dependence of the calculated values of blackness on lattice spacing indicates that the "small source" model with constant process tube parameters is adequate for handling this problem in neutron diffusion.

III. Radiation Damage

A. Effects of Radiation on Chemical Reactions - J. Braunstein

A survey is being made of work that has been done on the chemistry of gases in the presence of ionizing radiations. It is hoped that some of the methods used and results obtained can be applied to problems involving gas reactions in the piles.

B. Thermal Conductivity of Dielectrics - G. W. Stuart

A survey of the literature on this subject is underway. It is hoped that previous work can be extended to include the effects of lattice distortions such as those caused by neutron bombardment.

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IV. Plant Assistance - J. O. Erkman

A. Assistance was given the local AEC office relative to the derivation of data presented graphically in HW-25176 by C. V. Larrick.

B. Equilibrium Iodine and Xenon Reactivity Effects

Following the method used by P. F. Gast in HW-23729, the following equations may be derived.

$$M_s = 4.40 Zw$$

$$L_s = \frac{1110 Z}{Z + \frac{0.1734}{w}}$$

where

M_s = Iodine poisoning in inhours

L_s = Xenon poisoning in inhours

w = Power in megawatts of the central tube

$$Z = \frac{\int_0^R [\text{FLUX}]^3 2\pi r dr}{\int_0^R [\text{FLUX}]^2 2\pi r dr}$$

If the flux is represented by a combination of Bessel functions across the buckled zone, the integrals may be evaluated from curves derived from data entered in the Technical Activities Report for March, 1953, HW-27636.

An alternative method is to use the data recorded by the tube-by-tube accounting equipment installed on the piles. Using this method, Z is evaluated directly, and the evaluation of flattening as an intermediate step is unnecessary.

Using the Bessel function representation of the flux, the accompanying graph of Xenon Poisoning vs Inhour Flattening illustrates the desirability of this method by comparison with values derived from the Xenon Tables, HW-25565. At large values of flattening, the tables give a decrease in xenon poisoning with a further increase in flattening, which is improbable.

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Figure 5

XENON POISONING
VS
INHOURS FLATTENING

W = Central Tube Power in MW.

— From New Equation
--- From HW-25565

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HW-28283

V. Reports Issued

HW-27463 - "Estimated Control Requirements for the Lattice Test Pile".
H. Neumann, 3/20/53

HW-27986 - "Neutron Diffusion and Random Walk, II", G. E. Duvall, 5/7/53

HW-27993 - "Summary of Neutron Economy C-Pile and K-Pile", E. J. Seppi,
5/7/53

HW-28038 - "A Study of the Fast to Slow Neutron Flux Ratio in the Core
of an Externally Driven Reactor", E. J. Seppi, 5/12/53

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