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GUIDE TO THE LITERATURE ON PILE CONTROL

P. J. Bendt

* * * * *

June 27, 1947

Date Received: 9/24/47 Date Issued: 10/6/47

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GUIDE TO THE LITERATURE ON PILE CONTROL

Foreword

This report has been typed from a card file assembled by Mr. Bendt while he was at the Clinton School on leave of absence from General Motors. In a number of cases the typed entries have gotten in incorrect order.

Time did not permit Mr. Bendt to work over the material again before he left, and so it has been subsequently issued as is. A number of older references have been missed in it, as well as newer ones which have appeared since the work stopped.

G. Young

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GUIDE TO THE LITERATURE ON PILE CONTROL

P. J. Bendt

Clinton Laboratories
27 June 1947

Summary

This report contains abstracts of approximately 250 reports containing information in some way related to the problem of pile control. The abstracts are arranged by subject into nine groups.

Purpose

The purpose of preparing these abstracts is (1) to form a convenient reference to the literature for anyone working on a pile control problem, and (2) to do the ground work for a comprehensive report covering the theory and practice of pile control, such as J. A. Wheeler wrote in 1944 (Principles of Nuclear Power, Chapter 22, Control, N-2292, 6-28-44).

8-p.43
9-p.50

Arrangement of the Abstracts

2-p.8
3-p.15
4-p.19
5-p.25
6-p.34
7-p.36

Theoretical calculations are covered in groups 1 through 4; experimental measurements in groups 5 through 7; description of control apparatus on specific piles in group 8; and instruments in group 9. At the end of each group reference is made to reports abstracted in other groups.

Within each group the abstracts are arranged in numerical order, with the "C" abstracts placed first.

Related Subjects Covered in Abstracts

In addition to pile control, reports on the following subjects have been abstracted:

(1) The temperature coefficient of reactivity.
(2) Calculation of linear extrapolation length.
(3) Neutron streaming in gaps.
(4) Delayed neutron periods and yields.
(5) Delayed gamma rays from fission fragments, and resulting photo-neutrons.
(6) Pile poisoning by Xe and Sm.

Sources of Reports that were Covered in the Survey

(1) All "C" reports listed on library index cards, and to which any reference could be found.
(2) All Argonne and Clinton Laboratory Monthly Reports from 1944 to date.
(3) All of the Los Alamos LA and LAMS series that are available, which is perhaps half the reports that exist.
(4) All the Montreal and Chalk River reports that are available, or to which reference was found; this covers perhaps half the recent reports, and includes progress reports for 1946.

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(5) All the letters and reports in the Pile Technology Section, Physics Division, Clinton Laboratory. (Gale Young, Section Leader).
(6) A very few recent reports from General Electric and N.E.P.A.
(7) Miscellaneous references from members of the Physics Division.

The Abstracts

Group (1). Theoretical reports. General control theory and survey reports. Reactivity change due to control rods. Calculating the critical mass. Size, position, heating and cooling of control rods. Equations for k effective. Control rods shadowing each other.

(CP-113, Metal. Project, Report for week ending; Group VI, E.P. Wigner, 6/6/'42).

One central absorbing rod 1/100 diameter of reactor decreases effective dimension by 12%, and one rod with 6 in a circle around it decreases effective size by a factor $\sqrt{2}$. Central rod must be cooled.

(C-197, On a Plant With Water Cooling, A. M. Weinberg, 8/'42).

p. 10 - The pile has six vertical control rods in an outer circle (for emergency), and one center rod (for continuous control). Outer rods are of iron and B_2 moving in stuffing boxes. Center rod will be water cooled, and by dissolving B in the water, the heat will be produced in the cooling solution.
p. 26 - The size of the pile is calculated.

(CP-314, Notes on Lecture, Fermi, 10/20/42).

One group equations on control of a spherical pile by concentric absorbing sphere. Pile equation is solved for different boundary conditions.

(CP-341, Metal. Project Monthly Report, Theoretical Grp. II, J. A. Wheeler, 11/15/'42).

The partial insertion of a control rod does not increase the number of neutrons lost by the pile, but causes a re-distribution of flux; the rod acts like a lightning rod. The neutron leakage remains unaltered, but the neutron production is decreased; a region of the pile is shielded by the rod action, this region being proportional to

$$\frac{c^3}{2\ln\left(\frac{2c}{e}r\right)}$$

where c is distance rod enters pile, r is radius of rod, e is base of natural logs. To calculate effect on neutron density, consider an imaginary source outside of the pile of the same dimensions as rod inside, the arrangement constitutes a dipole, from which neutron density is calculated in a manner analogous to electric potential.

(CP-387, Metal. Project, Report for Month Ending; Theor. Grp. II, J. A. Wheeler 12/15/42)

Calculations have been made on (1) k as a function of depth of entry of a control rod, (2) distribution of heat along a rod, (3) distribution of heat in

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the pile, for rectangular and circular reactors, and the mathematics compared to electromagnetic and heat conduction problems. No results or information is given.

(CP-430, Method of Measuring Value of K eff < 1., G. L. Weil, 1/5/'43).

An equation for (1 - k eff) is derived from the pile equation including a central point source of fast n.

A calibrated source was placed at center of West Stands pile, and counts made with control rod at critical position, and at a position 4.7 inches in from critical. Sensitivity of the rod was measured to be 2.1×10^{-5} change in k per conventional inch.

(CP-742, Critical Value of k for Cylindrical Pile and Thermal Control Rod, F. H. Murray, 6/22/'43).

Uses two-group theory; assumes Fermi slowing down equation; assumes central rod; uses boundary conditions fast nv goes to zero at radius of pile, and thermal nv goes to zero at radius of rod, and of pile. Rod is black to thermal n only. Equations

Fast n $\quad \Delta q - \frac{dq}{d\tau} = 0 , \qquad q = (nv)\text{fast}$

Thermal n $\quad \Delta Q - \eta^2 Q + q(\tau_1) = 0 \qquad Q = \frac{\lambda}{3} (nv)_{th}$

Newly created fast n $\quad q(0) = k \eta^2 Q , \qquad \eta^2 = \frac{3}{\lambda_s \lambda_a}$

Solutions are series in Bessel functions.

A graph is computed giving $\frac{(k-1) \text{ with rod}}{(k_0 - 1) \text{ no rod}}$, k referring to k_∞ needed to make pile critical, as a function of

$\frac{\text{radius of rod}}{\text{radius of pile}}$ for a rod black to all neutrons, and for a rod black to thermal neutrons only.

(CP-964, Metal. Project Monthly Report, Lattice Design Group, A. M. Weinberg, 9/25/'43).

The size and arrangement of Hanford safety rods is calculated assuming each has a cell $\sim$60 cm in radius, and computing the thermal utilisation of the rod. Usual equations and boundary conditions are given. A correction taking account that production of nascent thermals is lower near rod because it is a sink reduces the effeciency of a rod of 2.54 cm radius from 5.54% to 5.34%.

(CP-1069, Some Cases of Pile Activity Flattening, N. Morehouse, G. Young, 11/10/'43).

When control is effected by giving nv distribution a flat top, a minimum amount of absorbing material is required, and largest fraction of pile is operating at maximum intensity. Equations for average value of reactivity are given for spherical and cylindrical piles. The heating effects in a pile decrease the buckling more in the center than near the edge, and likewise produce partial flattening of the activity curve.

[redacted]

Graphs show the fractional increase in total output, and the ratio of radius of flat region to pile radius, as a function of $\frac{\text{excess } B}{B_o}$ where B_o is constant value of B which just makes pile operate; B is the buckling.

(CP-1175, Monthly Report, Pile Design Grp, G. Young, 12/25/'43).

Theoretical calculations on heating of the tip of a control rod indicate that the end section of length equal to the diameter will receive 2.3 times higher flux than the remainder of the rod, rather than 1.4 times higher, as was measured by Seren.

Calculations were made by assuming sinks along the length of the rod, such that the flux vanishes at the rod surface.

(CP-1389, Metal. Project Monthly Report, Lattice Design Grp, A. M. Weinberg 2/24/'44).

Simplified two-group theory, in which ordinary differential equations replace partial differential equations, has been applied to control rod effectiveness, and shows

$$\Delta k = \frac{2}{K_t^2 r_s^2}\left[1 + \frac{K_t^2}{K_f^2}\right]\left[\ln \frac{2}{\gamma K_1 r_o} - \frac{K_t^2}{K_f^2} \ln \frac{2}{\gamma K_2 r_o}\right]^{-1}$$

r_o is effective radius of rod; r_s is radius of pile region; K_t and K_f are reciprocal diffusion length and age, K_1 is radial buckling; $K_2^2 = K_t^2 + K_f^2$; $\ln \frac{2}{\gamma} = .116$.

Agreement with Morrison's measurements is within experimental error; theory may underestimate by 14% the effectiveness of Hanford rods.

(CP-1461, Efficiency of Control Rods which Absorb only Thermal Neutrons, Wigner, Weinberg, Williamson, 2/24/'44).

Assume there is the same probability at each collision of a fast n reaching thermal energy. Assume for boundary conditions (nv)th is zero at edge of pile and control rod, and ∇(nv) fast is zero at edge of rod; further approximation to ∇(nv) fast is zero at center of rod. The increase in local k to keep pile critical when rod is inserted is calculated for central rod in a cylinder, and also for a lattice of rods, each one central in a cell.

For small radii rod, efficiency of thermal rod is $\frac{L^2}{L^2 + \tau_o}$ times that of rod absorbing fast n as well as thermal n. For large radii rods, efficiencies tend to be equal. The effect of a control rod is partly due to increased leakage of n to outside; the excess outward leakage is computed.

For an array of control rods, the change in the Laplacian and in k necessary to keep pile critical is calculated, assuming $(nv)_{th}$ and $(nv)_{fast}$ have zero derivations at edge of each cell. Graphs comparing calculated results with CP-742 and experimental work by Morrison are given.

(CP-2182, Metal. Project Monthly Report, Physics Sec., L. W. Nordheim, 9/30/'44).

A new approach to solving the pile equation treats control rod as a sink. The equation $\Delta\varphi + K^2\varphi = 0$ is solved for prescribed singularities. $\varphi = \varphi_1 + \varphi_2$. φ_1 is solution with desired singularity. φ_2 is determined to fill boundary condition $\varphi_2(B) + \varphi_1(B) = 0$, where B is outer radius of pile. φ_2 can be found by elementary methods for a spherical pile with singularity at any point; a cylinder with sing. on any line parallel to axis; cylinder with sing. on any plane parallel to end; and a cylinder with any distribution of sing. on the axis.

(CP-2203, Metal. Project Monthly Report, Physics Sec., L. W. Nordheim, 11/30/'44).

Continuation of pile control theory from CP-2182, CP-2185. Effectiveness of off-axis control rod in cylindrical pile similar to Clinton Pile is given in a table. The effectiveness of two diametrically opposite control rods each at a distance r_o from center is calculated rigorously, with results (1) beyond a certain r_o the effectiveness of two rods is more than twice that of a single rod in the same position, (2) there is a certain r_o for which the effectiveness of two rods is a max. Table and figures give this effectiveness.

Influence of gaps on diffusion. Equations for the total flow are given for flow parallel to direction of gap, with certain restrictions, and are solved for a gap in a cylindrical pile for the case where gradient of nv is constant, and case where $nv = \cos Kz$.

(CP-2841, Monthly Physics Sec. II, L. W. Nordheim, 6/30/'45).

The effective radii for thermally black, and for thorium, control rods are calculated as a function of grams of 25/liter of reactor, and given in a table. For Δk of 1%, 5% and 10%, black rods have radii of order of 0.04 cm, 0.25 cm., and 0.65 cm, and thorium rods have radii of order of 0.34 cm, 0.80 cm, and 1.30 cm., respectively. Rigorous two-group theory (CP-2824) was used for the calculations; the equations are given.

(MonP-228, Monthly Report, Physics Sec. II, A. M. Weinberg, 1/15/'47).

Effectiveness of Th - H_2O - Al control rods in the high flux pile has been calculated assuming a central rod in a cell across whose boundary there is no net flux. A 3.9 cm raduis rod of 1 part Th, 1 part Al and 4 parts H_2O changes $\frac{\Delta k\ eff}{k}$ by 0.72 R where R is ratio of volume of rod to volume of active pile material in the cell.

(M-3194, Summary of New Pile Studies, G. Young, 10/22/'46).

Controls, p. 87 - Lists the types of controls that have been considered, and gives references for each.

Names special problems, such as getting productive use of captured neutrons, faster signaling and activation mechanisms, "blind spots" in intensity measuring instruments, control of fast neutron piles, for the purpose of giving references to each.

(MDDC-42, Theory of Pile Control Rods, R. Scalettar, L. W. Nordheim. Paper for Am. Phys. Soc. Meeting. 6/17/'46).

Elementary description of the principal effects of a control rod; additional absorption of neutrons; changed neutron leakage; changed neutron production. The important equations for one group and two group theory are given; extrapolation distances, boundary conditions, shadow effect of one rod on another are discussed. Effective radius for rods to take up a given Δk for infinitely long cylindrical pile are given, and the form of the solutions for a bare pile with two group theory is given.

(LA-399, Theory of Water-Tamped Water Boiler, E. Greuling, 9/27/'45).

The paper shows that simple diffusion treatment yields results in agreement with measurements, and also calculates the minimum critical mass of 25 in water tamped spherical, infinite cylindrical, and plane slab cores.

Safety calculations, p. 42. For each geometry there is an optimum water concentration for which the mass of 25 reaches a minimum. This concentration does not correspond to the minimum volume in which some mass of 25 can make the boiler critical.

Two types of safety curves are given: (1) minimum critical mass as a function of enrichment percentage. (2) minimum critical dimension for various uranium enrichments.

(N-2292, Principles of Nuclear Power, Chapter 22, Control, J. A. Wheeler, 6/28/'44).

142 page report covering thoroughly the complete theory of central at the time it was written, with applications and calculations to the Hanford Piles. Contains numerous charts and graphs of practical value, and of value as teaching aids.

The approach distinguishes two methods of calculating control: (1) as a change in the boundary conditions, (2) as a change in local reactivity.

Calculations in which the pile is divided into cells around each control rod are stressed. A section is devoted to pile periods and the speed of control. Numerous references to other reports are made.

(TPI-29, Preliminary Roport on Control Rods, F. T. Adler, 3/11/'46).

Not available.

(MPT-30, Progress Report, One-Group Theory of the Dependences of the Effectiveness of Control Rods on their Position in a Cylindrical Pile. F. T. Adler, 10/'45).

A single rod of effective radius 0.01 R where R is pile radius, is placed d from the center; the ratio of effectiveness relative to a central rod differs from $J_0^2(2.4\,\frac{d}{R})$ by not more than 20%. If 4 rods are placed d from the center, the effect per rod is less than for a single rod if $d/R < .23$, and is greater than for a single rod if $d/R > .23$. Only these results of calculations are given.

(MPT-31, Progress Report, Two-Group Theory of Control Rods in a Cylindrical Pile, F. T. Adler, 11/'45).

If extrapolation distance λ at a black rod in one-group theory is set equal to λ for thermal neutrons in two-group theory, increased by a definite amount which depends on pile properties, then the Laplacian computed by one-group for off-center control rod or ring of rods is nearly equal to that obtained by two-group theory. Calculations have been made for proposed NRX pile, Chalk River, assuming 3 rod radii, as correct boundary is not known.

Change in k due to rods is given by $\Delta k = M^2 . \Delta \beta^2$ where M^2 is migration area, $\Delta \beta^2$ is Laplacian. Results calculated for Δk are:

Eff. rod radius in units of reactor radius:

		.019	.025	.030
Inner rods,	1 rod	.58%	.74%	.80%
	2 rods	1.3%	1.6	1.8
Outer rods,	1 rod	.29%	.34%	.40%
	2 rods	.78	.94	1.1%
All 4 rods		2.2%	--	--

(ME-231, Cooling of the Shut-off rods in the NRX Pile, R. E. Newell, 4/24/'46).

The rods are air cooled; calculations of heat generated, heat removal and temp. use are made for normal operation and emergency conditions. Conclusions are: (1) Normal operation, max. difference in temp. between rod and cooling air is 48.5° C. (2) If cooling air fails in normal operation, no damage if pile is shut-down in a few minutes, with control rods. (3) Failure of cooling air during shut-down will cause no damage if tank is filled with D_2O. (4) One shut-off rod must not remain in the pile while it is operating. Temp. of rod will rise at rate of 270° C/min.

(NEPA No. 4, Progress Report; Controls, p. 23, 5/15/'47).

A brief description is given of chain reactors, of control by mechanical motion of part of the reactor, reflector, or of a control rod, and of pile stability considerations.

The pile simulator is mentioned, and its use in a control system, to anticipate reactor behavior, is suggested.

(8.44 Notes, Seminar in Nuclear Science and Engineering, M.I.T. Staff. Control and Operation of a Pile, p. 264, W. J. Oseroff, Summer/'46).

An elementary description of a pile, the effect of a control rod, and the power level, and pile-period monitoring circuits. It contains a lengthy discussion of construction and performance characteristics of ion chambers, and D. C. amplifiers.

References to abstracts in other groups:

	Group		Group
CP-510	(6)	CP-2187	(2)
CP-1088	(7)	CRP-287	(8)
CP-1088	(8)	CS-3026	(7)
CP-1252	(4)	MonP-196	(3)
CP-1252	(8)	MonP-216	(8)

Group (2). Theoretical reports. Kinematics of piles. Periods, stability, bubbles. Coolant turbulence calculations. Calculations relating to Clinton high flux pile. Calculations depending on delayed neutron periods.

(CP-65, Burst Method of Determining Approach to Self-Sustaining Reaction, H. W. Ibser, J. H. Manley, J. A. Wheeler, 5/'42).

Starting with the pile equations, the theory is developed giving the neutron density as a function of time, for small values of $(k-1)$; delayed neutron period data from C-35 is used. Temp. effects are neglected and very long periods result from the calculations.

The use of a time controlled neutron source and instantaneous recording of neutron density to determine $(K-1)$ is suggested. The decrease in flux from time of pulses to flux level a fraction of a second later would give, from curves calculated in the report, the value of $k-1$, $(k<1)$. The source could be pulsed 100 times a minute. The accuracy of the method would equal that of measuring the spacial variation of neutron induced activity, and the method could be developed into meter type indication.

(CP-291, Notes on Lecture, Fermi, 10/7/42).

Elementary equations relating k, pile period, and delayed neutrons.

(CP-349, Slow Control of a Chain Reaction, R. F. Christy, 11/17/'42).

Restricted to systems where neutron density n has small and slow variations and k has small variations. $\frac{d}{dt}(k-1) = -C_1\frac{\Delta}{\tau} - C_2\frac{d}{dt}\Delta$ where τ is lifetime of one generation; $\Delta = \left(\frac{n}{n_0} - 1\right)$; n is neutron density and n_0 is density to which n is stabilized. Best control is one which has C_2 dominant; but limitation is detection of slow change in n; detection of 1%/100 sec. is required. Control dependent on C_1 results in slow damped oscillations of n around n_0.

(CP-351, Variations of Power Output of a Running Pile, E. P. Wigner, 11/11/'42).

Effect of delayed n of 4 periods on pile equations with sudden change of k is studied, and steady state and transient solutions given. A method of "limits control" is described, that is applicable to piles with very slow period, and has these disadvantages. (1) unforseen variations in k must be

smaller than difference between limits to which k changes; (2) relatively large fluctuations in power output and temperature of pile take place.

(CL-697, Project Handbook, Chap. IV, E, Theory of the Slow Neutron Chain Reaction, 5/'45).

p. 27 Effeciency of control rods. The equation for Δk eff in terms of migration area, diffusion length, Fermi age and reactor dimensions of a central control rod in a cylindrical pile is given. See CP-1461.

p. 28 Time dependent pile equation. The equation for rate of change of neutron density $\frac{dn}{dt}$ is given. A table of delayed neutron periods and yields is given. The relation between excess k and pile period is given; the inhour is defined; approach of a pile to critical during construction is discussed, and transients are briefly mentioned.

(CP-884, Effect of Insertion of Safety Control Rod on Power Output of a Pile, J. Schwinger, 8/16/'43).

Rate at which neutron density diminishes depends on time for rod to reach final position, and on delayed neutrons:

$$\frac{d}{dt} n_\lambda (t) = -\sigma_\lambda n_\lambda (t) + w_\lambda n(t)$$

$$\frac{d}{dt} n(t) = \sum_\lambda \sigma_\lambda n_\lambda (t) + \left[k_e(t) - \sum_\lambda w_\lambda \right] n(t).$$

where n(t) is neutrons present; n_λ (t) is radioactive nuclii emitting neutron with mean life $\frac{1}{\sigma_\lambda}$; k_e is (k eff - 1); w_λ is probability of forming nucleus that emits delayed n.

Calculations give, if $\delta k = .02$, neutron density falls to $\sim$25% in 0.8 sec; and if $\delta k = .03$, to 18% in 0.7 sec. Calculations are for instantaneous insertion and for 0.93 sec. to accomplish insertion.

Equations are given for power production of pile at time t after insertion of rod, taking account of β and γ emission from fission fragments.

(CP-1295, Monthly Report, Phys. Sec. II, L. W. Nordheim, 2/29/'44).

A method of determining changes in k from the neutron density.

A formula is given for instantaneous value of k in inhours, in which in every term $\frac{dn}{dt}$ is evaluated at a time retarded by a delayed neutron period Ti. n is neutron density.

(CP-1428, Metal. Proj. Monthly Report, Physics Div., L. W. Nordheim, 4/15/'44).

It is estimated the fastest transient accuring with sudden change Δk, with period $1/T = k\,\delta/\ell$ where δ is fraction of delayed neutrons with lifetime ℓ, has amplitude of order $\frac{\Delta k}{k\delta}$ compared to amplitude of fundamental, and transients of periods between delayed neutron periods have smaller but comparable intensity.

[redacted]

(CP-1147, Determination of Time Variations of k in a Going Pile, L. W. Nordheim, 5/10/'44).

Time variations in k can be determined from observed variations in neutron density, the equations are derived for Δk constant in time and Δk a function of time. For Δk constant, (see CP-641),

$$\Delta \text{ inhour} = \frac{54}{\tau} + \frac{33}{\tau+0.7} + \frac{1139}{\tau+6.5} + \frac{1793}{\tau+34} + \frac{585}{\tau+83}$$

where τ is pile period. For Δk a function of time,

$$\Delta \text{ inh} = \frac{1}{n}\left[B_o \frac{dn}{dt} + \sum_i B_i \left[\frac{dn}{dt'}\right]\right] \text{ where } t' = t - T_i \text{ where } n \text{ is neutron}$$

density, T_i is period of delayed neutrons; and where

$$B_o = \frac{3600}{1+(k/\ell)\sum \delta_i T_i} \qquad B_i = \frac{3600\,(k/\ell)\delta_i T_i}{1+(k/\ell)\sum \delta_i T_i}$$

where δ_i is fraction of delayed n of period T_i and ℓ is lifetime of neutrons in the pile. Second equation is for slow changes of the power output.

(CP-1611, Metal. Project Monthly Report, Physics Div., L. W. Nordheim, 5/15/'44).

Equations are derived giving time response of pile to small change of k, and taking temp. effect into account. New power and temp. levels are reached asymptotically with changes determined by

$$\Delta\theta = \frac{1}{\alpha}\Delta k \;; \qquad \Delta P = h\,\Delta\theta$$

θ = temp. P = power output, α = effective temp. coef; h = total heat transfer coef.

(CP-2185, Metal. Proj. Monthly Report, Physics Sec., L. W. Nordheim, 10/31/'44).

Transients at sudden changes in pile reactivity. The reaction of a pile for change in Δk consists of superposition of 5 exponentials, for delayed neutrons with four periods. The equation relating periods with Δk is given and a table of length of periods and their amplitudes for changes in Δk from $\Delta k = 0$ to $\Delta k = 1$ (k goes to zero).

Under theory of pile controls, the exact equations are given for the case of cylindrical pile with rod parallel to axis but displaced arbitrary distance from center. Calculated results are compared with those obtained using usual weight factor method. and it is shown that weight factor can give appreciable error.

(CP-2222, Monthly Report, Physics Sec. II, L. W. Nordheim, 12/31/'44).

Kinematics of Enriched piles, p.24. Two-group theory is used, see p.14. Equations are given for the pile period T, neutron lifetime ℓ, multiplication constant k, and it is found $\Delta k \approx \mu_1^2 \Delta M^2$ where $-\mu_1^2$ is the Laplacian and M^2 the migration area. For certain conditions, $\Delta k = .6\%$ for change of concentration

of 1% and = 1.4% for change in density of 1%. The pile follows changed conditions rapidly, and bubbling causes stability with respect to power by decreasing reactivity.

(CP-2568, Monthly Report, Physics Sec. II, L. W. Nordheim, 1/31/'45).

Reactivity changes in piles, p. 16. A general equation for $\frac{\Delta k\ eff}{k}$ is given, in which terms represent changes in k, migration area, pile size, and reflector effectiveness. The equation is modified for the special cases of change in density due to bubbling in a pile, change in concentration, and change in resonance absorption.

The effect of uniform change in temp. of the pile or the reflector is studied in detail. It is assumed the fission and absorption cross sections follow a 1/v law. The effects treated are leakage effect, thermal expansion of pile fluid, change in the neutrons produced per neutron absorbed, and change in resonance absorption, the last two being found negligible.

(CP-2601, Monthly Report, Physics Sec. II, L. W. Nordheim, 3/31/'45).

Stability Problem of Piles. See CP-2589.

Perturbation equations describing pile stability in the neighborhood of a stationary state are derived. Considered are reactivity changes due to temp. effect, gas bubbling, and automatic control. The impedance equation is solved for the natural periods of the system, by use of a graph of the functions, and real and complex roots are indicated.

Response of Pile to Periodic Perturbations.

In order to obtain limits for the fluctuations that can be tolerated, a Fourier decomposition of the perturbation is performed, and the response to each component determined. The equations are given for fluctuations in gas removal, reactivity, and heat transfer. The pile behavior is discussed for different frequency regions.

(CP-2813, Monthly Report, Physics Sec. II, L. W. Nordheim, 4/30/'45).

Kinematics of enriched piles, p. 13. See CP-2601.

Equations for the change in temp. and power level are given for applied $\delta k(t)$; δk may be an impulse. It is found that power and temp. change linearly during the time of impulse, and decay to equilibrium afterwards; tables are given of numerical values for periods and coefficients for large bubbling and no bubbling of pile fluid. The danger of short impulses is that they cause automatic shutdown. The equations are perturbation equations, which are valid only if $\int_0^t \delta k(t)dt$ is $<< \ell$, ℓ being the lifetime of neutron in the pile. The consequences of a pumping failure in a circulating enriched pile are evaluated, and it is found that the temp. rise is not rapid.

(CP-2824, Metal Proj. Monthly Report, Physics Sec. L. W. Nordheim, 5/31/'45).

A two-group theory dealing with small inhomogeneous disturbances in piles by

a weight formula, which is used on a composite pile structure with different properties in different regions is given. Solutions of diffusion equations are exponentials; the adjoint problem is set up; a perturbation theory is worked out. Method is applied to calculating pile period.

Control rod theory continuation of CP-2185. The pile equations are solved for a single control rod at distance r_0 from axis of cylindrical pile for reactor and reflector by one group theory and for bare reactor by two-group theory. Control rod radius is given for rod at center of pile.

(CP-2841, Monthly Report, Physics Sec. I, A. H. Snell, 6/30/'45).

Another formula relating Δk to pile periods is given, (See CP-641, CP-1447)

$$\frac{\frac{54}{P} + \frac{33}{P \mp 0.7} + \frac{1139}{P \mp 6.5} + \frac{1793}{P \mp 34.0} + \frac{585}{P \mp 83}}{1 + \frac{33}{P \mp 0.7} + \frac{1139}{P \mp 6.5} + \frac{1793}{P \mp 34.0} + \frac{585}{P \mp 83}}$$

For neg. pile periods the neg. signs are to be used. The equation was checked by operating Clinton pile at low power and producing a series of negative pile periods around 83 sec. No discontinuties indicated by the equation observed.

(CP-2926, Metal Project Monthly Report, Physics Div., A. J. Dempster, 4/15/'45).

p. 24, Bubbles. If bubbles are created instantaneously with power, the pile is stable if the decay curve of k loss with time as bubbles rise to top is concave upward everywhere; with other shapes it may be unstable.

(MonP-3, Monthly Report, Physics Sec. II, A. M. Weinberg, 7/31/'45).

Temp. and Concentration Coef. of Pile.

For the high flux pile being designed at Clinton, the following table is given.

temp. change	20° - 30°	20° - 40°	20° - 50°	20° - 60°	20° - 70°	20° - 80°	20° - 90°
$\frac{\Delta k \text{ eff}}{k}$	-.00897	-.0184	-.0284	-.0363	-.0497	-.0608	-.0723

See MonP-8 for corrections. See CP-2824 and MonP-3, p. 9 for method of calculation, by perturbation theory.

(MonP-8, Monthly Report, Physics Sec. II, L. W. Nordheim, 8/31/'45).

Perturbation theory, p. 10. A change in the equation for $\frac{\Delta k \text{ eff}}{k}$ due to change in the temp. of the reacting solution, which causes a change in the diffusion constant of the reactor, and thus in the boundary condition, is worked out.

The new term is a surface integral over the boundary of the reactor.

Temp. fluctuations in a cylinder resulting from trubulence; investigation of temp. fluctuation at a point in a moving fluid which is heated at the samd time. An expression is derived for $(\theta_2 - \theta_1)^2$ where θ_2 and θ_1 are 2 successive measurements of the temp. fluctuations. Temp. coef. of enriched pile, p. 13; this is high flux pile being designed at Clinton Lab. A table of results is given

T° C.	10	20	30	40	50	60	70
$\frac{\Delta k \text{ eff}}{k}$	-.0085	-.017	-.026	-.035	-.045	-.054	-.065

(MonP-17, Monthly Report, Physics Sec II, A. M. Weinberg, 9/31/'45).

Turbulent fluctuations in homogenous pile. Power fluctuations are given by

$$\left(\overline{\left(\frac{\Delta p}{p}\right)^2}\right)^{\frac{1}{2}} = \frac{1}{\beta}\left(\overline{\left(\frac{\Delta k \text{ eff}}{k}\right)^2}\right)^{\frac{1}{2}}$$

for small Δk, where β is effective fraction of fission neutrons which are delayed. For the high flux pile, these power fluctuations are estimated to be 20%, for temp. coef. of 10^{-3}/oC., and $\beta = \frac{1}{2}\%$, and $\frac{\Delta k \text{ eff}}{k}$ due to turbulence $\cong$ .001.

Reflector temp. coef. p. 10. For the proposed high flux pile, the effect on k of a temp. changes in the reflector are tabulated:

Reflector temp. change	$20^\circ - 30^\circ$	$20^\circ - 40^\circ$	$20^\circ - 50^\circ$	$20^\circ - 60^\circ$	$20^\circ - 70^\circ$	$20^\circ - 80^\circ$	$20^\circ - 90^\circ$
$\frac{\Delta k \text{ eff}}{k}$	-.0004	-.0010	-.0018	-.0027	-.0038	-.0050	-.0064

(MonP-85, Monthly Report, Physics Sec., II, A. M. Weinberg, 3/31/'46).

Reactivity changes in a flat fluid surface pile due to bubbling. If the height of a pile that produces 3000 cc. of gas per sec. is held fixed, $\frac{\partial k \text{ eff}}{k}$ due to bubbling is approximately 0.6%. If the bubble velocity varies inversely as the temp., the stability of a pile is better than if bubble velocity varies with temp.

(MonP-104, Monthly Report, Physics Sec, II, A. M. Weinberg, 4/31/'46).

Reactivity change due to bubbling in pile with reflector. Effect of bubbles on multiplication constant is computed with the aid of a bare cylindrical reactor equivalent to reactor and reflector.

(MonP-151, Monthly Report, Physics Sec, II, A. M. Weinberg, 7/31/'46).

Temp. Coef. of Plutonium Thermal Piles.
The temp. coef. may be positive; the Pu resonance at 0.3 ev is sufficiently

broad to cause absorption and fission in a Maxwellian distribution of n to increase with temp. The coef. is dangerously large if the thermal utilization is small. The following table is given:

k	f	R	$\frac{\Delta k \text{ eff}}{k}$ per 10° temp. rise
1.00	.505	∞	+ .48%
1.06	.535	5	+ .40%
1.43	.722	1.67	+ .05%
1.77	.893	1	- .15%

where f is thermal utilization and R is radius of graphite pile in meters. Pile is prompt critical for 10° rise if $f < .57$.

(MonP-228, Monthly Report, Physics Sec., II, A. M. Weinberg, 1/15/'47).

Time Lag of Thermal Neutron Signal.

When a sudden burst of thermal neutrons diffuses, the time for the signal to reach a distance x is $x^2/2D$ where D is the diffusion coef.; this amounts to a millisec to travel 20 cm. in graphite, which is long for the control circuits of the high flux pile.

The above delay suggests the diffusion coef. can be measured directly.

(MPT-33, Progress Report; Effect of Resolving Time, G. M. Volkoff, 2/'46).

Observed pile fluctuations will be decreased due to elimination of short periods by a measuring instrument having a resolving time $\Delta\tau$. Equations are given for the mean square fluctuations and for the normalized spectrum of fluctuations.

For the Zeep pile, the decrease in fluctuation is negligible except at powers of a fraction of a watt; greatest part of the fluctuations are long period.

(TL-4, Multiplying Media, Critical Size, Exponential Experiment, Systems Less than Critical Size, G. Volkoff; Lecture, 11/'44).

p. 16 The approach to critical condition is discussed.

(TL-6, Time Dependent Phenomena (Pile Kinematics) G. Volkoff; Lecture, 1/'45).

Contents:

p. 2 - Instantaneous neutron model of a chain reaction.

p. 6 - The effect of delayed neutrons.

p. 11 - The reactivity of the pile (Inhour formula).

p. 14 - The effect of photo neutrons, in D_2O piles.

p. 15 - Transient phenomena due to delayed neutrons.

This is a lengthy and comprehensive discussion of the above named subjects.

References to abstracts in other groups

	Group		Group
CP-641	(6)	MonP-74	(4)
CP-1173	(8)	MonP-104	(4)
CP-1461	(1)	MonP-151	(4)
CP-2589	(3)	MonP-206	(8)
MonP-3	(3)	MonP-271	(3)
MonP-56	(4)	ANL-RGS-6	(3)
		N-2292	(1)

Group (3). Theoretical reports. Control of special type piles. Enriched piles, circulating piles, homogenous solution piles. Special types of control. Gap control, curtain control, liquid alloy control. Calculations on BeO power pile.

(CP-360, Memo on Bi Cooled Power Unit, L. Szilard, 11/23/'42).

A liquid alloy containing Bi, Pb, Sn, and Cd is contained in a pipe in a closed circuit, and fills the portion of the pipe in the pile. Starting a pump pumps the alloy out of the pile; the pump is controlled by a transformer, which is controlled by the radiation intensity. In the event of pump failure, alloy again flows into pile. Alloy is in steel tubes, cooled by Bi flowing around tube.

This is for a Bi cooled, unenriched U-carbide and graphite pile, for conversion of 28 to Pu.

(CP-1121, Displacement of Delayed Neutrons in Homogeneous Pile, G. Young, 12/7/'43).

Short delay periods. The motion of pile slurry is a constant mean flow superimposed on the fluctuating motion of turbulence; the turbulence is analyzed as equivalent to spreading the particles in an expanding sphere. The delayed neutron contribution to k is multiplied by a factor $(1 - \Delta^2)$ where Δ is the distance the slurry flowed during the delay period; more complicated expressions are given.

Long delay periods. Slurry is stirred about so emissions occur equally throughout the system. If fraction f of the slurry volume is outside the pile, the contribution to k is multiplied by $.61(1-f)$ for a spherical pile and $.53(1-f)$ for a cubical pile.

(CP-2589, Monthly Report, Physics Sec. II, L. W. Nordheim, 2/28/'45).

See CP-2568. Progress report on a study of behavior of homogenous solution piles. Temp. coef., concentration coef., and density coef. are defined, as these factors cause change in reactivity. Equations for average behavior and steady state solutions are given; equations for small perturbation are derived. Flashing the pile with large excess k is studied; the sudden temp. rise of pile material temp. above coolant temp. is twice the equilibrium temp. difference as determined by the excess reactivity; the temp. period is $\ell^x = \frac{\ell}{\delta k - k\beta}$, where ℓ is neutron lifetime, δk is excess reactivity and β is fraction of delayed neutrons. For a

D_2O pile, $\ell = 10^{-3}$ sec, and for $(\delta k - \beta k) = 10\%$, then $\ell^x \approx .01$ sec. If time for formation of gas bubbles is long, the temp. rise for above will be 400° C.

(CP-3444, Pile with Transverse Gap, G. Young, 2/18/'46).

A discussion of a cylindrical pile with end reflectors and transverse gap. The cooling of the pile, and consequently the power output are treated. If coolant enters center gap, it is coldest where heat production and temp. drop is greatest. To get same ratio of maximum temp. in pile to coolant temp. rise, with center entrance, the stream diameter must be reduced by 1.4; the pressure drop will be reduced by 1.3; the power output and coolant circulation will be doubled. Opening the gap to change reactivity of pile by $\sim$ 20% changes above temp. ratio by 18%.

(CS-135, Meetings of Eng. Council, 6/18/'42).

p. 7 Suggestion is made that thorium powder could be blown through a pile for control; also Freon gas for small amounts of control, Boron carbide for large control. Contains no information.

(MonP-3, Monthly Report, Physics Sec. II, A. M. Weinberg, 7/31/'45).

Stability of circulating enriched pile. Equations relating power and variations in k for time intervals $<$ 1/5 liquid circulation period simplify so analysis of Nordheim can be applied. $\frac{\delta P}{P} = \frac{1}{Z} \frac{\delta k \text{ eff}}{k}$ where P is power and Z is pile impedance.

Control of enriched pile. Describing control in terms of effective reactivity change $\frac{(\Delta k) \text{ eff}}{K}$ takes account of change in migration area.

K expression is related to relative change in 25 concentration, C_{25}, $\frac{(\Delta k) \text{ eff}}{K} = .446 \frac{\Delta C_{25}}{C_{25}}$. A black control rod with 2.3 cm. radius in the center of bare infinite cylindrical pile will neutralize $\frac{(\Delta k) \text{ eff}}{K} = 10.7\%$. A black control rod in the reflector 5 cm. from interface with radius 5.2 cm. in cylindrical pile of given dimensions neutralizes $\frac{(\Delta k) \text{ eff}}{K} = 0.63\%$. Calculations on a B curtain in the reflector of an infinite slab pile 13.3 cm. and 10.4 cm. from interface indicate it will neutralize $\frac{(\Delta k) \text{ eff}}{K} = 10\%$ and $\cong$ 20% respectively.

(MonP-8, Monthly Report, Physics Sec. II, L. W. Nordheim, 8/31/'45).

Curtain Control Sheet. The effectiveness of a Cd curtain around 60 cm. radius and 150 cm. high cylindrical reactor in infinite D_2O reflector is calculated. The following table is given:

Concentration of solution (gr. of 25/liter D_2O)	1.03	1.16	1.29
Δk eff/k	0	5.7%	11.7%
y(cm.)	18.3	10.5	5.5

[redacted]

where y is distance of curtain from edge of reactor tank, plus 1.7 cm. $\frac{\Delta k\ eff}{k}$ is the reactivity taken up by the curtain. See MonP-3, p. 12.

(MonP-24, Monthly Report, Physics Sec. II, A. M. Weinberg, 10/31/'45).

Split curtain control. A black curtain partly surrounds a cylindrical pile, and it is desired to calculate critical pile size as a function of the angle α_o subtended by the opening. The problem is solved for $\alpha_o << 2\pi$ and for $(2\pi - \alpha_o) << 2\pi$ (narrow strip of Cd). It is found for these cases change in critical radius is proportional to $\frac{\alpha_o}{2\pi}$ or $\frac{(2\pi - \alpha_o}{2\pi}$, constant of proportionality being of order unity.

(MonP-178, Monthly Report, Physics Sec. II, A. M. Weinberg, 9/30/'46).

A Cd sheet that cuts the high flux heterogenous pile and reflector in two equal halves is nearly sufficient to control a 3.5 kg pile, the overall margin of control being 10% $\frac{\Delta k\ eff}{k}$. Calculations are in progress on how many Th sheets are needed to do the same.

(MonP-196, Monthly Report, Physics Sec. II, A. M. Weinberg, 10/31/'46).

The thickness of a Th sheet and radius of rods necessary to control piles of different shape surrounded by Be and H_2O reflectors is tabulated:

Shape of Pile	k	Thick. of Th absorber	Critical k	23 produced per 25 destroyed
Rectangular 40x40x60 cm	1.606	1.86 cm	1.36	8.57 %
	1.55	1.46 cm	1.36	8.11 %
	1.50	0.50 cm	1.36	5.76 %
Cylinder 22.6 cm radius 60 cm height	1.606	5.85 cm radius	1.32	Rods
	1.606	4.81 cm radius	1.41	

(MonP-271, Control Problem in Piles Capable of Very Short Periods, H. W. Newson, 4/21/'47).

A comprehensive report on control of piles with large excess reactivity. The operation is divided into power level ranges, in units of operating power: Power range is 1 to 10^{-3}, Period range is 10^{-3} to 10^{-6}; Counter range is 10^{-6} to 10^{-11}, and Source range is 10^{-11} to 10^{-18}. Problem of background radiation in instruments, and time available for start up is discussed. The equations for growth of neutron intensity, and permissible periods during start up are discussed. Accidents and available excess k that can be controlled is treated. Control activated by measurement of pile period, and the rise in neutron intensity while control operates is covered. Control in the different power-level ranges; transients; and control of different types of piles is discussed. A table compares periods, total motion of control rod, total k of control rod, start up time, maximum rate of increase of k, for the H_2O high flux pile, D_2O high flux pile, a typical thermal power pile and a typical fast neutron pile.

(MUC-RGS-AVM-5, Control Problem and Critical Size of an Enriched BeO Moderated Pile, A. V. Martin, 5/15/'46).

A number of calculations are made of the critical size of reactors, and of the required number of control rods, for a fresh pile, and for one containing Xe poisoning. The theory of CP-1461 is used; actual data from MUC-KW-60 and MUC-KW-61 is used.

The effective radius of a control rod surrounded by coolant is computed, using extrapolation length computed from theory of MT-135. An equation is given for total number of neutrons leaking from the pile per sec. Tables are given for max. theoretical conversion ratio and for no. of control rods as a function of $\frac{\text{wt of } UO_2}{\text{wt of BeO}}$; also for ratio of buckling B when pile is hot to B for pile cold, and of B max. to B for pile cold.

(MUC-KW-58, Slow Changes in the Laplacian of a Thermal Pile, K. Way, 12/28/'45).

In start up temp. rise of 500° C, of BeO pile, k changes slightly but diffusion length L^2 changes by $\sim$1.6 and the buckling B by $\sim$ 1.45. The limiting change in B due to Xe poisoning is 7.3%.

The following other causes of change in B are computed for 1 year's operation of the pile: depletion of 25 (from 20% enriched U); poisoning from radioactive fission products, Sm^{149}, other stable fission products, and neutron reactions on Be. A table of results is given, for two power levels. The Be+n reactions are listed and discussed.

The change in B must be compensated for by control devices.

(MUC-JEW-127, Current Status of Work on High Temp. Oxide Pile, J. E. Willard, F. Daniels, 6/21/'46).

Control, p. 16. Refers to BeO power pile. In a high temp. pile, temp. coef. of the pile causes a large change in the reactivity, making the start up require great care and long time.

It has been calculated 7 control rods 2½ inches in diameter will control the pile. Less sensitive rods will be used during the start, to keep temp. rise carefully controlled. Gives no additional information.

(ANL-RGS-6, Transient Behavior of the BeO Pile, R. G. Sachs, 8/28/'46).

Transient behavior is treated in order to obtain requirements for control. Pile will oscillate with increasing amplitude unless temp. of entering He coolant is stabilized; this oscillation must be avoided at power operation. If coolant temp. is stabilized, pile undergoes damped oscillations if radiative heat transfer is neglected; radiative heat transfer introduces increase in amplitude of oscillations which is controllable.

The unstable oscillation is introduced by recycling the coolant, making temp. proportional to power in the pile. The period of oscillation in a hot pile is 5 times smaller than in a cold pile, but damping is the same. The extensive equations used in these calculations are given, and start up procedure is discussed in detail, accompanied by graphs of the pile behavior. This is a major report on the control of the BeO power pile.

References to abstracts in other groups:

	Group		Group
CP-3443	(4)	MonP-17	(2)
CP-3443	(8)	MonP-206	(8)
MonP-3	(2)	MonP-216	(8)
MonP-8	(2)		

Group (4). Theoretical reports. Neutron streaming in gaps. Flux from an open channel. Calculations on the linear extrapolation length. Thermal utilization of neutrons. Reactivity change due to pile poisoning and depletion. Depletion and poisoning intervals. Build up of poison during shutdown.

(CP-341, Metal. Project Monthly Report, Physics Group VI, E. P. Wigner, 11/15/'42).

Calculations indicate a pile can be operated until 1/3 of the 25 is used up before poisoning stops operation. Results depend critically on the ratio of thermal absorptions of 28 and 25; ratio of cross sections of 49 and 25; and on the average cross section of fission products. A geometry in which resonance absorption is increased at expense of thermal loss increases the lifetime of the pile.

(CP-1252, Neutron Flux from a Channel in the Pile, H. Soodak, G. Nordheim, L. W. Nordheim, 1/18/'44).

The neutron flux from an open channel is calculated, and the result utilized to obtain the heating of the tip of a control rod at any position outside the actual pile. The equations are derived from elementary equations. A table gives the heating in the rod tip in calories/sec, as a function of the ratio of distance outside pile to radius of rod, and assuming maximum thermal flux at pile center equals 5.5×10^{13}. Simplifying assumptions are made in the calculations.

(CP-1858, Monthly Report, Physics Sec. II, L. W. Nordheim, 7/31/'44).

Influence of streaming in an exponential pile with gap geometry. See CP-2019. Neutron distribution in direction of gaps, z, is $\varphi = e^{-bz} + R \frac{L^2}{M^2} J(z)$ where L is diffusion length, M^2 migration area, R ratio of flux from M^2 source into gap to that into pile elements, b is reciprocal relaxation length; J(z) is an integral given in the report. A table of corrections to relaxation length measurement, due to streaming, is given for a specific pile, and is found to be less than 1%. It is concluded streaming will not interfere with exponential experiments.

(CP-1883, Monthly Report, Physics Sec II, L. W. Nordheim, 8/15/'44).

Longitudinal gap along a cell produces anisotropy of migration. An approximate expression is given for the additional diffusion coef. along the gap, $D_I = \frac{S}{A} (\overline{Z^2})$ where A is cross section of cell exclusive of gap, S is circumference of gap, $\overline{Z^2}$ is mean square component along the gap of the distance a neutron travels in the gap, when emerging from pile elements. Diffusion coef. in transverse direction can be obtained assuming a homogeneous expansion

of the pile material across the gap.

(CP-2019, Monthly Report, Physics Sec. II, L. W. Nordheim, 8/31/'44).

Equation for extra flow in Z direction due to presence of a gap with sides parallel to Z, but of arbitrary cross section, per unit $\frac{d\,rw}{dZ}$ in the gap, is (see CP-1883)

$$F_I = \frac{1}{16}\int ds \int \rho^2 \cos\varphi\, d\varphi + \frac{\lambda}{6\pi}\int ds \int \rho \cos\varphi\, d\varphi$$

and the extra flow in the pile due to presence of gap is

$$F_{II} = \frac{\lambda}{6\pi}\int ds \int \rho \cos\varphi\, d\varphi$$

, where ds is element of gap circumference, φ is angle to normal of ds in meridional plane, ρ is distance to other gap side in direction φ ; λ is transport free path in pile. Equations and values of a form function are given for an annular gap.

(CP-2292, Pile Reactivity During Shutdown, F. L. Friedman, 10/22/'44),

The Xe^{135} decay chain is analysed. The loss of reactivity during operation is computed, and the further loss of reactivity after shutdown, and dead time of the pile is computed as a function of the power. At Hanford, dead time is about 20 hours at 1.5 MW/ton. To keep pile alive during shutdown, 0.4 (loss of k) must be kept in excess in pile during operation. Results of calculations are given on graphs.

(CP-3443, Effect of Gaps on Pile Reactivity, M. G. and M. L. Goldberger, J. E. Wilkins, 2/20/'46).

Equations of neutrons emerging from a surface are discussed. The equations governing the effect of a cylictrical hole axial in a cylindrical pile, and of a transverse gap cutting a cylindrical pile in two equal parts, are worked out. Certain mathematical idealizations are made. Variations of nv at the surface parallel to the gap are ignored; these become important as the gap approaches zero. End effects are also neglected. Graphs of B/B_o where B is buckling including gap and B_o is buckling without gap for optimum cyclinders are given as functions of gap diminsion/radius of cylindrical reactors.

Calculations are for bare piles: a reflector over the hole would decrease the effeciency of the control. Conclusion is that $\sim$15% change in k can be obtained from cylindrical hole 10 cm. in radius, or transverse gap 10 cm. wide.

(MonP-56, Monthly Report, Physics Section II, A. M. Weinberg, 1/31/'46).

Xe poisoning in pile. In enriched pile, Xe rise on shutdown is much larger than calculated by Friedman, CP-2292. The ratio of max. Xe to steady state Xe is tabulated for different fluxes:

Flux	1×10^{13}	5×10^{13}	1×10^{14}	2×10^{14}	4×10^{14}	1×10^{15}
$Xe\ max/Xe_o$	1.3	3.0	5.1	9.7	22.4	47.0
t (hours)	6.7	11.1	11.1	11.1	11.1	11.1

Proposed high flux pile has flux $\sim 4 \times 10^{14}$. The time of shutdown after an accidental scram will be about 3 days.

(MonP-74, Monthly Report, Physics Sec. II, A. M. Weinberg, 2/28/'46).

Xe instability of enriched Pile; the preliminary calculations show the high flux pile instability associated with Xe has a period of about 50 sec, at a flux of about 2×10^{14}. The instability is not serious if the temp. coef. is sufficiently negative; in H_2O cooled pile the temp. is less sensitive to power than in D_2O cooled pile, and hence H_2O cooled pile is less stable to power change.

(MonP-85, Monthly Report, Physics Sec. II, A. M. Weinberg, 3/31/'46).

Xe poisoning and pile stability. Because reactivity depends on temp., bubble formation, and poisoning as well as control rod position, piles have an equilibrium power; stability depends on whether deviations decay or build up. Taking into account Xe and temp., but not bubbles, the following periods are computed from the impedance equation, CP-2601.

	Clinton Pile	Hanford Pile	High Flux Pile
Xe alone	98 min.	11 min.	0.9 min.
Xe plus temp.	stable	14 min.	8 min.

(MonP-104, Monthly Report, Physics Sec. II, A. M. Weinberg, 4/30/'46).

Samarium poisoning in new high flux pile. Poisoning is defined: $p = \frac{N^{Sm}\,\sigma_a\,Sm}{N^{25}\,\sigma_a\,25}$. In steady state operation Sm reduces thermal utilization by approx. its fission yield; after shutdown the amount of Sm increases; the poisoning can reach a max. of 5.8% at flux of 4×10^{14}. A table is given of poisoning f at different fluxes at times after shutdown.

(MonP-151, Monthly Report, Physics Sec. II, A. M. Weinberg, 7/31/'46).

Calculation of Δk eff/k for a pile with non-uniform depletion. In the new high flux pile depletion of 25 causes large change in k after several days operation. Calculating this change, a variational method instead of first order perturbation has been used, and numerical density of 25 at any point r is assumed to be

$$N^{25} = N_o^{25} \exp -.022\,T \frac{\sin \frac{\pi r}{R}}{\frac{\pi r}{R}}$$

where R is radius of pile, central flux assumed to be 4×10^{14}. Table is given of $\frac{\Delta k\ eff}{k}$.

k_o	1 day	10 days	20 days
1.4	.86%	9.0%	19.2%
1.6	.80%	8.4%	17.8%

(MonP-284, Pile Extrapolation Distance According to Two-group Theory, B. I. Spinrad, 4/15/'47).

It is often essential to know the leakage of neutrons from unreflected surfaces in terms of the buckling B perpendicular to the surface. In two group theory λ transport may differ for the groups, but to obtain simple coupled solutions to the pile equation, B must be taken the same for both groups. The extrapolation length is derived for slab pile of infinite extent and thickness $\gg \lambda$ transport, and result may be applied to any pile in which dimensions are large compared to λ_t. The equations are derived; final equation is

$$H - h = 0.71 \left[\lambda_{tf} + \frac{L^2}{\tau} \frac{(1 + .71 \frac{\lambda_{tf}}{L})}{(1 + .71 \frac{\lambda_{ts}}{L})} (\lambda_{ts} - \lambda_{tf}) \right]$$

for Fermi age $\tau \gg L^2$; λ_{tf} and λ_{ts} are fast and slow transport m.f.p., L^2 is diffusion length, and H - h is difference between extrapolated and physical pile dimension.

(MonP-314, Quarterly Report, Extrapolation Distance in a Bare Pile, B. I. Spinrad, 6/21/'47).

p. 37 The extrapolation distance for a thermal pile in which Fermi age $\tau \gg L^2$ is obtained by two group theory, and is

$$H - h \approx 0.71 \left[\lambda_{tf} + \frac{L^2}{\tau} \frac{(1 + .71 \frac{\lambda_{tf}}{L})}{(1 + .71 \frac{\lambda_{ts}}{L})} (\lambda_{ts} - \lambda_{tf}) \right]$$

where H - h is difference between extrapolated and physical pile dimension and λ_{tf} and λ_{ts} are fast and slow transport m.f.p. See MonP-284.

(CL-GY-1, Formulation of the Fission Product Poisoning Problem, Gale Young, 4/12/'46).

The report deals with reprocessing of pile materials, and on the comparable poisoning that results when metal is fed periodically, constantly, or by batch, and purified constantly, or by batch. A function S(t) which depends on the total Σ_a of the atoms formed in a decay chain after time of birth in fission is used; the neutron flux is a parameter in this function. Equations are derived for constant neutron flux, and also for the simple case of constant S, which may apply to poisoning in a fast pile.

(C-170, Longitudinal Diffusion in Cylindrical Channels, E. Fermi, A. M. Weinberg, 7/7/'42).

The increase in leakage of neutrons because of the presence of empty cylindrical channels is calculated by diffusion theory, in order to calculate the critical size of a pile. The equations are derived from elementary diffusion formula, for uniform transverse flux distribution, and cos transverse distribution, for a single cylindrical channel, and many parallel channels. The increased flow inside pile material outside the channel is also calculated.

(MT-88, Influence of a Small Black Sphere Upon the Neutron Density in an Infinite Non-capturing Medium, B. Davison, 11/'44).

By a perturbation method, the linear extrapolation length λ for the asymptotic solution of the neutron density in the surrounding medium is found, in terms of sphere radius "a", to be:

$$\lambda = \frac{4}{3} - \frac{5}{9}a - \frac{2}{3}\left(\frac{\pi^2}{4} - 1\right)a^2 \log a - 1.4002\,a^2 + O(a^3 \log^2 a)$$

where a is in units of m.f.p. The equations are derived in this report.

(MT-93, Influence of Large Black Sphere Upon Neutron Density in an Infinite Non-capturing Medium, B. Davison, 11/'44).

By perturbation method the linear extrapolation length λ is calculated for the asymptotic solution to the neutron density in the surrounding medium in terms of the radius of sphere "a" and found to be

$$\lambda = .7104 + .5047\frac{1}{a} + .2336\frac{1}{a^2} - \frac{1}{4a^3}\log a - .1704\frac{1}{a^3} + O\left(\frac{\log 2a}{a^4}\right)$$

where a is in units of one m.f.p.

(MT-124, Large Spherical Hole in a Slightly Capturing Medium, B. Davison, 3/26/'45).

The cavity is large compared with the mean free path. The angular distribution of neutrons at the center of the cavity, and the neutron density on the surface of the cavity were calculated approximately.

For the particular case where, if the cavity were absent the neutron density would be $\rho = e^{\nu z}$, the results are illustrated with tables and graphs; ν is the positive root of $\frac{1}{1-\alpha} = \frac{1}{2\nu}\log\frac{1+\nu}{1-\nu}$ and α is ratio of capture σ to total σ of material.

(MT-135, Linear Extrapolation Length λ for Large Cylindrical Black Body in Uniform Medium, B. Davison, 12/'45).

The extrapolation length ℓ is $\ell = \lambda\left(0.7104 + \frac{.2524}{a} + \frac{.0949}{a^2}\right)$ where λ is transport m.f.p. and $a = \frac{r_1}{\lambda}$, r_1 is radius of control rod.

(MT-196, Capture of Neutrons by Cylindrical Absorbing Rods Placed Around a Pile, J. M. G. Feld, G. Volkoff, 1/'46).

The fraction T of escaping neutrons captured in rods of radius R and spaced $2a$ apart in a single row of distance b from the edge of the pile is given by an equation and a graph. Other graphs give T as a function of R and "a" for thorium rods and different values of the reciprocal diffusion length K. The equations are derived. See MPT-34, p. 3.

[redacted]

(MT-208, Xe Poisoning in Spherical and Cylindrical Piles, C. A. Rennie, 6/'46).

The increase in 1/f where f is the thermal utilization factor is found theoretically, due to Xe poisoning.
Not available. See CRT-272.

(MPT-31, Progress Report; Linear Extrapolation Length λ for a Small Black Cylinder in a Uniform Non-Capturing Medium, B. Davidson, S. Kushnerink, 11/'45).

Iteration method has been applied to the case of rod infinitely long and with radius "a" small compared with mean free path in medium:

$$\lambda = \frac{4}{3} + \left(1 - \frac{16}{3\pi^2}\right) a \log a - 0.2164 a + O(a^2 \log^2 a)$$

a in units of m.f.p. ("O" in last term means "order of magnitude of").

(MPT-33, Progress Report, Effect of Hollow Cylindrical Shaft on Neutron Density in Surrounding Medium, B. Davidson, 2/'46).

The number of neutrons escaping through the open end of a hollow shaft perpendicular to the boundary of a medium, plus those escaping from free surface due to presence of the shaft, is equal to the flux in the shaft if the medium extended to infinity.
The linear extrapolation length λ is computed for the case of shaft diameter large compared to m.f.p., and medium slightly multiplying, and equations are given as a function of the thickness of the medium.

(MPT-33, Progress Report, Linear Extrapolation Length λ for Black Bodies in Uniform Non-Capturing Medium, S. Kushnerink, B. Davidson, 2/'46).

This work is covered in the following reports:

Small cylinder	MT-207
Small sphere	MT-88
Large sphere	MT-93
Large cylinder	MT-135
Finite black sphere by spherical harmonics	MT-92
" " cylinder " "	MT-97
A comparison of the results of the above calculations,	MT-214.
Small sphere separated from Medium by Air Gap,	MT-232

(MPT-33, Progress Report, Linear Extrapolation Length λ for Small Black Sphere Separated from Medium by an Air Gap, B. Davidson. See MT-88, MT-93, 2/'46).

Sphere radius a surrounded by gap of thickness $a(\cosh \varphi - 1)$ has same influence on neutron density at large distances as a black sphere of radius a' with no air gap, where

$$a' = a + \frac{a^2}{6\ell}\left(1 - \frac{3}{2}e^{-\rho} + \frac{1}{2}e^{-3\rho}\right) + 0\left(\frac{a^3}{\ell^2}\right)$$

where ℓ is mean free path in medium.

(MPT-34, Progress Report, Capture of Neutrons by Thorium Rods Around a Pile, J.M.G. Feld, 4/'46).

In MT-196, all neutrons leaving reactor were assumed thermal; a two-group theory has been used to take account of fast neutrons entering reflector. A correction factor to the thermal utilization T computed in MT-196 is given.

(TL-2, Diffusion of Thermal Neutrons, G. Volkoff, Lecture, 10/'44).

p. 10 Boundary conditions and extrapolation length are discussed.

(CRT-272, Xe Poisoning in a Cubical Pile, C. A. Rennie, 7/'46).

The effective increase in 1/f due to Xe poisoning, where f is the thermal utilization factor, is computed for a cubical pile.

Results were calculated for power operation of 0.6 to 1.2 megawatts/ton of natural uranium. Graphs are given comparing these results, and also the ratio of average to maximum power, with the results for spherical and cylindrical pile. See MT-208.

References to abstracts in other groups:

	Group
CP-1255	(7)
CP-2203	(1)

Group (5). Experimental reports. Delayed neutrons from 23, 25, and 49. Delayed gamma rays from fission products, and resulting photoneutrons. Note: Delayed neutrons are covered in survey report CF-3596.

(CP-1014, Use of Delayed Neutrons for Detection of Coating Failures, A. H. Snell, M. B. Sampson, J. S. Levinger, 10/28/'43).

A study is made on emission of delayed neutrons in outgoing cooling water as a means of detecting jacket failure in Hanford slugs. In the course of this work, the decay curve for 25 delayed neutrons following 1 sec. activation was measured,

[redacted]

$$A_t = C_{25}\left[.57\, e^{-1.38t} + .40\, e^{-.154t} + .024\, e^{-.030t} + .002\, e^{-.014t}\right]$$

the periods are 50 sec, 23, 4.5 and 0.5 sec.

(CP-1954, Monthly Report, Cyclotron Sec., A. H. Snell, 7/29/'44).

Short-lived delayed neutron emitters, p. 18. The apparatus is not giving satisfactory results. The following periods were measured from 0.19 sec. bombardment:

Half Life	Relative Intensity
4.2 sec.	1.03
1.8 sec.	1.16
0.44 sec.	4.3

(CP-1965, Monthly Report, Physics Sec. IV, H. L. Anderson, 7/29/'44).

Delayed neutrons from 25 and 49. See CK-2318 and CP-2317.

(CP-2081, Monthly Report, Physics Sec. III, W. H. Zinn, 8/26/'44).

γ-n neutron intensity after shutdown of P-9 pile, p. 10. Curves are given showing counts per minute from thermal column of CP-3, from 40 sec to 42 hours after shutdown, and counts per minute is standardized to power output in the pile.

The pile was operated at 300 KW for 30 hours prior to shutdown. The operation after shutdown, attributed to delayed γ-n neutrons, at times after shutdown, is given below:

Time	Power Level
1 min.	~ 5 KW
3 min.	~ 1 KW
1 hr.	~ 200 watts
8 hr.	~ 10 watts
18 hr.	~ 1 watt

(CP-2081, Monthly Report, Physics Sec. IV, H. L. Anderson, 8/26/'47).

Yield of delayed neutrons. See CK-2318 and CP-2317. Preliminary work indicates yield from 25 is 0.8%.

(CP-2222, Monthy Report, Physics Sec. III, E. O. Wollan, 12/31/'44).

Energy distribution of delayed neutrons from 25. See CP-3044. Description of experiment in progress using hydrogen filled cloud chamber. Curves of breakdown into energy groups are given. Relative intensities of 23, 7, 3 are obtained for delayed neutrons with energies of 0.34, 0.62, and 0.83 mev., respectively. Problems of resolution and proton recoil angle measurement are mentioned.

(CP-2301, Monthly Report, Physics Sec. IV, H. L. Anderson, 10/28/'44).

The absorption cross section for Th was measured by the danger method in CP-2; for description of the apparatus, see CP-2079. A sample of 20% Th CCO_3 was used, and was dried in a muffle furnace at 800°C for several hours. Result, for thermal neutrons, σ_a(Th) = 6.03 ± 0.10 barns.

(CP-2301, Monthly Report, Physics Sec. III, W. H. Zinn, 10/28/'44).

Pneumatic transfer device moves 23 oxide from CP-3 to BF_3 counter in 1/20 sec. Only the long period (55 sec.) has been studied, and counts were made during first 1/2 minute and between 1 and 3 min. The ratio of number of delayed neutrons per fission of 23 to 25 was 2.1 during first 1/2 min. and 2.8 during 1-3 min. period.
(CP-3147 gives above ratio as 0.331).

(CP-2317, Delayed Neutron Yields from 25, D. Nagle, C. Redman, P. Saxon, 11/4/'44).

The experimental procedure is described in detail: a graphite brick containing In foils and U cylinder is radiated in thermal column for 2 min; U is then transferred to sigma pile where similar foils are irradiated. The total delayed neutron yield is found to be 0.77%, and this gives the inhour a value of 2.9×10^{-5}.
See CP-3195, where above is raised to 0.81%.

(CP-2749, Monthly Report, Physics Sec. VII, D. J. Hughes, 2/28/'45).

Delayed neutrons from 25, being measured by the pneumatic transfer rabbit at CP-3. Energy measurements are made by measuring decrease of counting rate of BF_3 counter with increase in distance in paraffin from the 25 sample. Preliminary results are

Period	Energy
55 sec.	~400 kev.
22.5 sec.	~700 kev.
4.5 sec.	~800 kev.

(See CP-3094).

(CP-2902, Monthly Report, Physics Grp. VII, D. J. Hughes, 3/28/'45).

Delayed neutrons, see CP-3094.

(CP-3094, Delayed Neutrons from Fission of 25, D. J. Hughes, J. Dabbs, A. Cahn, 7/30/'45).

Measurements were made using the rapid transfer apparatus of the CP-3 pile. The apparatus and measurements are described in detail, and graph of data taken are included. Neutrons delayed longer than 0.2 sec. are:

Half Life	Energy	Relatice Yield
55.6 sec.	250 kev.	0.153
22.0	560	1.000
4.51	430	1.28
1.52	620	1.45
0.43	420	0.51

The total absolute yield is given as 0.81% on basis of work reported in CP-2317. [redacted]

(CP-3147, Delayed Neutrons from Fission of 23, A. Cahn, J. W. T. Dabbs, D. J. Hughes, 10/2/'45).

Measurements were made using the rapid transfer apparatus of CP-3 pile; the apparatus and methods are described in detail in report CP-3094. Results are:

Half life	Energy	Relative yield	Yield 23/Yield 25
55.6 sec.	250±60 kev.	.316	.72
22.0	560±60	1.000	.35
4.51	430±60	1.473	.40
1.53	620±60	1.07	.26
0.42	420±60	.35	.21

The ratio of total yield of delayed neutrons in 23 to 25 is 0.331, and using the value 0.81% total delayed neutrons in 25, the total delays in 23 are 0.27%.

(CP-3195, Monthly Report, Physics Grp. VII, D. J. Hughes, 6/'45).

(1) Delayed neutrons from 25, see CP-3094.
(2) Absolute yield of delayed neutrons, see CP-2317; latest value for 25 is yield equals 0.81%.
(3) From above, the latest value of the inhour is 2.86×10^{-5} times excess k.
(4) A new inhour vs. period formula results from the new relative yields given above in (1):

$$\text{inh} = \frac{54}{T} + \frac{20.7}{T+.62} + \frac{207}{T+2.2} + \frac{543}{T+6.5} + \frac{2070}{T+31.7} + \frac{802}{T+80.3}$$

A curve is given of inhour vs. period for old, usual relation, and above, new relation.

(CP-3195, Monthly Report, Physics Grp. VII, D. J. Hughes, 6/'45).

Absolute yield and short periods with Lichtenberger's neutron beam chopper, for measuring delayed neutrons. After 1 millisec, instantaneous neutrons have disappeared and delayed neutrons with periods longer than 1 millisec can be measured.

Main difficulty is large background counting rate; also, efficiency of the detector is different for high energy instantaneous neutrons and for delayed neutrons.

Results: 5 usual periods account completely for decay curve after 0.2 sec; and all periods between .001 and .043 sec. have yield less than ½ the total yield of the 5 periods.

(CP-3209, Monthly Report, Physics Grp. VII, D. J. Hughes, 8/'45).

Photo neutrons from fission products, in D_2O and Be. See CP-3472.

(CP-3472, Photo Neutrons Produced in D_2O and Be by Fission Product γ-rays, W.D.B. Spatz, D. J. Hughes, A. Cahn, 4/25/'46).

[redacted]

The energy and period of long period delayed photo neutrons formed in D_2O and Be cylinders by fission products γ-rays was measured, for the purpose of studying the control value of photo neutrons. The energy and period of short period γ-rays was measured directly, and the short period neutron production predicted.

(γ-n) yields were 0.2% in D_2O and 0.66% in Be, compared with delayed n yield of 0.73% in 25 and 0.24% in 23. High energy γ-rays with periods of 2 hr, 32 min, and 6.5 min each have a yield of $\approx$ 2% per fission. Graphs are given showing the longer period of D_2O pile as compared with graphite piles, for the same excess k. The experiment method is described in detail.

(CF-2161, Monthly Report, Physics Sec. IV, H. L. Anderson, 9/23/'44).

Delayed neutron yield, p. 18. See CK-2318 and CP-2317. Latest work indicates delayed neutron yield from 25 is 0.78%.

(CF-3403, Monthly Report, Physics Group VII, D. J. Hughes, 1/12/'46).

Delayed neutrons. Short period from 25 has half life .05$\pm$.02 sec. and yield of 0.025$\pm$0.005%. Table is given of absolute yields of 25 and 23. Total yield of 25 is now 0.84$\pm$0.12%.

Photo neutrons from fission products. New 30 sec. and 6-8 sec. γ-ray periods are found, and photo neutrons in D_2O are observed from the 30 sec. period; they have low energy. The absolute yield, number relative to total neutrons emitted, of periods 30 sec. and greater, in infinite amount of D_2O is order of 0.1%. See CP-3472.

(CF-3490, Monthly Report, D. J. Hughes, 4/22/'46).

p.24 Periods and yields of photo neutrons and D_2O and Be are listed, see CP-3472.

(CF-3596, Delayed Neutrons, D. J. Hughes, Chapter for P.P.R., 2/1/'46).

This report is a survey of all measurements of delayed neutrons up to the time it was written. It gives a critical discussion of the methods, accuracy, and results of the various investigators, and contains graphs of the counting rate data. The report covers periods, yields, and energy of delayed neutrons.

(CRPP-34, Progress Report, Work on Delayed Neutrons, C. W. Gilbert, G. Fergusson, 4/'46).

p. 9 The Zeep pile is modulated by a rotating Cd shutter, and the a,c component of the ion chamber current is amplified. The amplitude of pile modulation and phase log between shutter and pile response can be determined. From this the delayed neutron periods and intensities will be computed. Shutter rotates with a period 1 sec. to 1000 sec.

(CRP-266, Photo Neutrons Produced in Zeep, F. W. Fenning, 6/18/'46).

The Chalk River D_2O pile, Zeep, was operated at 50 watts for 225 min., then

shutdown, and the neutron density in reflector was followed from 30 min. to 24 hr. after shutdown. Correcting for spontaneous fissions, the following periods were found:

Period	Fraction of neutrons produced at steady operation
275 ± 10 min.	1.5×10^{-6}
128 ± 6	5.4×10^{-6}
30 ± 3	6.0×10^{-6}

(CRP-266 or PD-190, Photo neutrons produced in Zeep, F.W. Fenning, Chalk River, Canada, 6/18/'46).

γ-rays from fission products produce photo-neutrons in D_2O. Manner in which power of a D_2O pile decays after shutdown depends on photo-effect neutrons and on k that remains after shutdown. The experimental decay curve for photo effect neutrons is analysed into three exponentials, after correcting for infinite time of operation before shutdown, where I is neutron intensity in counts/min. and t is in minutes after shutdown.

$$I = 5900\, e^{-t/275} + 21{,}250\, e^{-t/128} + 23{,}600\, e^{-t/30}$$

Measurements were taken with BF_3 chamber for 24 hrs, starting 30 min. after shutdown. Measurements were made on Zeep pile, after operation at 50 watts for 225 min.

(C-35, Monthly Report, Metal. Project, Cyclotron Grp, A.C.G.Mitchell, 4/11/'42).

A table gives initial activity of delayed neutrons

Half life	Intensity. No./sec.	% of total activity
57 sec.	.0154	3.83
24	.114	28.3
7.0	.137	34.0
2.5	.137	34.0

These were obtained from the cyclotron, a count of 10,000 fission neutrons/min before it was shut off. Total of all periods was 0.403/neutrons/sec.
For full report, see C-81.

(C-81, Study of Delayed n Associated with U Fission, A.H. Snell, A. V. Nedzel, H. W. Ibser, 4/'42).

The delayed neutron periods were measured with a cyclotron, and the decay curve is

$$\text{activity} = \text{const.} \left(1.2\, e^{-.28t} + 1.2\, e^{-.099t} + 1.0\, e^{-.029t} + .135\, e^{-.013t}\right)$$

Comprising 1.0 ± 0.2% of the neutrons; t in seconds. The decay periods are 2.5, 7, 24, and 57 sec. A complete description of the apparatus and procedure is given.

(CK-1761, Monthly Report, Physics Grp. IV, H. L. Anderson, 5/25/'44).

The 54 sec. delayed neutron emission of 49 is compared to the same emission by 25. The ratio of fission yield (54 sec.) of 25 to 49 was found to be 2.15. See CK-2318.

(CK-2318, Delayed Neutron Decay Curves from U and Pu Fission, C. Redman, D. Saxon, 11/4/'44).

Measurements were made in the Argonne graphite pile. For 49,

$$A_t = C_{Pu}\left[1.2\ e^{-.660t} + 1.1\ e^{-.154t} + 1.0\ e^{-.0310t} + 0.11\ e^{-.0126t}\right]$$

and for 25,

$$A_t = .302\ e^{-.613t} + .258\ e^{-.156t} + .190\ e^{-.0308t} + .028\ e^{-.0126t}$$

Within experimental errors, the half lives are the same, at 55.0 sec, 22.5 sec, 4.4 sec, and 1.1 sec. The neutron yields given for 25 are from CP-2317. Limitations on the experiment are the counter resolving time, 105 microsec; and the time required for moving source from pile to geometry. The delayed neutron yield from Pu is estimated equal to ½ that from 25.

(MonP-17, Monthly Report, Physics Sec. III, E. O. Wollan, 9/31/'45).

Energies of delayed neutrons. Compare with CP-3094. Using a hydrogen filled cloud chamber and pneumatic tube with Clinton pile, the following energies are measured:

Period	Most probable energy	Average energy
22.0 sec	520 kev	580 kev
4.51	350	400
1.52	720	720
0.43	350	380

(MonP-104, Monthly Report, Physics Sec. IV, L. B. Borst, 4/30/'46).

Relative value of saturated photo neutron activities from fission products and D_2O is

Period	Relative activity
53 hrs.	11.1
4.4 "	34.9
1.6 "	267
27 min.	235
7.7 "	359

The photoneutrons of periods given have a total activity only 3/4% of that of the delayed neutrons, any additional appreciable number of photo neutrons must come from shorter periods. Measurements were made in 10" radius sphere of D_2O.

(MonP-172, Yield of Photo neutrons from 25 Fission Products in D_2O. S. Bernstein, W. M. Preston, G. Wolfe, R. E. Slattery, E. Greuling, 9/24/'46).

Results obtained are:

Half life	Relative neutron yield 22 sec. delayed n yield = 1.000	Absolute number of photons per fission
53 h	.00038	.00125
4.37	.00119	.00394
1.65	.0093	.0415
27.3 m	.0082	.0354
7.7	.0124	.0407
2.4	.0276	.121
41 s	.090	1.43
2.5	.225	.673
		2.3

Total photo neutrons is about 16.5% of total delayed neutrons; energy of assumed -rays is above 2.17 Mev.

Measurements were made in a 10" radius sphere of D_2O set in a tank of oil beside the Clinton graphite pile. Pneumatic transfer of enriched U slug from center of pile to sphere took 0.25 sec. Neutron distribution in the oil was studied by fission chambers containing 90% enriched U; these were less sensitive to γ-ray background than BF_3 counters. Modified Simpson proportional counter amplifier and cooling circuit had a resolving time of 20 μ sec. Theoretical appendix contains "Neutron Yield from Multiply Scattered Compton Photons", by E. Greuling.

(MonP-192, Description of an Average Fission, K. Way, 12/11/'46).

A complete discussion including historical references about the radiations, fission products, and energy released in a fission. Section on delayed neutrons summarises the known information and lists many references, which are all covered in these abstracts.

Half life	Energy	Yield in Units 10^{-4} 25	23	49	
Delayed neutrons					
55.6 sec.	250 kev	2.5	1.8	1.4	
22.0	570	16.6	5.8	10.5	
4.51	412	21.3	8.6	12.6	
1.52	670	24.1	6.2	11.9	
0.43	400	8.5	1.8		
		73.0	24.2	36.4	Total Yield.

(MonP-250, Monthly Report, Physics Sec. I, A. H. Snell, 2/19/'47).

Photo neutrons from fission products and D_2O. Number of photo neutrons per delayed neutron for 23 is the same as from 25.

(MonP-314, Quarterly Report, Photo neutrons from 23 and 49 Fission Products, S. Bernstein, E.P. Blizard, Leslie, McKinney, Jackson, 6/21/'47).

p. 21 Continuation of work of MonP-172; results are curves for photo neutrons/delayed neutrons vs. time for 23, 25, and 49; curve for 23 lies above 25 and curve for 49 lies below; the difference may not be real.

The results indicate that the number of hard γ's goes up or down with the

number of delayed neutrons. To check this, hard γ rays were selected by their absorption in lead; the γ ray count to delayed neturon count is designated R, and $\frac{R_{49}}{R_{25}}$ was found to be 1.2 ± 0.12. Curves are given comparing delayed neutron periods and yields from recent reports and from these experiments.

(MonS-29, Metal. Project, Information Meeting, Energy of Delayed Neutrons, M. Burgy, 9/18/'45).

p. 29 Energy curves obtained with pneumatic tube at Clinton, which has transit time of 0.25 sec., are given in a table.

Half life	Most Probable energy	Average energy
0.43 sec.	.35 Mev.	0.38 Mev.
1.52	.72	0.72
4.51	.35	0.40
22.0	.52	0.58

(LA-183, Criticality of Water Boiler, No. of Delayed Neutrons, and Dispersion of Neutron Emission Per Fission, F. DeHoffmann, 12/8/'44).

f = fraction of delayed neutrons; γ is relative effectiveness of delayed and prompt neutrons in leading to fission. For the water boiler, γf is measured to be 0.79%, by an elaborate experiment in which a Cd sheet is oscillated.

The average time between fissions due to prompt neutrons is measured to be 122 microse.

(LA-231, Delayed neutrons from 49, B. T. Feld, F. DeHoffmann, 2/27/'45).

The ratio of the relative no. of delayed neutrons from 49 to those from 25 is found to be 0.47 for delays over 2 sec. and 0.40 for delays over 5 sec. Relative abundance and periods, for 49 are

Relative abundance	Period
.040	79.6 sec.
.288	32.5
.371	7.5
.301	1.6

Decay curve is given.

(LA-252, Delayed Neutrons from 25 after Short Irradiations, F. DeHoffmann, 4/6/'45).

Delayed neutrons are measured after exposures of 3 and 11 milisec in the dragon. A period of $6.3 \pm .1$ millisec is discovered.

(LA-253, Short Period Delayed 's from fission of 25, P. B. Moon, 4/7/'45).

[redacted]

[redacted]

Measurements of γ activity following pulses of the dragon are observed by ion chamber and counter. Activity having a period of a few millisec is observed.

A curve is given of $\alpha(t)$ as a function of t, where $\frac{\alpha(t)}{t}$ is rate of emission of γ ray energy in Mev/sec.

See LA-253A which is a critical discussion of this work, and compares results with those obtained in water boiler and with a V. deGraff generator, and concludes that the few millisec period does not exist.

Group (6). Experimental reports. Bringing piles to critical. Exponential and critical experiments. Startup and drift of a pile. Calibration of rods. Shadow effect of rods. Measurements of cinch and the inhour. Experiments on rod shape and length. Measurements of temperature coefficient.

(CP-455, Metal. Project, Report for Month Ending; Physics Grps. III and IV, W. H. Zinn, H. L. Anderson, 2/6/'43).

The results of a series of standardization experiments are reported. Barometric pressure change of 1 mm. of Hg. corresponds to 0.396 cinches of control rod position. Results of experiments on the change in critical position of control rod with a 200 mg. Ra+Be source; BF_3 poison in Al tube; Cd foil poison; U and UO_2; inserted in the pile are reported. The change in k due to inserting these materials is given by giving $N\chi$, where N is no. of central cells and $\chi = \frac{dk}{x}$, x being cinches rod is inserted.

(CP-510, Metal. Project Report for Month Ending; Physics Grps III and IV, W. H. Zinn and H. L. Anderson, 3/6/'43).

The effectiveness of two Cd strips 8 feet long and 2 inches wide separated by 45 inches was found to be decreased by 8.6% and separated 90 inches to be decreased by 4.7% due to shadow effects.

(CP-570, Metal. Project Report for Month Ending; Physics Grps. III, IV, V, H. L. Anderson, W. H. Zinn, G. L. Weil, 4/17/'43).

A description is given of how CP #2 was first brought to critical, by measuring the saturated activity of Indium foils which successive layers of dead and live-graphite were added. The inhour is defined. On page 6, results of experiments to test the prediction that the effect of an absorber in a pile is proportional to the square of the neutron density at its position measured by Indium foils are given and show good agreement with prediction.

(CP-641, Metal. Project Report, Physics Grp IV, H. L. Anderson, 5/10/'43).

Definition of the inhour is given, and an equation relating it to the period of the pile, using Snell's data on delayed neutrons.

[redacted]

The equation is

$$\text{inhour} = \frac{64}{\tau} + \frac{245}{\tau + 3.57} + \frac{688}{\tau + 10.1} + \frac{1938}{\tau + 34.5} + \frac{665}{\tau + 83}$$

where τ is period of the pile. The control rod is calibrated measuring the period for various positions; neutron intensity in control rod slot is measured from activity of Cu foils; control rod sensitivity is proportional to integral of the square of the activities over the length of the rod. Conversion has been calculated for

$$\delta k = 3.04 \times 10^{-5} \quad \text{inhours}$$

$$1 \text{ cinch} = 0.8135 \quad \text{inhours}$$

Period of Argonne pile with all rods out believed to be 6 sec, giving k = 1.004. The standardizations are still tentative.

(CP-718, Metal. Project, Report for Month Ending, Physics Grps. V and VI, G. L. Weil, J. Marshall, 11/27/'43).

p. 14, Safety rod #3 for CP-2 of simple construction and held by magnetic clutch can be removed from pile in 7 sec.

p. 16, Cd control rods 60" long formed of sheet shaped like 0, 1, +, are compared in a pile and ratios of effectiveness in changing the Laplacian found to be $\frac{+}{1} = 1.11$; $\frac{0}{1} = 1.18$.

(CP-1081, Metal. Project, Monthly Report, Clinton Lab., H. W. Newson, 11/27/'43).

On calibration of Clinton control rods. Monitoring is done by BF_3 counter. The reactivity of the pile with control rods all the way in is equivalent to the reactivity during loading with a given number of fuel channels filled. Each full channel is assumed equivalent to 4 inhours, and 1 inhour equivalent to change in k of 2.95×10^{-5}. The results of the test on regulating, shim and safety rods are given. Barometric coef. has not been measured.

(CP-1173, Monthly Report, Physics Res. H. W. Newson, 12/28/'43).

In the Clinton pile, the temp. coef. due to temp. change in metal while graphite remains constant is approx. twice that predicted. Measured values in inhours/°C. are .407 to .457. A graph of temp. distribution in metal and graphite across the pile is given.

(CP-1295, Monthly Report, Physics Sec. I, H. W. Newson, 2/29/'44).

Start up of Clinton Pile. Calibration curves for #1 and #2 regulating rods have been taken. Sensitivity at the center is 2.92 inhours/inch. The "old" inhour formula, in terms of the pile period, is 10% to 20% low.

(CP-1300, Metal. Project Monthly Report, Clinton Lab., H. W. Newson, 3/6/'44).

p. 19. An attempt is made to calibrate control rod in a short test while the pile is in operation at high power. The change of temp. with slight movement of rod introduces a temp. effect. A graph shows power level and pile temp. as a function of time; also a plot of power level against temp. Temp. corrections in inhours/degree C. are computed.

p. 24. Control rod calibration and absorption measurements. A thermocouple was attached to a slug, and the temp. of the pile kept constant during tests. To calibrate #2 rod, a Cd strip was inserted into the pile and the movement of the rod to maintain the temp. was measured. The absolute effect of the Cd strip on k was obtained later when pile operated at zero power; 4 methods are described, which involve pile period measurements. Control rod #1 was compared against rod #2. Equations for the sensitivity as a function of position are given. Experiment on the ripple of slow neutron intensity due to rod structure of the lattice is described and no observable ripple was detected. The axial distribution of the square of the neutron intensity was measured; the sensitivity to poisoning by a Cd wire; the poisoning method was used in several foil slots to scan the neutron distribution through the pile.

(CP-1389, Metal. Project Monthly Report, Diffusion Experiments, P. Morrison, 2/24/'44).

An exponential experiment is described. An Al rod wrapped with 30 mil Cd sheet at a radius of 2.05 cm was inserted in a central cell. Foil activation showed steep rise in flux from center to 35 cm. back from rod, and slow decline to edge of pile. The change in k eff was — 3%; and effective radius of the rod, considered black for thermal neutrons, is 2.2 cm.

(CP-1400, Monthly Report, Physics Section I, H. W. Newson, 3/15/'44).

Pile Drift, operating characteristics of Clinton pile. The change in inhours of the regulating rods, temp., pressure, and humidity record for 11 days of steady power operation are given, using 1°C = 0.6 inh, 1 mm Hg = 0.25 inh (pressure), 1 mm Hg (H_2O partial pressure) = .036 inhours. Daily fluctuations are too great to collect data on pile poisoning due to fission products.

(CP-1729, Monthly Report, Physics Grp. III, W. H. Zinn, 5/25/'44).

p. 3. Exponential experiment prior to starting CP-3, a D_2O pile, show the pile will have an excess reactivity of about 6%. It is decided to add two more control rods, position adjustable by hand, and remove a number of metal rods. Suggestions for utilizing the excess k are listed.

(MonP-104, Monthly Report, Physics Section I, A. H. Snell, 4/30/'46).

[redacted]

Critical experiment for the heterogenous (high flux) pile. The critical mass of 25 extrapolated to no penetrating holes was 869 gr, a concentration of 10 gr of 25/liter of D_2O. A control rod was calibrated against a uniformly distributed poison; the temp. coef. is strongly negative.

(MonP- 357 Critical Experiments on Small Reactor of Enriched 25, M. M. Mann, 7/'47).

Contains a section on the effectiveness of a control. The change in k eff is given, and the change in number of grams of 25 required to make a pile critical is given.

(PM-247, Title Unknown, C.N. Watson-Munro, 4/'46).

Experimental work done on Chalk River Zeep Pile. Effect of short control rod, and effect of control rods immersed to various depths.
Not available: ref., see CRPP-34 p. 9.

(PM-248, Title Unknown, C.N. Watson-Munro, 4/'46).

Experimental work on Chalk River Zeep Pile. The positive interference of control rods was found; reference: TPI-29, F. T. Akler. The best position for four control rods in Zeep is 0.18 effective radius or 0.25 geometric radius from the axis.
Not available: ref., CRPP-34, p. 9.

Reference to abstracts in other groups:

	Group		Group
CP-430	(1)	CF-3582	(8)
CP-1088	(7)	MonP-206	(8)
CP-2301	(8)		

Group (7). Experimental reports. Pile poisoning by Xe, Sm, and C^{14}. Cross sections of Th, and other elements. NH_3 and C_2Cl_4 as safety solutions. Boron glass control rods. Radioactivity of control rod materials. Measurements of pile fluctuations, and of coolant turbulence. Measurement of diffusion length. Reports on the Hanford piles.

(CP-964, Metal. Project Monthly Report, Physics Grp. IV, H. L. Anderson, 9/25/'43).

Radioactivity of control rod materials. Saturation activities in dis-

integrations/sec/gram/kw, half lives and energies, induced by slow neutron flux of 4×10^8 are given for Al, Cu, Na, Fe, Ni, and Cd.

The cross section of a design for a control rod for Hanford, including .005" Cd sheet sandwiched between 1/16" Al sheets, and attached to four 1/2" O.D., 1/16" wall Al water cooling tubes is shown.

(CP-1016, Metal. Project Monthly Report, Lattice Design Grp., A. M. Weinberg, 10/23/'43).

The drop safety rods for Hanford will be 29 2½" B steel crosses, each serving a cylindrical region of radius 57.4 cm. The k loss per rod is 5.65% and overall k loss is 3.83%; required reduction in k is 3.5%.

A "last ditch" safety mech. in case drop safeties fail to work is described. It would be 7.4 grams NH_3 dissolved in 100 grams H_2O from 2.9 to 2.5 cm. If this liquid filled the 4" dia. tubes surrounding the drop safeties, the loss of k would be same as if safeties were in place.

Cleanup during operation of 0.5 ppm of B in graphite will increase k of Hanford 0.3% after 100 days at 300,000 KW, and will offset poisoning due to fission products.

(CP-1088, Metal. Project Monthly Report, Physics Grp. IV, H. L. Anderson, 10/23/'43).

A 4.57% water solution of NH_3 gives about ½ as much reduction in k in the Argonne pile as 1-7/8" Cd strip. A 3" Al tube filled with the solution inserted 104" changes k by 77×10^{-5}. It is calculated a 30% solution would not equal the Cd strip.

Activity induced in Cu foils distributed along a slot indicate that when a square tip, 3" wide Cd control rod is in place, (1) Ratio of activity with and without rod is constant along length of rod, but (2) rises by a factor of 2 at the tip. (3) Neutron density is decreased nearby, and increases farther away.

(CP-1255, Monthly Report, Diffusion Experiments, P. Morrison, 1/24/'44).

The diffusion length of thermal neutrons in square channels 6.2 cm on edge spaced in a 8" lattice in a sigma pile of AGOT - S graphite was measured, and results are

$$\frac{D(\text{channel, parallel to axis})}{D(\text{solid graphite})} = 1.40 \pm .03$$

$$\frac{D(\text{channel, perpendicular to axis})}{D(\text{solid graphite})} = 1.08 \pm .04$$

The values calculated by the equations of C-170 give 1.35 and 1.22 respectively.

(CP-2298, Metal. Project Monthly Report, Lattice Design Grp., A. M. Weinberg and Theor. Phys. Grp., E. P. Wigner, 10/28/'41).

Excess multiplication required to overcome Xe poisoning for 250,000 Kw operation at Hanford is 1.25% for the 2004 tube pile. Fermi gives the equation $\delta k = \frac{.022\ p}{p + 1550}$ where p is local power output in Kw/ton U. An increase in k of 0.54% can be obtained by reducing thickness of slug end caps from 0.35 inches, graded through the pile; such thick caps are needed only at center.

Hanford control rods are calculated to have effective radius of 1.43 cm. 9 rods control 1.1% k, while excess k in clean 2004 tube pile is calculated to be 1.17%

(CP-2301, Monthly Report, Physics Sec. III, W. H. Zinn, 10/28/'44).

Poisoning of the chain reaction by Xe^{135}. Two long runs of CP-3 at constant temp. were made, and the change in reactivity due Xe^{135} was observed; curves of reactivity vs. time were taken but are not reproduced. No other poisoning as large as 10% of Xe poisoning with half lives between ½ hr and 40 days was observed.

(CP-2601, Monthly Report, Physics Sec. I, A. H. Snell, 3/31/'45).

Observations on bubbling with an open surface, p. 4. A 55-gal. oil drum was mounted on its side, with outlet at top of ends and inlet at center of bottom; water was circulated at 70 gal per minute and glass bubbles distributed on horizontal plane inside, giving 3 liters per sec of air. The frustrum of a cone, narrow end down, placed over the inlet reduced piling up of surface over inlet to less than 1/4 ". Surface agitation was last where water velocity is greatest. Conclusion is that bubbling will make it very difficult to control a pile.

(CP-2601, Monthly Report, Physics Sec. I, A. H. Snell, 3/31/'45).

The resonance level of Samarium has been examined with high resolving power. A curve is given.

Resonance energy	E_0	= .096 ev.
Max	σ_0	= 14,200 barns
Half width	Γ	= .035 ev.
Resolving power		= .004 ev.

(CP-2902, Monthly Report, Physics Grp. I, W. H. Zinn, 3/28/'45).

The cross section of Samarium, p. 1, has been measured with the crystal

spectrometer, and has a resonance at .096 ev, with a max. σ_a of 15,500 barns and a half width of 0.074 ev. A curve of this resonance is given. Resonance peaks were observed at the positions for the second and third order Bragg reflection of the above energy neutrons.

(CP-2984, Monthly Report, Physics Grp. VII, D. J. Hughes, 4/25/'45).

The method of measuring the resonance absorption in Th is described, with no self-absorption, and with self-absorption. Using the values

$$\sigma_{KT}\ (Th) = 6.83 \text{ barns}$$

$$\sigma_{KT}\ (In) = 190 \text{ barns}$$

$$\int_{In} \frac{\sigma dE}{E} = 2712 \text{ barns}$$

the resonance absorption of thorium is calculated

$$\int_{Th} \frac{\sigma dE}{E} = 81.3 \text{ barns}$$

(CF-3403, Monthly Report, Physics Grp. I, W. H. Zinn, 1/12/'46).

Total cross section of Th. Extrapolation of a curve for total (given in the report) for energies .08 to 15 ev gives for thermal energies:

total σ(KT) = 18.5 barns
capture σ(KT) = 6.2 barns
scattering σ = 12.3 barns

Below .07 ev then appears to be a crystal effect lowering the predicted total σ.

(CF-3574, Monthly Report, Physics Grp. II, W. J. Sturm, 7/26/'46).

Total cross section of Sm. A curve is given of cross section taken with crystal spectrometer at energies from .04 to 65 ev. The resonance at .096 ev has σ_o = 15,500 b. and a half width of .074 ev. A new resonance is found at 10 ev, σ_o = 2800 b., and at 30 ev.

(CP-3574, Monthly Report, Physics Grp. VII, D. J. Hughes, 7/26/'46).

Effect of C^{14} as a pile poison. p. 31. It is found by the danger coef. method that absorption cross section of C^{14} is less than 200 barns, and it is computed that effect on Hanford pile after one year of operation is less than 0.6 inh.

(MonP-33, Monthly Report, Physics Sec. I, A. H. Snell, 11/30/'45).

Study of turbulence (contributes to fluctuation of pile power). Motion picture study of air bubbles when introduced into flowing water in long smooth pyrex tube yield the following data:

aver. axial vel $\bar{y} = 109$ cm/sec
Reynolds no. R $= 1.04 \times 10^5$
Turbulent component perpendicular to axis

$$\left(\overline{x^2}\right)^{\frac{1}{2}} = 15.2 \text{ cm/sec}$$

$$\text{Ratio } \frac{\left(\overline{x^2}\right)^{\frac{1}{2}}}{\bar{y}} = 0.14$$

(MonP-85, Monthly Report, Physics Sec. IV, L. B. Borst, 3/31/'46).

Neutron diffraction. Transmission of fission product rare earths for neutrons of energies .03 to 0.2 ev shows one absorption line at 0.1 ev, where Sm^{149} has a resonance of 95,000 barns. The yield of the Sm^{149} chain should be 1%; however, these measurements indicate yield is .02%. The absorption spectrum of Xe^{135} is to be studied.

(MonP-130, Metal. Project Monthly Report, Physics Sec. II, A. M. Weinberg, 6/30/'46).

Pile Poisoning by Xe and Sm. Equilibrium operation of high flux pile indicates Xe and Sm change $\frac{k\ eff}{k_o}$ by - .037 and -.008 respectively. After shutdown, Xe poisoning $\frac{k\ eff}{k_o}$ is -.081 at 20 min., -.116 at 40 min., and -.176 at 80 min., while Sm poisoning remains at -.008 for these times, rising later to a max. of -.036.

(MonP-314, Quarterly Report, Progress Report on Xe^{135}, S. Bernstein, p. 25, 6/21/'47).

An experiment is in progress to measure total σ for Xe^{135} between .02 and 2 ev by using the crystal spectrometer. The division of responsibility for separate parts of the project is outlined; the spectrometer performance is discussed; amount of Xe required, and efficiency of chemical separation is discussed. Work on extraction of Xe, and analysis the sample of Xe^{135} is covered.

(MUC-HHG-7, Neutron Cross Sections of the Elements, H. H. Goldsmith, H. W. Ibser, 8/11/'45).

[redacted]

Contains graphs of cross section vs. energy for high energies and low energies for most of the elements used in pile construction or in control rods.

(MPP-30, Progress Report, Sec. VI, L. Kowarski, 10/'45).

Fluctuations of Zeep D_2O pile, are proportional to the inverse root of power, and at ½ watt the standard deviation is 0.07%. Power range studied was 5×10^{-4} to 0.5 watt.

The Cd shutter pile modulator gives a peak to peak change in k of 10^{-4}. The cross section for graphite could be measured to 0.1 millibarn by swinging it in a tangential channel with a period of 10 to 20 sec. and a power of 10 to 100 watts.

(CC-418, Metal. Project, Report for Month Ending, Chem. Group C-II, M. Burton, 1/15/'43).

C_2Cl_4, considered as a possible safety gas, was radiated with 2.5 Mev for 0.5 hour, equivalent to 10 days in Hanford pile, at room temp, and then distilled; distillation curve is given. 40% C_2Cl_4 was not decomposed; another 40%, not identified, boiled at 152° - 154° C., and remaining high boiling fraction crystallized when cooled. 0.11% of Cl was in water soluable form. The decomposition implies C_2Cl_4 would not be useful.

(CC-1036, Metal. Project Report, Chem. Grp. IV, W. L. Kay, 11/6/'43).

Boron glass for control rods. Cd rod causes excessive heating in surrounding material due to (n,γ). B rod heats itself with (n,γ). A method for incorporating B is to coat coolant pipes with B glass in control rods. The properties of the following B glasses were studied and are listed: B_2O_3; $PbO:B_2O_3$; $Bi_2O_3:B_2O_3$; $BaO:B_2O_3$; $BeO:B_2O_3$; $Al_2O_3:B_2O_3$; MnO, MgO, CaO.

The glass can disintegrate to a powder without injury to its effectiveness in the control rod.

(CS-406, Minutes of Conference at Wilmington, M. D. Whitaker, 12/22/'42).

The control information necessary to operate Hanford piles is tabulated.

(CS-977, Project Council, Information Meeting, 10/5/'43).

Discussion of same topics covered in CP-964. Hanford rod should be placed in Al thimble, and Cd should taper at the end of the rod. Various proposals for number and spacing of Hanford Rods. B coated ion chamber is satisfactory, but sensitivity of photronic cell will probably change in few hours.

(CS-2172, HEW Tech. Progress Letter No. 11, S. J. Bugbee, 9.21/'44).

Hanford Pile 105-B loading is discribed. The dry pile became critical with 404 tubes charged; the central safety rod effectiveness was 0.5%. With 748 rods pile was non-reactive with 12 safety rods in place. When filled with H_2O, pile was reactive with 838 rods.

(CS-3026, HEW Tech. Progress Letter No. 46, P. W. Crane, 5/23/'45).

p. 11. It is calculated that increasing Hanford D pile by 15 M.W. above rating will increase the reactivity by 15 inhours.

If a Hanford pile loses all its water, the reactivity increases by 900 to 1050 inhours. The safety system is designed to control this. There is a question if the safety system is adequate if the neutron density is heavily flattened, by P-columns; the reactivity is then pushed to the edges of the pile where the safety system does not penetrate; analysis indicates that safety rods in a 500 MW unit with 600 inh of flattening have 300 to 400 inh control in excess of that needed in case of loss of water and high temp. rise in graphite.

(CRPT-35, Progress Report, Xe Poisoning of Enriched Piles, H. H. Clayton, 6/'46).

Not available: see CRPT-36, p.4.

(CRPT-36, Progress Report, Effect of Xe Poison on the Neutron Distribution in the NRX Pile, H. H. Clayton, 8/'46).

By first order perburbation treatment of one group theory, the NRX pile at Chalk River at 20 Megawatts will have the maximum neutron density moved from 25 cm to 70 cm from the axis, and the ratio of average to maximum neutron density raised from 0.42 to 0.58, due to Xe poisoning.

(CRTPI-41, Pile Instability Due to Poison, H. H. Clayton, 8/'46).

Not available: see CRPT, p. 4.

Reference to abstracts in other groups:

	Group		Group
CP-964	(1)	MonP-85	(4)
CP-1014	(5)	MonP-104	(4)
CP-1400	(6)	MonP-206	(8)
CP-1389	(1)	N-2292	(1)
CP-2292	(4)		
MonP-56	(2)		
MonP-74	(2)		

Group (3). Description of control for specific piles. The first Fermi pile. Argonne CP-2 and CP-3 piles. Clinton graphite pile. Chalk River D_2O zero power pile. Chalk River NRX pile. Los Alamos water boiler. Proposed General Electric zero power pile, and resonance pile. Zinn's fast neutron breeder. Proposed fast Pu breeder (Soodak). Clinton high flux pile; see also group (2). Note: Not included in this group: BeO power pile (group (3)), and Hanford piles (group (7)).

(CP-413, Experimental Prod. of a Divergent Chain Reaction, E. Fermi, Appendix II, Monitoring and Controlling the First Pile, V. C. Wilson, 1/'43).

A complete description of the control apparatus used. Defects in the instruments are listed. Diagrams of ion chamber circuit, control system circuit, details of the safety, control, and "Zip" rods; and curves of counts as a function of completed layers, and of ion chamber currents with time, are included.

(CP-1173, Monthly Report, Physics Res., H. W. Newson, 12/28/'43).

Change of power with time and temp. at the Clinton pile. When control rod is displaced, the change of power is linear for first 10 minutes, indicating constant temp. coef. The power change becomes complicated when graphite temp. changes. The equation should be $C \frac{di}{dt} = \Delta ih - \alpha d(T - T_0)$, where C is const, i is current in ion chamber, Δ ih is control rod movement, α is temp. coef., T and T_0 are final and initial temp., d is a constant. A graph is given of ion current and central slug temp. as a function of time.

(CP-1401, Metal. Project, Monthly Report, Instrument Div., W. P. Overbeck, 3/15/'44).

Hydraulic drive on #1 rod at Clinton pile will give smooth operation at 4"/sec and 20"/sec.

(CP-1531, Metal. Project Monthly Report, Physics Grp. IV, H. L. Anderson, 3/25/'44).

The amplidyne driven control rod is being used at Argonne in CP-3, and is a marked advance in pile control. Whereas before the operator had a rough control of the speed of the rod, he now controls accurately its position; rod speed is 1 ft/sec.

(CP-2301, Monthly Report, Physics Sec. III, W. H. Zinn, 10/28/'44).

Temp. coef. of CP-3. Temp. coef. is found to be -6.8 inh/°C; a reduction of 1.7% in k follows a temp. rise of 100°C.

(CP-3006, Circuits for Control Systems, W. P. Overbeck, 7/'45).

Describes the control system for the Argonne Pile CP-2, covering same material as CT-669, with the following additional circuit diagrams: ion chamber supply and indicator, safety rod #'s 1,2,3. Also discusses differential equation of rod motion and conditions to prevent "hunting".

(CP-3431, Automatic Control System for CP-3 Machine, T. Brill, 1/7/'46).

A four chamber ion chamber that will handle currents up to 500 μa without saturation operates a galvanometer having sensitivity of .003 μa/mm. and 3 second period, the response being due to a differential current when ion current is opposed to a "buckling" source. Prisms on half the scale reflect light spot to photo electric cells which operate low speed drive on a control rod. Motors operate when power changes $\pm \frac{1}{2}\%$, and hold power level to $\pm 1\%$. About once a day disturbance takes machine out of automatic control and additional photo cells operate alarm bell. An operator must bring the pile up to power.

(CP-3647, Monthly Report, Physics Grp. IV. T. Brill, 10/23/'46).

Automatic control system installed on CP-2 similar to one on CP-3 holds the pile power to 0.2% or better. It will operate from two chambers, a high sensitivity BF_3 ion chamber, or a "power" chamber and a less sensitive, more linear, more reliable chamber lined with B and filled with He.

(LA-134, Water Boiler, C. P. Baker, H. K. Daghlian, G. Friedlander, M. G. Holloway, D. W. Kerst, R. E. Schreiber, 9/4/'44).

Automatic safety monitors, p. 12, are three BF_3 ion chambers. Control rod, p. 14, is Cd strip wrapped around brass tube, with a movement of 40.7 inches by D. C. motor, in a water tight sheath, in BeO reflector. Can be set to .001 inch, and position is indicated by Selsyn motor counter. Safety rod is Cd sheet $2\frac{1}{2}$ inches wide that falls free in reflector. It is held by electric magnet and magnet and rod are lifted by motor and cable. Total effect of control rod is 11.3 gr of 25 and of Safety is 22.1 grs of 25; critical mass with BeO reflector is 572.8 grms; period with excess of 0.4 grs is $\sim$ 25 sec.

Temp. is carefully controlled, monitored with platinum resistance thermometer and Cu-constantine thermocouples, and regulated by heaters in the room, held to 39° C. Control is 0.1 degree across pile and reflector, and 0.01 degree for many hours; temp. coef. is 0.73 gr of 25 per °C.

Additional safety is that solution is damped (p.5) if a leak occurs, if nw rises above set level, if liquid gets into the overflow, or if the power fails. A manual dump valve drains the solution out of the laboratory. Diagrams are given.

(MonP-113, Monthly Report, Physics Sec. V, H. W. Newson, 5/31/'46).

A general description of the control of the high flux pile is given; it will have 3 Cd safety rods, 4 Th shim rods, 2 Cd control rods. A circuit is being designed that will indicate pile period on a meter. Characteristics of a G. E. Differential Ion Chamber are being studied; a chamber with better sensitivity, and that will operate at high fluxes is planned. The way irradiated materials to accomplish this are tested is for "noise" described.

Pile similator circuit is described briefly. It provides for external control of $\frac{(\Delta k)\ eff}{k}$, effect of Xe, temperature, delayed neutrons, and possibly the study of max. bubble size.

(MonP-113, Monthly Report, Physics Sec. II, A. M. Weinberg, 5/31/'46).

Response of safety rods in new high flux pile should prevent overheating of assembly following sudden jump in k. If δk eff jump is 1.5%, neutron lifetime 5×10^{-4} sec, rod accelerated by 9 g., assembly film drop jumps by factor of 3. Conclude δk jumps of 1.5% are not permissible.

(MonP-206, Physical Data on New High Flux Pile, A. M. Weinberg, 11/21/'46).

p. 10, Xe and Sm poisoning, 10 hours after shutdown takes up a maximum of 55% of k. A table is given of poisoning vs. time after shutdown. 9.6% extra $\frac{\Delta k\ eff}{k}$ allows maching to be started within ½ hour or after 2 days.

Depletion. To allow pile to run 10 days, 3.3% $\frac{\Delta k\ eff}{k}$ must be built in for this purpose.

Temp. effect, estimate increase of 10° C will reduce $\frac{\Delta k\ eff}{k}$ by 0.3%. Experimental set ups require 5% $\frac{\Delta k\ eff}{k}$; a total of 18% $\frac{\Delta k\ eff}{k}$ will be obtained by 3 k gm loading.

p. 16, Th control rods will be followed by a Be extension which increases effectiveness of rod. A vertical Th sheet, or parallel line of Th slabs or rods is considered. Dead layer of water around Be will cause serious local heating; a table of local heating (without layer of water) vs. Be rod diameter is given.

The pile generation time is longer than neutron lifetime because of some neutrons reflected from Be, and depends on amount of metal loaded in pile. The Xe instability will cause a period shorter than 8 minutes. Bubbling will be reduced because moderating H_2O is in pile too short a time to allow decomposition gases to reach saturation pressure.

(MonP-216, Project Monthly Report, Physics Sec. II, A. M. Weinberg, 11/30/'46).

Possible arrangements for disposition of control rods in pile are (1) 6 equally spaced rods of one part by volume of Th, 1 part of Al, and 1 of H_2O coolant, will give $\frac{\Delta k}{k}$ of 14%. If one of six rods is Cd, $\frac{\Delta k}{k} = 18\%$ (2) Because Th has density of 11, it absorbs γ rays efficiently and develops heat. Li - Al alloy rods would develop less heat, still have high thermal neutron cross section. (3) Control by a Th sheet cutting pile in two or Th rods in a row has been rejected because it is less flexible and requires more Th.

To maximize effect of Th rod, it should be replaced by Be or U when it is withdrawn. If Be is used, and H_2O cooled, a severe local neutron density peak is created around rod, from 25% to 58% greater density than exists at a distance from the rod. If U is used, water flow is diminished due to pressure drop along Th part of rod, and reduced heat transfer may limit power output of pile. U gives larger net control.

(MonP-269, Monthly Report, Physics Sec. II, A. M. Weinberg, 2/'47).

High flux pile. 6 Th rods and 7 Cd rods give a control of 11% and 29% respectively. See MonP-272.

(MonP-272, Physics of the High Flux Pile, E. Greuling, H. Soodak, A. M. Weinberg, 3/27/'47).

The section on control describes the Cd safety rods, 29% of k, Th shim rods, 10.6% of k, their rate of movement; the central cylindrical region of control; the flux distribution and generating time. The steps of start up, and functions of the operator are described, and the equations for automatic control are given, and description of the operation of the servo-mechanism. It is calculated that regulating rod speeds of 3 meters per sec are necessary to control against reactivity changes of 0.4% k and keep the power level below 1.5 times steady operation.

(MonP-314, Quarterly Report, Control of the High Flux Pile. W. H. Jordan, J. D. Trimmer, H. W. Newson, Epler, p. 96, 6/21/'47).

A description (20 pages) of the operation of the controls for the high flux pile. The safety control devices are divided into "period supervision", under which, during start up, a period of 7 sec (or less) blocks with drawal of rods; "setback action" under which the power level at which scram occurs is set at a lower level than during normal operation; and "scram signals", which come from ion chambers, and crucial facility monitors, such as water pressure drop across pile. Another group of safety devices are the interlocks, which serve as a check on the operator. Auxiliary power supply is discussed. The regulating rod (0.5% of k, full swing in 0.25 sec.) calls for motion of a shim rod through a system of stops; the 8 shim rods control 45% of k eff. There are four speeds of shim rod withdrawal, obtained by intermittant operation. The instruments used for visual indication and automatic action are discussed, and the sequence of events during start up. A block diagram of the complete system is given.

(MonN-103, Preliminary Process Design Report, 1000 Project, M. C. Leverett, J. R. Huffman, 5/15/'46).

p. 23 Control Rods. Four Th metal shim rods, water cooled; two Cd - Al regulating rods, water cooled; two Cd control rods; also, D_2O level may be dropped. 16 ionization chambers will be placed in instrument holes. There is also a list of about 250 special instruments that will shut down the pile,

in case of failure of some external unit, such as pump, or excess reactivity in some part of circulating system.

p. 86, Controls and safety mechanism. The control rods will be black to thermal neutrons and each will absorb about 5% k. Safety rods falling free will stop the pile when rising with a period of 0.1 sec; if 0.1 sec delay time, the rise will be a factor of 4. The derivative system will operate if pile during startup is rising with period faster than 0.5 sec. The creation of bubbles may reduce k by 0.5%.

Accompanying report is blueprint E-950, assembly and control rod details, showing dimensions and construction of rods.

This is an extensive report in which details of design of an actual pile are quite complete.

(MonN-201, Status of 1000 Project Design, M. C. Leverett, 11/15/'46).

The same control of Clinton high flux pile is envisioned as described in MonN-108.

(MonN-224, Monthly Report, Tech. Div., M. C. Leverett, 12/20/'46).

Brief description of control rods in heterogeneous high flux pile, p. 6.

(1) Safety rods of Cd and U, normally run with U in the pile, Cd above.

(2) Shim rods of Th and U, normally run with Th in the pile, U used to overcome Xe in start up.

(3) Regulating rods of Cd and Be.

(CF-3107, Fast Plutonium Breeder, H. Soodak, 2/'45?)

p. 18 Control. Coarse control is best accomplished by moving a section of the reactor with respect to the rest.

An absorbing control rod would be bulkier than a metal rod since fission σ are larger than absorption σ at high energies.

A control rod would have to be of uranium or thorium for breeding efficiency. The lifetime of a neutron is of the order of 10^{-7} sec, meaning a change in k is dangerous. The timp. coef. of k might be a few tenths of a per cent per 100° C change in temp.

(CF-3403, Monthly Report, Phys., Grp. 5, T. Brill, 1/12/46).

Automatic control system consisting of differential galvanometer and photocells keeps CP-3 to within ± 1%. See CP-3431.

(CF-3414, Design of Fast Neutron Breeder Test Pile, W. H. Zinn, 1-25-46).

Controls, p. 12. Mechanisms being considered are: safety control: (1) Four fissionable rods in center of reactor to be lifted out of reactor by compressed air pistons or motors. (2) Dropping the external breeding blanket, by the screw

elevator for slow speed or the hydraulic lift for rapid motion.

Operating control: (1) A five inch wide section of the breeding blanket above coolant pipes will be hinged to open or close a gap, by rotation through 90°.

Shim control: (1) Changing number of fissionable rods in the reactor; (2) Changing number of breeding rods in inside breeding blanket. (3) Changing thickness of external breeding blanket.

See CF-3582 -II for later description.

(CF-3582, II, Design of Fast Neutron Breeder Test Pile, W. H. Zinn, 8/7/46).

Safety control rods, p. 54. Rods will have same dimensions as active rods; will be of active or blanket material. The rods and the manipulator mechanism are described in detail, with drawings.

Temp. coef., p. 52. A temp. change of 100° C would require change in k of 0.8%.

Operating controls, p. 70. (1) Each internal safety rod will change reactivity ~1%. (2) Sudden safety. A block of U in external cup will be forced down into the shielding block by springs with acceleration of several g. It will be reset by lowering the hydraulic lift. Internal safety to operated by power level and sudden safety by pile period.

(3) The shim control is to be the external cup, operated by the hydraulic lift against a mechanical stop mounted on a screw.

(4) The operating control will be two blocks of U in the outer blanket mounted on shafts so they can be withdrawn from the blanket along a radius of the pile. The shafts are moved by a fine screw mechanism and only one would be used, the other being locked in place.

(CE-60, Motor Driven Control Rod, Univ. of Chicago, 5/8/42).

Engineering drawing of gears and mount.

(C-61, Pneumatic Safety Rod Mech., Univ. of Chicago, 5/7/42).

Engineering drawing of piston to drive a safety rod.

(CRP-287, Experimental Determination of the Effectiveness of Control Rods in a Pile, C. N. Watson-Munro, 7/1946).

The effect of variation of length, position, diameter, material, and number of control rods in the low energy Chalk River D_2O pile, Zeep, has been investigated. Flux data to assist any theoretical analyses of the results is tabulated.

(CT-669, Control System for Argonne Pile, CP-2, W. O. Overbeck, 5/13/43).

Complete detailed description including performance characteristics of instruments and the following circuits: Regulating rod; shim rod, safety rods; control panel, rear view; manual control station; galvanometer circuits; high

voltage supply for proportional counter; the scalar circuit; proportional counter amplifier; ion chamber amplifier; and safety trip circuit.

(TecPI-32, Description of a 'Tagged' Shutoff Rod Unit for the NRX Pile, H. Q. Lawrence, 2-8-46).

Not available. See MTec-211.

(MTec-211, Description of the Shutoff Rod Units for the NRX Pile, H. Q. Lawrence, 12/29/45).

Shutoff rod units are described in detail. Basic design principles are discussed and operating performance figures are given. Not available.

(M-Tec-211, Description of the Shutoff Rod Units for N.R.X. Pile, H. Q. Lawrence, 3/46).

Safety rod for D_2O Chalk River Pile. Contains boron carbide powder in a steel tube, in an Al outer tube. Rod is air cooled.
Not available.

(A-4207, Feasibility Report for the Zero Power Pile at the Sacandaga Laboratory, K. H. Kingdon, G.E., 5/16/47).

Preparatory to a resonance breeder pile, this zero-power pile is planned, to be built in two parts, one on a movable table. The lead screw which brings halves together, measurement screw, and assembly drive are described. Interlocks are described; selsyn indicators show position to .001 inch. Safety rods are held by compressed air against springs that provide 5 g acceleration. Control rods, emergency power supply, and emergency switches are described.
p. 23, Safety monitors and circuits. Four circuits will work independently; one is activated by a trip point slightly above power level existing during previous 10 to 20 sec.; one has a trip point manually adjusted; and last operates entirely from batteries.
Drawings of the equipment are given.

(Memo DC-4, Minutes of Third Meeting, G. E. Nucleonics Project Consultants, 5/14/47).

p. 10, Dr. Brooks, intermediate pile design. Reducing the density of the 10 cm reflector to 75% of present proposed density results in 16% change in k. Estimate each control rod to have 1% reactivity control, and the Be reflector plug dropped from beneath the pile to cause 10% change in k.
Dr. Brooks claims photo neutrons will amount to half as much as delayed neutrons, giving a total delayed fraction of 1% for 25 and 0.5% for 49. Dr. Wigner did not believe photo neutrons would be of any significance.
Photo neutrons from decay of La^{140} will aid in starting the pile.

Reference to abstracts in other groups:

	Group		Group
CP-1016	(7)	Mon P-271	(2)
CP-641	(2)	Mon P-85	(4)
CP-718	(6)	Mon P-104	(6)
CT-491	(9)	CP-1300	(6)
CP-257	(9)	CP-1173	(6)
CE-197	(7)	CP-1295	(6)
MPP-30	(7)	CP-1400	(6)
MPT-31	(1)	CP-1081	(6)
MPT-33	(2)	CP-570	(6)
LA-399	(1)	CP-718	(6)
Mon P-228	(1)	Mon P-314	(9)
CP-2203	(1)	A-4207	(9)
		CP-2081	(9)

Group (9). Instrument reports. Ion chambers, counters, monitoring apparatus, and control system circuits. The Clinton pile simulator. Thermopiles and thermostats, bi-metallic strips. Pile period measuring circuit, and d ln n circuit. Silver tape monitoring device. Servo-mechanisms. Photronic cell.

(CP-964, Metal. Project: Monthly Report; Physics Grp. III, W. H. Zinn, 9/25/43).

BF_3 filled ion chambers do not retain their calibration over long periods; intensive runs cause changes. β coated chamber tested was linear from 1 to 1200 K.W., retained calibration about a month, when after some intensive operation it showed signs of changed calibration. (This statement in error, corrected in CP-1016, p. 4.) No change after two months' use.

As a substitute for ion chambers, a variety of thermocouples were tested. Bi-tin and Bi-antimony alloy wires show best results with a sensitivity of .006 cm/K.W., and when β coated, of 0.31 cm/K.W.; a graph is given showing response is as fast as ion chamber. A Western Electric 1-A thermister was tried but showed delay in recovery.

A photronic cell gives a sizeable linear response to pile activity; the sensitivity is increased by placing a sheet of U painted with zinc-sulphide over the cell. Bi-metalic strips are mentioned for safety rod release.

(CP-1016, Metal. Project: Monthly Report, Physics, Grp. III, W. H. Zinn, 10/23/43).

Data is given on sensitivity of a β coated ion chamber during two months operation showing no significant change. There is appreciable deviation from linearity of low energies.

A U-invar steel bi-metallic strip has closed a low voltage circuit successfully at same power level on repetition of experiment. A β coated commercial bi-metallic strip does not function.

Disadvantages of using bi-metallic stip to operate safety rod are activity induced in U, and fact that it cannot be used where there is wide temp. variation.

A thermopile shows no change in calibration after two months use.

(CP-1577, The Pile Safety Circuit, L. G. Nierman, 4/14/44).

Circuit diagram and description of an ion-chamber operated safety trip circuit; value of chamber current at which tripping occurs is stable to $\pm 0.4\%$.

Also described is a relay circuit to prevent false shutdowns due to circuit defects. There are three relays, each with three windings, designed so the solenoid is held by normal current in any two windings on one relay, and released if current ceases to flow in two windings.

(CP-1965, Monthly Report, Phys. Sec. IV, H. L. Anderson, 7/29/44).

Fission chamber for monitoring the pile, p.21. Several soft glass fission chambers have been constructed with 1 mg. enriched U oxide on Pt cathode, filled with Argon. They follow design by Veall of Montreal.

(CP-2081, Monthly Report, Phys. Sec. IV, H. L. Anderson, 8/26/42).

Silver tape recorder, p.23.

A silver tape moves continuously through the shield and pile of CP-2, at 1 foot per second; it passes over a G M counter 10 sec. after it is exposed, and it spends 5 min. on a storage spool. It is then recounted for background activity, before reentering the pile. It detects neutrons in the presence of enormous γ radiation, by activation of 22 sec. silver. It was designed to assist restart up of Hanford after operation and shutdown, and will be satisfactory if radiation level outside Hanford shield is not excessive.

(CP-2298, Metal. Proj., Monthly Report, Instrument Sec., W. P. Jesse, 10/28/44).

A neutron sensitive thermopile as means of measurement of pile power is being tried at Clinton. Measurements at 3000 Kw show variation of $\pm 3\%$ from power measured by ion chamber. A more constant measurement would be obtained by several suitably located thermopiles connected in series. Output voltage of three in series is .006 volts, sufficient to operate meter movement type relay in a safety circuit.

(CP-2301, Monthly Report, Phys. Sec. IV, H. L. Anderson, 10/28/44).

A BF_3 proportional counter and amplifier for high counting rates. This is for detecting fast neutrons in presence of high γ-ray flux. The counter is 8" by 1 1/2", filled with 25 cm. of BF_3.

The preamplifier, amplifier and Higgenbotham scale of 512 have a resolving time of 3 μ sec for equal size pulses; measurements with Ra-Be

[redacted]

source give about 10 μ sec. No increase in background where 100 m.c. γ-ray source is placed beside counter. Everything can be mounted on a single chasis.

(CP-3005, Measurement of Neutron Density, Wilkening, 7/45).

Description of proportional counters and their use; ionization chambers and foil counting technique.

Curves for effect of voltage on counting rate and effect of β and γ ray background are given, and use of pulse height selectors discussed. Galvanometer circuit for ion chamber and engineering drawing of compensation type chamber is given. Activity equations for foils are given.

(CT-491, Technology, Controls and Instrumentations, V. C. Wilson, 2/20/43).

Progress report. The following items are mentioned:

1. A pile control circuit has been developed with output over 100 volts and fluctuations less than volt, to be reduced to 0.1 volt, to give a regulating system capable of working to 0.1%.

2. A scale of 64 scales that loses less than 1% of random counts at 20,000 counts per minute.

3. Driving motors and gearing for control rod movement at 6 inches per sec. and .015 inches per sec. capable of precise setting.

(Mon P-130, Metal. Proj., Monthly Report, Phys. Sec. V, H. Newson, 6/30/46).

Pile simulator circuit has a range of only 10^4, and can be used only over range 10^2 for start up problems. Simulator will be disturbed by mock bubbles to determine max. allowable fluctuation in k. Ion chamber activation is due mainly to 110 min. Argon, $\sigma = 1.24$; 2.59 hr. manganese, $\sigma = 11.5$; 5.3 year cobalt, $\sigma = 22.5$. Suggested is use of N instead of A, low manganese steel, Cd mask over Kovar seal (containing cobalt), and lead-tin solder of silver and and copper. Ion chamber must be good over range of 2×10^5/ actual tests on a differential G. E. chamber suggest it would be good over range 8×10^5.

(Mon P-151, Monthly Report, Phys., Sec. V, H. Newson, 7/31/46).

Activity in G. E. differential chamber is sum of three decay curves,

10 parts	1.8 hr.	from A gas.
5 parts	2.6 hr.	from Mn in steel.
1 part	5 year	Co in Kovar

The first may be corrected by using N_2 gas, second by low Mn steel, and third by using automobile spark plugs, on which tests are being made.

(Mon P-203, Ion Chamber for Control and Operation of Clinton High Flux Pile, F. C. Arminstead, 11/6/46).

It is found necessary for the chamber to have a range of 10^5, and a minimum ratio of neutron amps to β and γ amps of 100_0. Results of testing

[redacted]

the G. E. chamber in Clinton Pile are given, showing above ratio to be 4,000, but range is only 4×10^3. Improvement of range can be obtained (1) by increasing absolute sensitivity of instrument, by improving β coating or using β enriched with B^{10}, and

(2) by decreasing the induced activity in the chamber, which has 2.5 to 3.0 hour average half-life, by building chamber of 25 Al, filling with N instead of A, and using materials containing no manganese, cobalt, copper, silver, tungsten, vanadium, chromium, or nickel.

(Mon P-216, Metal. Proj., Monthly Report, Phys. Sec. V, H. Newson, 11/30/46).

Best coating for ion chamber is given; consists of painting Al plate with suspension of B^{10} in 1:5 mixture of amphenol 912 and glycol thinner, to a thickness of 2.5 mg/cm^2. Where the range of G. E. chamber was 10^3 or 10^4, the range of new test chamber is 10^6; with 400 cm^2 coated surface and placed in flux of 10^9, current was 10^{-5} amp; and 1/2 hr. after pile shutdown, chamber activity caused ion current of 10^{-11} or less.

Superficially range of ion chambers may be extended by subtracting current from γ rays from current from γ's plus neutrons, but this gives a noisy signal. Location of ion chambers is discussed, and estimate they should be 2 meters of graphite between chamber and pile. If coating has short life at the flux here (10^{12}), may have to shield chamber with Pb or Cd. Greater distance from pile would cause delay time due to time for neutrons to diffuse.

(Mon P-228, Monthly Report, Phys. Sec. V, H. W. Newson, 1/15/47).

Indicator for δk eff. If the neutron density is made to oscillate about an average value, the phase lag between neutron density and driving source gives a measure of δk eff independent of pile level, oscillator amplitude, and ion chamber background current. Relation is

$$\tan \phi = \frac{2\pi f l}{\delta k \text{ eff} - \beta}$$

ϕ = phase angle
f = driving freq.
l = mean neutron life
β = fraction of delayed n

and holds if oscillations in δk eff $\ll |\delta k \text{ eff} - \beta|$

For max sensitivity near δk eff = 0, set $f = \frac{\beta}{2\pi l}$, ≈ 5 cps for high flux pile, where detectable increment is

$$\Delta(\delta k \text{ eff}) = 2\beta(\Delta\phi) = 2.7 \times 10^{-4}, \text{ if } \Delta\phi = 10.$$

(Mon P-250, Monthly Report, Phys. Sec. V, H. W. Newson, 2/19/47).

Power control. The band of freq. to which a servo-mechanism will respond is related to the time allowed for its output to build up from 10% to 90% of its final value. Stability criteria dictate that the freq. response fall off with increasing freq.

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For high flux pile the servo-mechanism is to drive rod 30 cm. in 0.25 sec., or reduce k at 2%/sec. Time required for servo system to reach steady state motion is .046 sec., after a step change in input signal.

(Mon P-250, Monthly Report, Phys., Sec. V, H. W. Newson, 2/19/47).

For high flux pile Dr. Wigner desires some indication of approaching critical in addition to $\frac{d \log n}{dt}$. An oscillator in the pile might be a useful test for the ionization chamber.

Shim and safety rod design: Th and Cd rods are specified so k eff of pile increases at 1/10% sec. on withdrawal; rods can be inserted much faster (for high flux pile).

(CP-257, Metal. Project; Report for Week Ending; Physics, Group V, W. C. Wilson, 9/15/42).

Cd strips 1/32"x3 1/2"x12' attached to steel will be regulating and safety rods for first pile.

A proportional counter containing 16 rings each acting as a separate cathode and counting recoil protons is being tested as a device for determining fast neutron energy spectra.

Contains no information.

(Mon P-269, Monthly Report, Phys., Sec. V, H. W. Newson, 2/47).

Mr. Jordan estimates a modulated ion chamber similar to that used on pile oscillator will give continuous indication over a range of 10^9 or 10^{10}. Neutron intensity will be modulated by 25% to 75%.

When the Xe and I periods are reduced from their actual value by a factor of 100 in the pile simulator, the condition of instability is demonstrated.

A circuit which measures log of intensity accurately over a range of 10^5 is completed, but the time derivative of (ℓn n) needs further development.

(Mon P-314, Quarterly Report; Period Measuring Circuit, S. MacNeille, P. R. Bell, 6/21/47).

p. 90. Monitron converts ion chamber signal to 160 cycle A.C. voltage, amplifies and then demodulates the signal, which goes to d ℓn n circuit. Redesign has reduced noise to .001 of max. signal voltage; further reduction requires narrowing the band width; for ion currents of 10^{-10} amps. a 1 cycle band may be necessary.

d ℓn n circuit has been modified to obtain minimum response, and in combination with monitron has rise time of .040 sec. For range .001 to 6.0 RMS volts input the bias voltage deviates less than 1% from a true log function.

(Mon P-314, Quarterly Report; The Model Servo, H. A. Straus, T. E. Cole, Cardwell, 6/21/47).

p. 94. The servo system has been operated satisfactorily as a velocity follow up on the deviation of pile power from desired level. A shim rod simulator is interlocked to the regulating rod. The shim rod advance starts when regulating rod tip is 1.5 cm. from the center of the pile; the regulating rod cannot run into the limit stop in such manner as to cause damage or pile oscillation; during the above, system retains full sensitivity to signal reversing regulating rod motion.

(Mon P-316. Title unknown, L. W. Meade, 7/47).

Final report on ion chamber design, the chamber being for use in monitoring Clinton high flux pile.
See Mon P-314, p. 90.

(Mon P-323, Instruction Manual for A-1 Amplifier, W. H. Jordan, P. R. Bell, 7/47).

Not available.

(M Tec-168, Ion Chamber Data, H. Carmichael, 8/17/45).

Operational characteristics of large ion chambers designed for Petawawa Plant are discussed. Tables of specifications for setting alarms or shutoffs are given. The currents corresponding to biological tolerance intensities of γ rays, fast and slow n are given.
This is a comprehensive report filled with data on specific instruments.

(A-4207, Feasibility Report for the Zero Power Pile at the Sacandaga Laboratory, K. H. Kingdon, G. E. Instrumentation, 5/16/47).

p. 21. A counter with concentric cylindrical electrodes is described. It contains on BF_3, at atmos. pressure. The electronic equipment dead time is 0.2 micro sec. A linear recording rate meter will record pulses from 100 to 100,000 per sec.; another type will be logarithmic.
To gain intensity at start up, a source of 10^7 neutrons/sec. will be placed at center, and 100 counts/sec. in BF_3 counter will enable safeties to measure intensity in 0.1 sec. Drawings of ion chamber (also to be used) and block circuit diagrams are included.

Reference to abstracts in other groups.

	Group
CT-669	(8)
CP-413	(8)
CP-3431	(8)
CP-3403	(8)
CP-3647	(8)
Mon P-228	(2)
Mon M-108	(8)
MPT-33	(2)
MIT notes 8-44	(1)
CP-65	(2)
Mon P-314	(8)
MEPA-No. 4	(1)
CS-977	(7)
Mon P-113	(8)

Additional References.

The following reports are believed to contain some control information, but were not available for abstracting.

Canadian	Los Alamos	Chicago
CRP-287	LA-105	CE-174
CRT-293	LA-115	
TPI-29	LA-151	
TPI-41	LA-289	
MT-207	LA-367	
Mtec-211	LA-397	
TecPi-32	LA-539	