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NUCLEAR REACTOR PROGRESS REPORT

(Prepared by members of the Nuclear Reactor Staff)

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Hugh Kinsler
Authorizing Official

Date: 8/5/08

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For The Atomic Energy Commission
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Chief, Declassification Branch let

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ERRATA FOR BNL-21

Please make the following corrections to your copies of this report before distribution.

<u>Page No.</u>	<u>Correction</u>
v	Numbers 28 and 29 should be interchanged
vi	2. Reactor Laboratories instead of 2. Reactor Laboritories
1	Para. 2, line 4, details instead of deteils
14	Equation 2, $\rho = 7.42 (10^{-2}) - 4.2 (10^{-8}) v^2$ instead of $\rho = 7.42 (10^{-2}) - 4.2 (10^{-8}) v^2$
14	Para. 2, line 5, $2/3$ instead of $2/2$
22	2nd and 3rd equations, " 0R " instead of " OR "
23	Last para., 1st line, significant instead of significan
32	Para. 3, line 3, "-it will be proof of the continuity between the $1/8$ inch ---" instead of "-this is to mean that there is a continuous passage between the $1/8$ inch ---"
33	Para. 2, line 4, insert temperature after operating
47	Next to last line, plunger instead of plungers
49	Next to last para., line 2, "These assemblies include" instead of "These include"
55	Para. 2, line 3, after 2.0 Mev insert the word "gammas"
55	Para. 3, last line, lmc to lC instead of lmc to lc
58	Under title "Ingestion Tolerance", $\mu C/cc$ of liquid instead of C/cc of liquid; same correction in Para. 3, line 4; Para. 3, line 5; Para. 3, line 6
65	Last para., line 10, precursor instead of precurson
66	Line 1 under heading 2, k_{eff} instead of K eff

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<u>Page No.</u>	<u>Correction</u>
72	Para. 2, line 1, insert "as" between estimated and quoted
75	Para. 3, line 2, 0.006 instead of 0.0006
80	Para. 4, line 5, between fragments and in, insert "in uranium to the extrapolated range"
81	Para. 5, last word, laminar instead of laminare
89	Para. 3, line 4, stack instead of stock
92	Para. 3, line 8, form instead of for
100	Para. 3, line 13, not instead of now
108	Para. 3, line 4, "C" instead of "B"; Para. 3, line 5, "B" instead of "C"

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INTRODUCTION

The present Scientific Progress Report covers the period of nine months since the last such overall report was issued. A six months report was in preparation last June when it became necessary to drop it in order to prepare a report for the Reactor Safeguard Committee of the Atomic Energy Commission. This was required on very short notice. These reports, BNL-18 and BNL-18 Supplement, contain material which may be taken to supply progress information, but certainly are not complete in this respect, nor is it presented in the manner of a Scientific Progress Report. To those who have access to these reports it will be apparent that there is some duplication of material.

The Reactor Safeguard Committee met to consider the overall safety devices and features being designed and built for the routine and emergency control of the reactor. These included the control rod (regulating and emergency) system; the shot-well system; the structural details concerning the foundation of the reactor and control systems which become important in the case of earthquakes or other natural catastrophies; the nuclear characteristics of the reactor; the instrumentation for control and information on reactor performance; the details on the construction and fabrication of the metal assemblies; the helium system for preventing and easily detecting cartridge failures; the cooling system and the associated filter system; the water canal for transport and storage of discharged metal; the electrical power system supplying power to the reactor complex, and finally, the Meteorology and Radiation Protection Program established to safeguard the personnel within the reactor complex and the Laboratory site, and for the protection of the areas outside the Laboratory limits. The Committee members were satisfied that the problems with which they were concerned were competently and adequately treated except for the shot-well system. The Committee recommended that additional "manually-operated, gravity actuated, shutdown facilities be provided which will reduce 'k' by at least 1.5% and which will remain operable even in the event of earthquakes, fire, or other major disasters." To this end two new safety systems have been incorporated into the reactor design and are described in detail elsewhere in this report. They are two more shot-wells which reside within the gap in the graphite structure, and a system for filling the pneumatic tube system with carbon tetrachloride. These, along with the original shot-wells, will contribute about 1.7% in "k".

The construction progress is now several months behind the original schedule established. The largest factor contributing to the failure to hold to the original schedule is the fact that it was not realistic in terms of the scope of the job. The scope of the job has, itself, been extended in a con-

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siderable measure since the original plans, but this constitutes only a much smaller contributing factor. It may be said that all original estimates on the part of the H.K. Ferguson Company and their subcontractors, both as to time required for design and construction and as to the costs involved were greatly in error on the optimistic side. This fact is reflected quite strongly in the report of the Project Engineer contained herein.

Those portions of the reactor complex which are required for the operation of the reactor are now well along toward the completion stage. The reactor itself has reached the stage where the shield is about 65% complete and will be finished by November 1. Graphite lay-up will begin immediately thereafter. The control system and the instrumentation associated with it are being installed now, and this will continue for several months. The fan building is completed except for minor features, and equipment is being installed and wired. The first of the five fans has been brought in and is being assembled and mounted in position. The rest of the fans and motors will follow along very quickly. The stand-by unit for pumping cooling air through the reactor in the case of power failure is a smaller fan driven by a gasoline motor, and will be capable of pulling about 10 % of the maximum requirement of cooling air through the reactor. This unit and that for providing the secondary air supply will be installed and tested well in advance of the date required for full operations. The water cooling towers and pump house are completed, and all that remains to be done here is to connect them to the heat exchangers in the air ducts when they are installed. The stack is completed except for finishing operations and installation of minor equipment. The exit cooling air ducts connecting the various components are rapidly approaching completion also. What work has yet to be done is confined to the section between the reactor and the fan building where the hot filters, the heat exchangers and the venturi sections are located.

The Reactor Building is now almost completely closed in, and the heating system will go into operation during November. Installations of equipment will proceed for several months. The water canal is being terminated outside the reactor building where a transfer of hot material into a transporting vehicle will be made. The canal may be extended to the hot laboratory at some later date. The overhead travelling crane was installed and operating directly after the steel work for the building went up, and has been in constant usage by the construction crews ever since.

Construction work on the laboratory wings is now about 25% complete. This building should be completely enclosed by December 1. All the laboratory equipment and furniture is on order and will be available for installation during the winter months. A model of the laboratories is under construction for the use of personnel operating in this area. A detailed

model of the reactor itself has been under construction now for many months. The scale is one-sixteenth full size. It is being built in sections which may be easily taken apart to reveal the intricate details of construction right down to the foundation. It is hoped that this model will serve a real function in acquainting research people who work with the reactor with what exists inside the shield and under the floor.

The first power generating unit of the Long Island Light and Power Company, at Port Jefferson, will go into operation during December. This will take care of the power demand of the Reactor Complex. The second unit is not scheduled for completion until the end of 1950. Until that time, if the first unit goes out of service, the reactor level will have to be dropped so that the power demand does not exceed 4000 KWs.

Ground was broken for the hot laboratory building in August after the original plans passed through several stages of review. The size, scope, and function of the various components of the hot laboratory were not given final approval until July. At this time the construction has not proceeded beyond the foundations.

At this time it appears that the reactor will not be ready for loading to critical much before early spring of 1949.

Following are a series of photographs showing the status of the construction as of October 1, 1948. Figure 1 is the architect's drawing of the Reactor Complex when completed. Figure 2 is the architect's drawing of how the reactor itself will look when completed. Figure 3 is an aerial photograph of the complex at the present state of construction. Figure 4 is a close-up view of the reactor building and the erection of the steel for the laboratories. Figure 5 shows the present state of construction on the reactor shield. Figure 6 is a photograph showing the space inside the shield where the graphite will be stacked.

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Figure 2.

Figure 3.

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Figure 4.

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Figure 5.

Figure 6.

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REPORT OF CHIEF PROJECT ENGINEER FOR AUI

The design and construction of the Pile Complex has progressed steadily although we will not meet the schedule originally set for completion. Difficulties encountered in detailed design and in construction operations indicate the original schedule was to optimistic.

Despite many reductions in scope of work and in economies effected, rising costs of labor and material, coupled with lower productivity of workmen than originally estimated, have increased the estimated cost to complete. Factors in design not appreciated until the detailed design was developed have also contributed to the increase in cost.

Estimates for the component parts of the Pile Complex are as follows:

Pile Building	\$ 1,984,400
Pile	6,777,700
Pile Laboratory	2,091,700
Fan Building	1,271,700
Stack	240,800
Site Development	269,800
Water Cooling Tower	304,400
Air Ducts and Coolers	693,100
Canal	110,800
Substation	410,400
Electric Service	111,500
Electrical Distribution	332,100
Service Distribution	409,400
Boiler House	467,900*
Hot Laboratory	2,764,700
Waste Field	<u>640,800</u>
 Total Estimated Construction Cost	 \$ 18,881,200
(Exclusive of Engineering, Con- tingency and Fee.)	

This compares with the estimated cost included in the original contract, of \$ 14,330,700 (including engineering, but exclusive of contingencies and fee.) However, in an effort to keep the estimated cost within budget allowance, we substituted a much smaller boiler plant, reduced the size of the Pile Laboratory wings, eliminated the Canal as a transfer medium, eliminated

acid brick lining in the stack, etc., thus reducing the scope of work, at an estimated saving of well over \$2,000,000. This economy has been more than offset by increased costs, and items not fully appreciated at the time of the original estimate.

PROGRESS

Design

Design of all features except minor details is substantially completed for the Pile Complex. The design of the Hot Chemistry Laboratory and Waste Field are under way. The basic design has been crystallized and details are being worked out.

Construction

Construction has proceeded in all areas except the Waste Field. The Pile Proper is estimated at 91%. Completion was scheduled for December 30 for determination of criticality and performance tests of instruments and controls. Setbacks in delivery of certain components of the Control Mechanism indicate now that this date will not be met. The revised schedule has been established as February 15. The first graphite will be placed Monday, November 8. The Fan House is estimated at 78%, completion scheduled by the end of December. The Stack is substantially complete. Overall completion of the entire project is estimated at 66%.

Commitments as of September 30 are as follows:

Payrolls	\$ 4,988,316
Purchase Orders	4,171,257
Subcontracts	4,251,642
Government Purchases	1,376,707
Fixed Fee Earned	<u>357,250</u>
	15,145,172

Reimbursements to The H.K. Ferguson Company, Inc. as of September 30 were about \$10,148,000.

* Includes \$63,100 for Paducah Boiler House.

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ENGINEERING

During the past nine months, several phases of the engineering studies on the reactor have been completed.

Experimental work done at Columbia University, Massachusetts Institute of Technology, and Brookhaven on the aerodynamic properties of the reactor air feed slot has been correlated by the Process Design Group of the H.K. Ferguson Company. A suitable pattern of restrictions insuring reasonably efficient distribution of cooling air through the reactor has been devised, for a rectangular loading of metal and an air discharge temperature of 400°F. Variations in this pattern are now being investigated in order that changes in the size and type of loading pattern and changes in the air discharge temperature can be properly compensated for.

Tests are currently being run to determine the heat transfer properties of the 11' finned cartridge metal assembly. Results to date indicate that for a maximum operation heat flux of 12 watts/cm² and an air flow rate in the central channel of 1200#/hr a maximum aluminum metal temperature close to the anticipated 350°C will be obtained. Various components of the mechanism of heat transfer from the metal assembly have been studied experimentally. Separate tests have been made to determine the heat transfer rate from the cartridge fins to the graphite by conduction and from the surface of the aluminum to the graphite by radiation. Results from these tests show that the amount of heat transferred from the metal assembly by these two paths will be about 10% of that generated in the central channels and between 25 and 30% of that generated in the outer channels. Cycling tests have also been made on an aluminum cartridge. These indicate that a daily change in aluminum jacket temperature from the anticipated maximum of 350°C to 50°C and back to 350°C again will not materially affect the cartridge or fins assuming that there is no reaction between the aluminum and uranium which might be detrimental to the cartridge structure.

All components of the air pressure drop through the pile proper have been determined experimentally. The over-all reactor cooling system pressure drop will of course depend upon the final metal loading. However, all indications are that, with the fan-compressor units which are being installed, operation at higher central heat fluxes of higher than the anticipated maximum of 12 watts/cm² will be possible.

A study to determine the oxidation rate of AGOT graphite under conditions approximating those in the reactor has been undertaken. Data so far indicate that the amount of oxidation will be negligible at the graphite maximum operating temperature of about 200°C.

Details of Experimental Tests

A) Tests on aerodynamics of reactor cooling system;
pressure drops and air distribution control.

The problem which necessitated the running of this group of tests was that of determining the air pressure at each of the channel entrances in the air feed slot which divides the two halves of the reactor. It was necessary to know this static pressure pattern in order to specify the size of the restriction to be placed in each of the channels so no more air than that quantity which is actually necessary to keep the temperature of the aluminum cartridge below the anticipated maximum of 662°F would be allowed to pass down the channel. The importance of using restrictions to control the air flow was demonstrated when it was found that an unrestricted pile of this type could operate at only one half the flux level of a restricted pile for the same air pumping capacity.

The apparatus for these tests has been described in BNL-14. The static pressure patterns obtained for typical runs on the two small scale models of an eighth section of the reactor feed slot as shown in Figures (7) and (8) for approximately a double cosine distribution of air flow on which the prototype is designed to operate. These patterns were made at velocities which approximately duplicate the actual reactor feed slot velocities, for a flux of 12 watts/cm^2 in the central channel. The similarity between these patterns and the velocity pattern (Figure 9) for the slot based on potential flow calculations illustrates that a theoretical solution to the problem is not far in error.

The data taken of both the Columbia Model and the M.I.T. Model were analyzed and correlated by the H.K. Ferguson Company. The results are reported in BNL Long No. C-1018 and BNL Log No. C-1473. Essentially, the basic information which was desired from these data was the slot static pressure pattern for a known air flow rate corrected for the difference in size between the models and the Brookhaven slot. However, it was considered advisable to devise a general method for determining the pressure pattern for cases where excess air may be used in the channels away from the center of the reactor or where a considerable number of the outer channels may be plugged.

This has been worked out for a rectangular loading and has proved useful in estimating the maximum flux level of the reactor for various systems of restricting the air flow through the channels.

Figure 7.
 STATIC PRESSURE
 CONTOURS
 IN AIR FEED SLOT OF COLUMBIA MODEL

Figure 8
 STATIC PRESSURE
 CONTOURS
 IN AIR FEED SLOT OF M.I.T. MODEL

Figure 10

Obviously the most efficient system for air flow control would be that using different size restriction in each of the channels, specially designed to limit the air flow to that required to keep the aluminum jacket below the maximum allowable aluminum temperature. In actual practice, however, it would not be wise to operate all the cartridges on such a close margin of safety. Neither does it seem practical to attempt operation with a large number of different size restrictions. A compromise must be made between complexity of operation and maximum flux level. The relationship between the number of sizes of restrictions and the flux level is shown in Figure (10). This relationship, of course, depends upon the loading pattern used. The curve of Figure (10) is based on a rectangular loading of 92 tons of metal. For cylindrical loadings the allowable maximum central heat flux would be approximately as indicated below:

MAXIMUM HEAT FLUX
W/cm²

Tons Metal Loaded	≈ 100 Orifice Sizes	≈ 10 Orifice Sizes	≈ 6 Orifice Sizes
72.5	14.6	13.5	12.3
64.3	16.0	14.7	13.4
55.5	17.3	15.9	14.5

The third test on the aerodynamics of the feed slot was made on a 9 channel full scale section also described in BNL-14. This test has been useful in designing the shape of the channel entrances and in determining the total head loss through the slot as a function of slot width and air velocity. The apparatus has now been tested using a total of three slot width dimensions: 2.04, 2.71, and 4.01 inches corresponding to hydraulic radii of 0.079(3), 0.102(2), and 0.146(0) feet respectively. The following correlation has been obtained:

$$\Delta P_T = 2.9 (10^{-6}) (V^{1.8}) (r_h^{-1.2}) \text{-----(1)}$$

where: ΔP_T = Total head loss, inches of water per foot of slot (measured along flow line.)

V = Air velocity in slot, feet per second

r_h = Hydraulic radius of slot, feet

The temperature of the air during the tests was $76 \pm 30^\circ\text{F}$. The density of the air varied with velocity approximately as indicated in the following equation:

$$\rho = 7.42 (10^{-2}) - 4.2 (10^{-8}) V^2 \text{-----} (2)$$

where

ρ = Air density, pounds per cubic foot.

In order to obtain the above correlation, a series of 10 or more runs were made at each of the three slot widths. In each series, three values of channel air flow rates were tested. Runs were made with zero channel flow, 460 pounds of air per hour per channel and 800 pounds per hour per channel (2/2 of central pile channel flow rate at maximum flux.) For each channel flow condition, at least two runs were made at two different slot air velocities. The static pressure data and flow measurements for each run were analyzed to determine the total head loss for an 8 inch section of the slot between channel centers.

These results showed that the total head loss was dependent on slot air velocity and slot width only and was independent of channel flow conditions. This fact is a significant aid in predicting the actual pile slot operating conditions knowing the flow distribution pattern from the small scale model tests. Results also showed that the channel entrance pressure drops were dependent only on the channel air flow rate and did not vary significantly with either slot width or slot air velocity.

The apparatus was tested first with unrounded channel entrances and then with entrances rounded with a radius approximately equal to the channel diameter. It was found that the total head loss through the slot was the same in either case, but that the channel entrance loss was reduced by a factor of 4 by the rounding. It was also found that the shape or position of the finned aluminum cartridge had very little effect on pressure drop provided the cartridge did not protrude into the slot. The air pressure drop from the gap to a point 10 inches down the graphite channel has been found experimentally to be as indicated in the following equation:

$$\Delta P = 2.46 (10^{-7}) (W_A) \rho^{-1} \text{-----} (3)$$

where

ΔP = Pressure drop, inches of water, from gap to channel section 10" downstream from gap

W_A = Weight rate of air flow, pounds per hour

ρ = Air density, pounds per cubic foot

With the experimental data which is now at hand, we are able to prescribe a reasonably correct air flow control pattern for a given air discharge temperature. If this temperature did not vary more than about 75°F the air distribution would remain substantially constant with the proper amounts of air going through each channel. However, if for instance, the pattern were set for a 400°F discharge air temperature on all channels and the ratio of air flow to power level were such that the actual average discharge temperature was close to ambient, it is very probable that some of the outer metal assemblies would overheat due to the change in air distribution.

Since it presumably will not be known at the initial startup period just what the allowable maximum metal temperature will be, this is another reason for operating for a considerable period of time at reduced exit air temperatures. Even during a normal startup, when the allowable maximum metal temperature has been decided on, it will probably not be feasible to control the air flow rate continuously to give the nearly constant exit air temperature dictated by the maximum metal temperature and the orifice pattern. Therefore, it would appear necessary to install, initially at least, a set of orifice controls which would permit operation at low discharge air temperatures without danger of overheating the outer metal assemblies. This effect of exit temperature on air distribution will be studied experimentally in the near future. A compromise orifice control pattern will be worked out, which will permit sufficient air to flow in the outside channels at low average air discharge temperatures, while permitting a relatively small amount of excess air to flow in these channels when the pile is up to full power.

Several different types of channel restrictions have been designed and tested in the downstream section of a full size graphite channel. Three different modifications of a type using an annular orifice as a flow restriction have been discarded because of the difficulty of inserting and extracting them from the channel exit section. This type has also proven unsatisfactory because it has been found that the pressure drop across it depends very critically on its position with respect to the enlargement section at the end of the channel. The type which is being tested at the present time is a conical shaped graphite plug seven inches in length, which fits snugly into the enlargement section of the channel. Grooves for air flow are cut lengthwise along the periphery of the plug. The depth and number of grooves determine the flow resistance. With the data which have been taken to date on this type of orifice, a correlating equation has been obtained as follows:

$$P_{Net} = 1.24(10^{-5}) A_F^{-2.23} W_A^{1.9} \rho^{-1} \text{-----(4)}$$

$$- 2.58 (10^{-7}) W^{1.9} \rho^{-1}$$

where

P_{Net} = Effect static pressure drop from a point 1" upstream of the cartridge end to the plenum, inches of water

A_F = Area for air flow measured at upstream end (area for flow remained approximately constant over entire length) square inches

W_A = Weight rate of air flow, pounds per hour

ρ = Air density (downstream), pounds per cubic foot.

The third term of this equation represents the static pressure recovery when no orifice is used in the channel.

Orifices will be designed on the basis of this type of general correlating equation. However, once they have been fabricated, each size will be tested individually as a further check on its air resistance characteristics.

In those outside channels of the pile which will not contain uranium, it is planned to insert a number of cylindrical graphite plugs to restrict the air flow. Tests were made in a 2.660" diameter graphite channel using various diameters of one foot long cylinders with and without threads cut in the surfaces. It was found that threads on the surface decreased the air flow rate about 24%. The depth of the threads had very little effect on the rate. It was decided to use shallow threaded plugs with diameters 60 to 70 mils smaller than the diameter of the channels. If, for example, the two outer rows of channels (a total of 560) in the reactor were each filled with 11 one foot plugs, it is estimated that the leakage through these channels would be about 24,000#/hr. or about two percent of the air flow through the pile. Since it is planned to use graphite plugs in the enlargement section at the channel end, the actual leakage would be much less than this amount.

B) Tests of the heat transfer characteristics and thermal stress properties of the finned aluminum cartridge.

Temperature cycling test: A three foot length of aluminum cartridge was cycled between a maximum temperature of 350°C and 50°C for a total of 1200 cycles. The test was divided into three periods. The first lasted 285 cycles with no temperature differential between the top and bottom of the cartridge periphery. The heat flux was about 25% of the maximum pile heat flux through the aluminum. The second period lasted 730 cycles with a 40°C temperature increase between top and bottom cartridge periphery

temperatures with the same input of power as the first period. The last period included 180 cycles with a 40°C temperature differential and a power level of 50% of the pile maximum. Visual inspection showed that the cartridge had a slight wave in the fins at the hottest point on the cartridge. The surface coating was unchanged. The length of the cartridge was unchanged. There was a slight bow in the cartridge when cold. It raised a maximum of 1/16" in the middle. Operation at maximum power level would not be expected to change the above results. The cartridge was heated by a globar supported outside the cartridge at each end. Both ends of the cartridge were held down during the test.

In order to evaluate the heat transfer data for the system consisting of air flowing past a six-finned aluminum cartridge resting asymmetrically in a circular graphite channel, it is necessary to be able to calculate the amount of heat transferred by radiation and conduction from the aluminum cartridge to the graphite channel. The following two experiments were conducted to determine the radiation and conduction heat transfer rates.

Test of conduction through fins to graphite: The apparatus used consisted of a 14 inch length of cartridge with one fin in contact with a one foot length of graphite. The graphite was in contact with a uniformly heated slab of copper. A coolant was passed through the aluminum cartridge at a rate to give negligible temperature rise. Thermocouples were embedded in the aluminum fin and graphite both parallel to and perpendicular to the direction of heat flow.

The temperatures of the aluminum fin and graphite at the interface were determined by extrapolation of the temperatures in each section. The heat flow was calculated from the coefficient of heat conduction, the temperature distribution in each section, and the cross sectional area for the heat flow.

The following equation relates the heat flow to the surface temperatures:

$$q = K (t_f - t_g) \text{-----} (5)$$

where

q = the heat transferred in PCU per hour per foot of cartridge.

K = the contact coefficient in PCU per hour per degree Centigrade temperature difference per foot of cartridge

t_f = the fin tip temperature

t_g = the graphite surface temperature under the fin

The value of K obtained in the above mentioned test, increased for two fins, was $2.2 \text{ PCU}/(\text{hr.})(^\circ\text{C})(\text{ft.})$. Investigators at the Oak Ridge Laboratory obtained a value of $4 \text{ PCU}/(\text{hr.})(^\circ\text{C})(\text{ft.})$ for a cylindrical aluminum can resting in a V-shaped graphite trough. The difference is probably due to the larger area of contact in the case of the Oak Ridge experiment.

Test of radiation from cartridge to graphite: The apparatus used consisted of a 3 foot length of aluminum cartridge suspended within a 3 foot length of a 2.67" I.D. cylindrical graphite channel, one-half inch in thickness. A globar heating element was used to heat the aluminum cartridge. The aluminum cartridge had thermocouples attached at the middle of the six peripheral surfaces between the fins at 3 different cartridge cross-sections, at the center and spaced 4 inches from the center. The graphite had six thermocouples placed at the inner surface diametrically opposite those on the cartridge at each cross-section.

Since the experiment was performed at atmospheric pressure, heat was transferred from the aluminum to the graphite by radiation and natural convection. In calculating the results the effect of natural convection was included in the heat balances. The thermal emissivity of the aluminum was found to be 0.29, which is within the range of published values. The thermal emissivity of the graphite was found to be 0.38. No published values for a smooth surface could be found. Since the graphite surface was quite smooth, the emissivity would have to be less than that for a black-body.

Calculations made using these results indicate that the net amount of heat transferred by radiation from the aluminum cartridge to the graphite channel will vary from less than 4% in the center to about 15% in the outer channels of the pile.

Temperatures and power input were recorded for three different values of heat flux. The aluminum cartridge temperatures ranged from 64°C to 324°C . The temperatures were read to within $\pm 2^\circ\text{C}$ and the power input could be determined to within 2%. Since the temperatures had negligible variation longitudinally, it was assumed that there were negligible end effects at the points where the thermocouples were located. In calculating the results, the graphite and aluminum temperatures were averaged. A point calculation, when averaged proved this method accurate for the data of this experiment.

The graphite channel was hotter at the top than at the bottom, while the aluminum cartridge was hotter at the bottom than on the top. This was probably due to natural convection in the channel. There was a maximum temperature differential in the aluminum cross-section of about 12°C . The

maximum temperature differential in the graphite was 7°C. The maximum temperature drop possible through the one-half inch wall thickness of the graphite was calculated to be 1/2°F. Therefore, no erroneous temperatures could be expected from small variations in the depth of thermocouple placement in the graphite. The maximum temperature drop through the fins was calculated to be about 4°F. This was less than the peripheral variation in the aluminum temperatures.

The amount of heat transferred from an 11.5 foot cartridge can be determined from the following equations:

$$dq = 0.046 \left[\left(\frac{T_A}{100} \right)^4 - \left(\frac{T_G}{100} \right)^4 \right] dx$$

where

q = the rate of heat transfer in B.T.U./hr.

T_A = the average aluminum temperature at a given cross-section in degrees Rankine.

T_G = the average graphite temperature at a given cross-section in degrees Rankine.

x = the distance from the end of the aluminum cartridge in feet.

Integration of this equation over a cartridge length will give the amount of heat transferred by radiation. An approximate result can be calculated from the following relation

$$q = 0.53 \left[\left(\frac{T_A'}{100} \right)^4 - \left(\frac{T_G'}{100} \right)^4 \right]$$

where

T_A' and T_G' are properly averaged temperatures in degrees Rankine.

In cases where there is little change in temperature over the length in question an arithmetic average may be used.

Test simulating reactor channel conditions: This test was designed to duplicate as closely as possible the actual conditions to be expected in a central channel containing an 11.5 foot aluminum cartridge generating heat with a cosine distribution. This unit is being used to determine the temperature distribution along the surface of the aluminum cartridge, as well as heat transfer coefficients at several points along the cartridge length. Determination of pressure drop across the cartridge at anticipated operating temperature conditions is also of interest. In addition, the temperature attained by the graphite can be investigated.

The heat source provided consists of 3 Nichrome coils. Starting at the upstream end, there are 2 coils, each 2.3 feet in length, followed by a third coil, 6.9 feet in length. The shorter coils are close-wound and of uniform pitch whereas the longer coil is made with a continuously varying pitch of constant increment. The coils are electrically insulated along their entire length by a sleeve consisting of alundum tubes 2 inches in length, made to specifications by the Norton Company. Surrounding the alundum tubes for the entire cartridge length, there are 4 inch sections of copper tubing drawn to specification and designed to make for a smoother distribution of heat generation. The 4 inch section was chosen here in order to make the coil approximate more closely the flexibility at these intervals in the actual cartridge loaded with 4 inch uranium slugs. The entire assembly of nichrome, alundum and copper was inserted into the full-length cartridge.

Thermocouple junctions were peened into the aluminum surface at critical points on both the core and fins. These were distributed with 22 on the aluminum core recorded on 2-12 point Micromax recorders, and 12 differential thermocouples on the finned surface at mid-point and edge of the fin read by means of a Type K-2 potentiometer. In addition, 3 thermocouples were imbedded in the graphite surface of the channel floor and 3 at analogous positions in the channel roof. Thermocouples are also present for measuring entering and exit air temperatures. Since the geometry of the system made thermocouples impractical for simultaneous air temperature and static pressure measurement along the cartridge length, it was initially planned to attempt calculation of these temperatures from static pressure readings obtained at the desired positions (described in Report C-1986). However, subsequent attempts using this method indicate that direct measurement is preferable. Now that static pressure data has been collected, shielded thermocouples will be placed in the air stream.

A series of runs has been made covering 26.8%, 35%, 50%, 60%, and 70% of full power for central channel conditions (based on a heat flux tolerance of 12 watts/cm²). The heat flux tolerance quoted by Driver-Harris for Nichrome wire B & S Gage No. 9 oriented as described permits operation up to approximately 70% of full power generation. Though the downstream end of the cartridge was left open to allow for free expansion of the coil upon heating, there was apparently sufficient inhibition of such movement so that expansion had to take the form of a wave in the coil length making for random contact between heat source and the aluminum wall. This makes for higher temperatures in some cases on the top or side aluminum surfaces rather than on the bottom where maximum temperatures are expected to occur with the asymmetrically located uranium. Individual thermocouple readings are, therefore, not dependable so that an averaging of the metal core temperatures at any given cross-section would seem the more meaningful way of examining the data.

The average of the aluminum core temperatures at a point 63 inches from the upstream end, the region of expected maximum temperature from previous theoretical consideration, was plotted against % of full power and extrapolated to 100% to give 680°F with an air flow rate of 1054 lbs./hr. For reasons given below, this is corrected to give 662°F at 1200 lbs./hr. A plot of exit air temperature from the region of the cartridge vs. % of full power extrapolated to 100% gives 420°F for the exit air temperature. Heat balances calculated for each run made give good checks of heat generated vs. heat removed by the coolant air. The graphite temperatures obtained were unreasonably low and proved to be caused by the wiring system rised for the thermocouples. The large number of couples resulted in a cumbersome wiring system so that advantage was taken of the theoretically sound technique of using a common cold junction. This resulted in some shorting among the couples giving erroneous results. The recent failure of the two short Nichrome coils has delayed the running of the system with individual leads. However, runs made using the 6.9 ft. coil remaining give a correction factor which indicates a maximum aluminum temperature of 662°F at an air flow rate of 1200 lbs./hr. The air temperatures do not require correction, having had individual leads. The system is being repaired enabling verifications of the corrected figures as well as determination of graphite temperatures.

Data has been obtained covering the pressure drop across the 11.5 ft. heat aluminum cartridge. The variation of the drop with exit air temperature is given below for 1054 lbs./hr., 100 F entering air temperatures:

EXIT AIR TEMPERATURE DEGREES F	PRESSURE DROP EXCLUDING END EFFECTS INCHES OF WATER
200	15.0
300	17.0
400	19.0
500	21.0

These data are correlated by the following equation:

$$P = 2.12 (10^{-7}) W_A^{1.85} (T_{Ave})^{1.372} (P_S)^{-1.0} L^{---(6)}$$

where

P = Pressure drop, inches of water

W_A = Weight rate of air flow, pounds per hour

T_{Ave} = Weighted mean temperature;

$$\left[\frac{[T_{A_2}]^2 + [T_{A_1}]^2}{2} \right]^{1/2}$$

T_{A_1} = Entering air temperature, OR

T_{A_2} = Discharge air temperature, OR

P_S = Average static pressure in channel,
inches of water absolute

L = Length of cartridge, feet

The pressure drop across one half of the pile at any one channel can be determined as the sum of equations (2), (4), and (6) all of which have been determined experimentally.

C) Test of graphite oxidation rate

A study of the oxidation rate of AGOT graphite was undertaken to determine the effect which would be produced by the coolant air in contact with the channel graphite in the pile. The consequences, if an appreciable oxidation rate should exist with corresponding changes in density, structural strength, and physical dimensions, are obvious.

Both irradiated and unirradiated material are of interest in a study of this kind so that graphite stringers were obtained from Hanford and Oak Ridge, irradiated for a four and two year period respectively. The samples used are in the form of small cylinders 1/8 inch in diameter by approximately 1 1/2 inches in length. The radiation hazard involved in the machining operation, principally from dust inhalation, necessitated the setting up of a hot graphite shop to meet Health Physics standards.

The particular sample size was chosen to enable measurements of the elastic modulus of the material as an index of structural strength after extended exposures. An apparatus has been set up which accomplishes this end dynamically without destroying the sample so that continued work is possible on the same sample. This apparatus will be described in detail in a separate report when this study is complete.

The apparatus used in oxidation consists of an Eimer and Amend Multiple-Unit Furnace of the tube variety. The samples are kept in small glass trays supported on a small brass rack designed for the purpose, which in turn fits into the glass reaction tube of the furnace. Each rack contains a dummy gra-

phite sample into which a thermocouple is inserted. This thermocouple in conjunction with a Leeds and Northrup Micromax provides a temperature record as well as regulation of approximately $\pm 3^{\circ}\text{C}$. One furnace unit containing several samples each of irradiated and unirradiated material is run at 350°C , and another smaller unit containing irradiated material only at 225°C , which temperature is slightly in excess of the maximum graphite temperature anticipated in the Pile. An adequately steady air flow rate past the samples is maintained by means of an aspirator using a Fischer and Porter rotameter for flow measurement. The air flow rate is sufficient to completely oxidize the graphite in a four hour period if complete oxidation could occur at the stated operating temperatures. The low reaction rate for these temperatures makes for a considerable excess in the present flow rate. A glass wool filter is present in the downstream section to trap any active dust which may come through. The samples are weighed in the glass trays eliminating the need to handle the material directly.

Graphite is intrinsically a non-homogeneous material, a fact which is apparent in the results obtained on Hanford material. Although the samples were taken from adjacent positions in a given cross-sectional cut of graphite, there is considerable variation in individual behavior under identical experimental conditions.

The Hanford samples run at 350°C have been exposed for a total of 590 hours (24.6 days) with the initial weighings after 193 hours (~ 8 days) exposure, and again after additional periods of exposure of 138, 43 and 113 hours. Weight losses on unirradiated samples after the first 193 hour period ranged from 0.4% to 1.0% with further increases of from 0.04% to 0.15% after an additional 138 hour exposure. Further exposures totalling 257.5 hours produced no change.

Irradiated Hanford samples lost 0.25% to 0.34% after the first 193 hour period at 350°C , 0.07% to 0.22% after an additional 138 hours, with no appreciable change in the subsequent 257.5 hours exposure.

Irradiated Hanford samples run at 225°C lost 0.04% to 0.66% after 79 hours with no conclusive further change in 336 hours of subsequent exposures.

It was thought that a significant part of the initial change is probably due to moisture lost in the initial exposure. Once under study, the samples are stored in a dessicator during cooling periods before weighings and during intervals between exposures in the furnace. Dr. Warren Miller of the Chemistry Division was asked to make carefully controlled studies on unirradiated material collecting the effluent H_2O and CO_2 at 225°C and 350°C . Only insignificant losses were noted in this work, the CO_2 and H_2O collected being of the same order of magnitude as in blank runs. These experiments

used air from which CO_2 and H_2O were removed before entering the furnace. Moist CO_2 -free air was then used to determine possible catalytic effect of the moisture on oxidation. None was noted. Experiments are now being run without removing the CO_2 to determine whether the reaction $\text{CO}_2 + \text{C} = 2 \text{CO}$ is taking place.

The possible catalytic effect of NaCl upon graphite oxidation was investigated at 350°C . The samples were soaked in a salt solution, dried, and exposed as previously described. No significant changes were observed. The Oak Ridge irradiated graphite has been exposed at both 225°C and 350°C for a 144 hour period with no significant change noted.

Studies are in progress at 400°C and will be carried up to 700°C . The effect of NaCl will be further investigated at temperatures where significant weight losses occur within a 24 hour period. In addition, the possibility of selective oxidation in the case of irradiated graphite will be studied at higher temperature levels.

METAL PROTECTION

Slug Design and Fabrication

The fuel rod assemblies which have been selected for the Brookhaven National Laboratory Reactor are to be eleven feet in length. Since the length of the Reactor is to be twenty-five feet, two of these assemblies are required for each graphite channel, one for each half of the channel separated by the gap through the graphite structure. Attached to the ends of the assemblies facing the plenum chambers is a 1/8 inch O.D., 1/16 inch I.D. by twenty-five feet long aluminum tube through which the continuity between the helium in the assembly and the helium safety system located outside the shield is established.

Since the fuel elements are different from those presently used in other Reactors, the selection of the raw materials and the manner of fabricating the units will be presented in some detail.

The fuel proper consists of natural uranium metal. So-called "virgin" uranium metal was cast into nine inches long by four inches O.D. right cylinders. These were then formed into 1.2 inches diameter rods by extrusion in the gamma region. The selection of this mode of forming was based on cost considerations as well as on the experimentally known fact that gamma extruded material does not elongate on temperature cycling.

The long rods were machined to four inch length by 1.100 inches O.D. right cylinders. Each slug is provided with a 1/16 inch wide by .015 inch deep slot and one axial .9 inch by .020 inch button. The actual specifications on this machining operation call for two annealing operations in argon; these being so placed in the sequence so as to remove all forming and machining stresses. It might be pointed out that this is the first reactor which will contain stress stabilized metal (prior to irradiation). A drawing of the uranium slug is given in Figure 11.

The slot and button serve a dual function. They allow for ready communication of the helium gas and equally important, the dimensions of the slot and button have been calculated so that the helium gas will not have a tendency to either surge into or away from the assembly as a result of temperature changes. Either type of surging would add to the activity of the helium system (uranium fission products). It can readily be shown that for an isothermal* system there will be no gas surging if: -

$$V_g \left[\frac{273 + t_2}{273 + t_1} \right] = V_g + (V_a)(3 \alpha')(t_2 - t_1)$$

* With respect to transverse and longitudinal sections.

SLUG

Figure 11

TUBE

Figure 12

where t_2 = upper operating temperature

t_1 = canning temperature

V_g = gas volume built into assembly
(i.e. slot + button + clearances)

V_a = volume of uranium

$3 \alpha'$ = difference in volume coefficients of
aluminum and uranium

This reduces to: $V_g = (V_a)(3 \alpha')(273 + t_1)$

It is seen that V_g/V_a depends only on the canning temperature and the difference in volume coefficients and not on the power level of the reactor which is comforting.

Since it is necessary to protect the uranium from the oxidizing cooling gas, it is encased in finned aluminum tubing. Heat transfer, metallurgical, and fabrication requirements have led to the selection of the section given in Figure 12. The Aluminum Company of America deserves special mention for their development of the techniques and tools required in the fabrication of this very exact section.

Simply stated, the finned tube is formed from a solid aluminum billet by extruding it through a web type or port hole die. In this type of die, the mandril (the rod which forms the I.D. of the tube) remains stationary. There are six ports through which the metal is forced. The six streams of metal recombine around the stationary mandril. Just beyond this mixing chamber, the mandril faces that portion of the die in which the fins are formed. Each billet yields approximately ninety-five feet of tubing. This is cut into fourteen foot lengths which are then drawn through a die which is provided with six slots. The actual drawing operation takes place on the tube wall. Although the fins are not in contact with the drawing die walls, these are "cold worked" in that they must stretch along with the tube wall.

After a thorough inspection for tolerances and for absence of flaws, the tubes are electrolytically anodized on the interior. The latter operation results in an oxygen plating of the surface. Actually, the surface of the aluminum, for the depth of 0.0008 inch, is converted to aluminum oxide. This surfacing operation has been included since it has been known for some time that uranium and aluminum interdiffuse rather rapidly around 300° C. to form an intermetallic compound UAl_3 whose density is approxi-

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mately half that of uranium. This gives rise to bumps and may even be a cause for rupture in the Brookhaven reactor since it is at present thought necessary to attain an aluminum-uranium interface temperature of 350°C . The Al_2O_3 serves as a blocking layer since it is both tenaciously held to the aluminum and may, by proper treatment, be made almost pore free. Figure 13 is a photograph of an extruded and drawn finned tube section.

Fabrication of the Cartridge

The canning procedure has been developed at Brookhaven National Laboratory and the processing is being carried out on this site by Brookhaven National Laboratory personnel. This process can be more readily evaluated in terms of the individual operations outlined below: -

1. Chemical stripping of anode coating from one end of tube.
2. Facing and trimming the stripped end of the eleven and one-half foot finned tube.
3. Argon arc welding of stripped end of the tube.
4. Degassing of the welded tube in vacuo at 350°C .
5. Helium mass spectrometer leak testing of the first closure and entire tube.
6. Insertion of the finned tube into the process tube and the loading of slugs.
7. Trimming to length and mechanical stripping of oxide film to proper depth.
8. Brazing of second end of cartridge.
9. Removing the process tube and encasing cartridge in storage tube.
10. Helium mass spectrometer leak testing of brazed closure and entire assembly.
11. Compressing the finned tubing on the slugs.
12. Temporary storage.
13. Flame brazing of anchor to finned tube.
14. Flame brazing of the $1/8$ inch aluminum tubing.
15. Helium, continuity and leak test.

To date, some 1750 have been processed through operation number twelve. The vacuum equipment for the final leak is now complete and is under test. Operations thirteen through fifteen will be started shortly.

In order to effect a high quality, dense argon arc weld, the anodized surface adjacent to the weld must be removed. It has been found that it is possible to remove this coating without removing the base metal by a five-minute dip in a mixture of chromic and phosphoric acids held at 90°C .

AS DRAW

AS EXTRUDED

Figure 13.

CARTRIDGE

Figure 14

The second operation serves the dual function of facing the end of the aluminum can as well as gaging the position of the end of the anodized coating relative to the end of the can. In this operation, the can is trimmed to leave .060 - .100 inch of bare metal. Since the welding cap, the bottom surface of which is anodized, is inserted to a depth of .100 inch, the uranium slug is in contact with Al_2O_3 for its full length. (See Figure 14.)

The end to be welded is now inserted in a special welding jig, which consists of a pair of collets separated by a short length of tubing. At the same time, a long rod is inserted from, and attached to, the opposite end of the tube.

The composite unit is raised into the vertical welding machine. A uranium slug is dropped into the tube. It seats on the long rod and may be adjusted so as to make a good contact with the welding cap which is now inserted. The welding torch is properly spaced relative to the cap and can (.035 inch gap), the start button of the rotating mechanism and transformer is depressed and the weld executed. The tube assembly is withdrawn from the machine after which the welding jig and support rod are removed.

Operation number four consists of heating the cartridge to 350°C . for one hour in an evacuated furnace in order to remove the water which is adsorbed on the anodic film and the water of hydration of the aluminum oxide. Tests on the completed assemblies showed that on heating, the water reacted locally to give minute pimples. Since this results in a local stretching of the aluminum tubing and the anodic film, this operation has been added as a precautionary measure. Those assemblies which were fabricated prior to the inclusion of this step, will be heated to 350°C . under vacuum to remove the excess water, since it has been determined that an assembly is treated, most of the water can be removed without reacting with uranium. That water which does react apparently does so uniformly under reduced pressure.

The unit, after cooling, is attached to the pumping system of the helium mass spectrometer. The end on which the closure has been effected and the full length of tube is then sprayed with helium gas, the detection of which, within the vacuum system, constitutes a leak and a basis for rejection. If the tube is rejected because the weld leaks, this end can be cut off and another weld made. If it passes the first test, it is placed in the process tube. This consists of a pair of collets fastened to a sturdy aluminum tube, the overall length of which, after the collets have been tightened, is two inches less than the final length of the cartridge (11"). This assembly is placed on a table provided with Vee blocks and uranium slugs are inserted by means of a calibrated push rod. The calibration of the latter is required to make certain that the slugs seat against each other so that the volume of gas built into the cartridge is kept at the design value.

After loading, the tube is trimmed to length. Enough excess tube length is allowed for insertion of the brazing cap. Since this is critical for a high yield (.115 inch excess required), the trimming tool indexes relative to the last slug. The unit is then placed in the elevating mechanism of the brazing machine. The assembly at this stage of the operations weighs 135 pounds. It is raised into brazing position and prior to the insertion of the cap, .003 inch of the inner surface is removed by means of a hand scraping tool. This removes most of the Al_2O_3 and allows for easier brazing. The brazing cap is inserted, the region is fluxed, the power turned on, and the closure effected by high frequency heating using 95% aluminum 5% silicon alloy as a filler rod.

Upon completion of this step, the process tube is removed and a carrying tube is lowered around the finned tube. The elevating mechanism is lowered for removal of the cartridge and carrying tube from the machine.

The cartridge is now sealed at both ends. It is taken to the horizontal helium leak test. In this test the tube is again evacuated but now the whole exterior, as well as the welded and brazed joints, is sprayed with helium gas. If it passes this leak inspection, the assembly is taken to the compression chamber. This consists of a stainless steel tube with a gate and "O" ring seal at one end and connections for introducing water at the other end. The pressure on the cartridge is raised to 2500 p.s.i. by means of a manually operated hydraulic pump. This pressure is sufficient to compress the aluminum tube walls into good contact with the slugs. Since the brazed cap has a 1/8 inch hole for insertion of the helium tube, it must be sealed against the compressing fluid. This is accomplished by means of a rubber stopper. By providing the latter with the proper taper the pressure of the fluid aids in the sealing.

The pressure is released and the cartridge and carrier tube removed from the chamber. A rubber cap is placed on the open end and the cartridge is placed in temporary storage.

Another operation, in addition to those mentioned in the earlier report, has been added in order to anchor the cartridge relative to the graphite. An unanchored tube could walk either into or away from the slot (the cartridge expands approximately .9 inch in going from room temperature to operating level), either of which would be detrimental to the operation of the reactor. This possibility was recognized and steps were taken to avoid it, namely, a slot one inch in width and 3/4 inch in depth has been milled into a graphite, twenty inches from the slot face. The Operations Group has developed an anchor which is a section of a cylinder. It will be welded to the fins of the cartridge and will protrude beyond the fins so as to allow for seating in the provided groove.

The development work on the flame brazing of the 1/8 inch helium tube is completed and the production equipment is built. The forty foot length of helium conduit tube will be in the form of two inch diameter coils, the end of which will be inserted in the hole provided in the brazing cap. The joining will be effected by means of oxygen-hydrogen flame and an 88% aluminum 12 % silicon brazing rod. Since this composition was not available in the stocks of the aluminum companies, it was necessary to have this composition made up for us by Mr. J. Kyger of the Oak Ridge National Laboratories. Our desire to use this brazing rod rather than the commercial available stock, results from the well-known fact that a similarly acting brazing rod, namely, the ALCOA 716, contains 4% copper, the corrosion resistance of which is somewhat doubtful.

The now completed assembly will receive its final leak test. This test constitutes proofing of the continuity of the gas passage from the 1/8 inch tubing to the cartridge as well as applying a more stringent helium leak test. This is to be accomplished in the following way: the assembly, consisting of the full length finned tube and its forty foot coil length of helium tubing is inserted into a brass pipe, one end of which is connected to a pumping system. The other end is provided with a vacuum tight cap for closing off the interior of the tube. Prior to closing off the space to be evacuated, the free end of the 1/8 inch tubing is pushed through a vacuum tight seal. This free end which is now outside the vacuum is connected to a so-called "dead" volume. The cap is now placed against the brass tube, and it is evacuated. A helium pressure of fifty pounds is applied to the "dead" volume. This volume has been built to be equivalent in capacity to the combined volumes of 1/8 inch helium tubing plus cartridge.

The valve between the "dead" volume and the assembly is now opened. If the pressure in the pressure gage drops to one-half its previous value, this is to mean that there is a continuous passage between the 1/8 inch helium tubing and the cartridge. The actual pressure reading is a measure of the volume in the cartridge.

Just prior to opening this latter valve, the cartridge is connected to a pumping system and the pressure in it is lowered to approximately one thousand microns. After the pressure in the large containing tube has been brought to the proper value, approximately twenty-five microns, the throttle valve on the helium leak detector is opened and the issuing gas is "sniffed" for the presence of helium. The differential pressure between the outside and the inside of the tube is forty pounds helium. Since the helium pressure within the cartridge should never exceed six pounds, it is felt that this leak test constitutes a stringent one. Every attempt will be made to operate the leak detector at its maximum sensitivity; namely, with the throttle valve wide open and the valve to the pump shut. To insure the degree of success for such

a proposed operating procedure, a large trap will be interposed between the high pressure end of the diffusion pump and the leak detector. For complete set-up, note Figure 15.

The work which has been sponsored by Brookhaven National Laboratory at Massachusetts Institute of Technology has indicated that the creep on aluminum at 350°C . will not cause difficulty. The creep rate at ten times expected load and at operating (350°C .) is of the order of $1.8 \text{ by } 10^{-6}$ inches per hour. The creep rate at eight times load is below the sensitivity of the measuring apparatus. The recent work on the interdiffusion of uranium and aluminum, the latter being anodized, indicates that it will be safe to operate the pile at 350°C . Some tests run at very high temperatures (550°C .) on Clinton type slugs which had been anodized showed no pimpling after 313 hours, whereas, untreated slugs had completely deteriorated.

Proceeding on our recommendation, Massachusetts Institute of Technology is checking further by x-ray techniques. The testing of the brazed and welded joints in concentrated salt atmospheres has resulted in assurance that this, too, will not be a cause for lower power operation.

It should be pointed out that recent work done here suggests that the published data on the linear coefficients of expansion of uranium as obtained from x-ray measurements are probably in error. Certainly, if one adds these to obtain the volume coefficient for uranium, it does not correspond with that directly observed. The volume coefficient is of the order of $51 \text{ by } 10^{-6}$ rather than $40 \text{ by } 10^{-6}$. Since this value effects the planning with respect to the breathing of the helium within the cartridge, measurements on volume coefficients were made in two ways; i.e., by summation of the observed coefficients of the transverse and longitudinal, and direct measurement of volume coefficient.

The breathing of the completed cartridge has been measured over a range of temperatures. The results of this study are included in the discussion of the helium system.

A detailed report on the canning is in the process of being prepared and should appear in the next two months.

HELIUM, CONTINUITY & LEAK TEST EQUIPMENT

Figure 15

MATERIAL HANDLING

In January 1948 a "mock-up" of a section through the reactor had been completed in barracks building, T-111, for the purpose of testing tools and procedures for charging and discharging the uranium cartridges and the orifices to be installed in the channels to restrict the flow of cooling air.

Design requirements for these tools have been that they be used only while the reactor is down, that all tools be removed prior to the start-up of the reactor and that the number of moving parts be kept to an absolute minimum. This has resulted in the development of charging methods which do not involve the handling or maintaining of radioactive tools, and in which the probability of having to halt the operation to repair machinery is small.

After the individual tools were developed and tested, detailed procedures were established for the charging and discharging operations. The procedures were then repeated on the mock-up a large number of times to establish the time required to charge an average unit. With an experienced crew the best time for charging a cartridge to the north half of the reactor was 2.5 minutes, with an average of 7.5 minutes for 12 trial runs. For charging a cartridge to the south half of the reactor the best time was 3.8 minutes with an average 8.5 minutes based on 12 trial runs. For prolonged operation it is estimated that a crew can charge six cartridges per hour. It is further estimated that the reactor may be charged to critical in somewhat less than two weeks if the operation were carried on continuously around the clock.

Figure 16 of attached photographs indicates the manner in which the cartridge will be anchored in the channel, Figures 17 and 18 indicate the position of the graphite orifice for controlling excess air in the mouth of the channel and the manner in which the helium tube leaves the channel and Figure 19 shows the manner in which the uncharged channels will be plugged.

Figure 16

Figure 17.

Figure 18

DECLASSIFIED

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Figure 19

THE SHIELD

Fifteen hundred tons of limonite ore and twenty five hundred tons of steel punchings were required for the heavy concrete shield adopted for the Brookhaven reactor. Specifications were established on these materials, and the H.K. Ferguson Co., took care of their purchase. The limonite was obtained and processed in one lot from the Pickands-Mather Co., mines in Michigan. It was graded and crushed at the mine and shipped to the site via barge through the Great Lakes. Analyses of the limonite were made to insure that the specifications were met. The steel punchings were unobtainable in one lot and had to be purchased from various sources before the total quantity needed was acquired. In fact several hundred tons needed to complete the order were punched especially for us out of new plate. The cost of the punchings averaged over the whole lot was a good deal higher than that of scrap steel.

At the site the punchings were put through several operations in order to be made ready for use. Initially they were screened to remove all small foreign material. Then they were sorted as to size where this was necessary. Finally they were cleaned and degreased by a spray of steam. A concrete batching plant was set up especially for handling the ingredients of the heavy concrete. Individual batches of 1 1/2 cu. yards of the heavy mix were handled in the ordinary 5 cu. yard transitmix trucks. In placing the concrete in the shield the aggregate was handled in wheelbarrow lots. The placing was down in thin 8 inch layers, and each batch placed was vibrated with caution to insure the absence of voids and prevent segregation of the mixture. In those parts of the shield where the charging tubes made the placing of the concrete a difficult operation, an especially construction gamma-ray instrument was used to monitor the attenuation between adjacent holes. The instrument was calibrated against a standard sample specimen of the heavy concret. It proved very useful in detecting the presence of voids while the mix was still plastic so that vibration could be applied where such were indicated. In all cases vibration was effective in removing the voids indicated.

One change was made in the mixture directly after the initial experience in placing it. Because it was found that the original mixture was very dry in handling it was decided to try the use of a proven admixture such as "Plastiment." This proved very helpful and the specifications were changed to include 1 1/2 pounds of this material per bag of cement. Along with this the water content was lowered from 40 1/2 gals. to 35 1/2 gals. per cu. yard. Test cylinders were taken from each batch of concrete for test purposes. The measurements showed that the field-prepared batches had densities as high as those achieved under laboratory-controlled conditions. Compression strength tests yielded seven day results as high as 6000 lbs/sq. in.

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At this time only about one additional week is required for completing the shield proper. The top part of the shield cannot be poured until a good deal of construction work inside the shield is first completed. This roof over the reactor will be poured during the last week in October, after which the graphite lay up can begin. The plugs for the multitude of openings through the shield have all been designed and are now under fabrication.

HELIUM SYSTEM

In the last Nuclear Reactor Progress Report, dated January 1, 1948, the helium system was discussed at considerable length. That discussion covered several aspects of the helium system in the following order:

1. Fundamental advantages of a helium system in reactor design and operation.
2. Primary physical considerations affecting the design of the helium system.
3. Basic engineering design to include all important physical effects.
4. A fairly detailed scheme for piping, valves, automatic leak detectors, and other machinery to control the gas in the system.

The first three aspects above have scarcely changed since January, 1948. They will be reviewed briefly in this report. The fourth aspect, detailed engineering, has been revised and extended. These details will be described quite fully below.

Review

Uranium will be loaded into the reactor contained in gas-tight finned aluminum cartridges 11 feet long. The space between the uranium and the cartridge will be filled with helium for two reasons: First, because helium is an excellent thermal conductor and will aid in cooling the uranium slugs; second, and the more important, helium is inert and will isolate chemically active uranium metal from the atmosphere. Thus, the helium system will eliminate the hazard of accidentally injecting radioactive uranium oxide dust into the cooling air stream should an aluminum cartridge fail. The fact that helium is not decomposed by radiation in the reactor adds another desirable property.

Helium in the system will be kept under positive gage pressure to prevent the atmosphere from seeping in through any leaks too small to be detected quickly. It will be necessary to purge the system occasionally and replace the helium contaminated by fission products with fresh helium. Means must be provided to detect inadvertent leaks before appreciable gas is lost, and to locate leaks for repair quite promptly after the pile is shut down.

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RECORDED

TYPICAL HELIUM TUBE ROUTING SCHEME

Figure 20

To carry out these functions a separate metal capillary tube extends from each aluminum cartridge in the reactor through the external radiation shield to pressure measuring machinery on the outside. The course taken by these thousands of tubes running to the outside is shown schematically in Figure 20. A more complete description of that course, and the construction, protection, and shielding, may be found in the January 1948 report.

At the end of its sixty foot run around the plenum chamber each capillary connects essentially to a two way valve leading to either of two manifolds systems. The primary manifold system is used constantly for leak detection when the reactor is operating. It consists of 74 separate closed systems, one for each vertical column of cartridges in the reactor matrix. The differential pressure between adjacent primary manifolds is monitored constantly by remote indicating electrical gages tied in turn to an automatic alarm system. A relative pressure drop in any one manifold indicates a leak in the corresponding vertical column of cartridges and calls for immediate shut down of the reactor. The capillary tubes entering that one manifold can then be switched to the secondary manifold system and the leaking cartridge specifically located by means of direct reading instruments.

Detailed Progress

The procedure, described above, for detecting leaks by using differential pressure gages between adjacent sealed manifolds was evolved since the January 1948 report. In order to carry the design to maximum sensitivity, several changes have been made to equalize the extraneous physical conditions affecting adjacent manifolds:

First, adjacent vertical columns rather than horizontal rows of cartridges are manifolded together. This means that the average volume of capillary tubes running through the varying temperature plenum chamber will be equal for each manifold.

Moreover, the run of tubing outside the pile (approximately 60 feet per cartridge) was rearranged and made equal for all primary manifolds. Even though this volume is at nearly constant temperature, it acts to decrease the net pressure change due to temperature changes elsewhere and so should be arranged to cancel out differentially.

Second, the volume of gas in each cartridge has been carefully controlled. In the last report, it was shown that by varying the volume of gas in the cartridge breathing under temperature cycling conditions can be adjusted over a wide range of positive and negative values including zero.

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The metallurgy group has run a careful series of experiments substantiating general analysis for the particular case of cartridges to be used in the reactor. They have adjusted their measuring and fabricating procedures to minimize and equalize breathing. That work is presented in detail in the section of this report describing activities of the metallurgy group.

Shortly following the design change to a sealed constant volume system for detecting leaks through differential pressure changes, the Foxboro Company was engaged to manufacture the concomitant remote-indicating, recording, and alarm systems. This equipment consists of two essentially separate panels, one for each half of the reactor. The equipment for one panel only will be described here.

Each element sensitive to differential pressure consists of a phosphor-bronze diaphragm separating two flattened bell chambers. This diaphragm is strong enough to stand a differential pressure of more than one atmosphere to avoid damage during purging operations. The diaphragms will be deflected by a pressure difference between the chambers and a solid iron cylinder directly connected to the diaphragm will move axially inside a center-tapped solenoid. In operation this solenoid will form two arms of a self-balancing a.c. bridge. The bridge proper is a fast acting recording instrument sold commercially under the trade name Dynalog. The recorder and all associated electrical equipment are remotely located in a suitable panel cabinet in the control room. A telephone-type stepping switch will automatically scan the 36 differential pressure elements and, in addition, will scan two gage pressure transmitters and a self-checking circuit. A separate scale will show which pressure element is being indicated at each step of the switch. A precise separate electrical zero set is provided for each pressure element. The range of all instruments can be adjusted simultaneously to lie anywhere between 2.5-0-2.5 and 50-0-50 inches of water full scale. Precision at range 25"-0-25" is better than 1/2% full scale. A change of differential pressure range will not affect zero adjustments. The choice of scale from the gage pressure transmitters is independent of the differential range used. This change of range will allow the reactor operators to select a sensitivity value which best fits operating conditions.

One pressure element will be scanned every 3 seconds. The scanning order will be 1-3-5-7..... then 2-4-6-8..... Thus every manifold will be scanned from one side once a minute and from both sides every two minutes. Self-locking electrical releasing high and low limit alarms may be adjusted to any fraction of full scale. A separate alarm is provided for the static pressure gages.

Figure 21

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Recording is done on a circular chart at a rate of one chart per day for each half of the reactor. An ingenious staggered cycle is used for recording: one differential gauge reading per minute is recorded approximately radially on the chart. The chart has 39 segments, each lettered for the appropriate pressure gauge and manifold pair it represents. Time is represented in a clockwise direction around each segment. Thus 39 readings as a function of time are recorded separately on a single chart each in an appropriate area.

Figure 2. is a reproduction (reduced scale) of a chart for use on the helium system recorder.

Work has been done in narrowing the range of estimate of radioactivity to be expected in around the capillary tubing and valve manifolds. The theoretical group will include a discussion of that analysis in the appropriate section of this report. In addition, measurements made on a small experimental cartridge and capillary placed in the Oak Ridge reactor place a reasonably low upper limit on expected activity. The expected value of activity is comfortably small-especially in the region of trench at the far end near the valves and manifolds. In case the estimate of activity proves to be too low, the wooden panels will be replaced by metal plates.

Design work on the helium system has now been completed for some time; orders have been placed, component materials are coming in, conduits are being fabricated and installed in the reactor. The major hurdle remaining is the adequate construction of a large, complex, gas-tight system. That work will continue to be done by the H.K. Ferguson Company at the site.

The requirement for permanent tightness of the system is very stringent, and unusually refined techniques and workmanship will be required in the construction and testing procedure. The Nuclear Reactor Group has been trying to aid the Ferguson Company in gathering information about those techniques and planning the procedures. Modified by experience as fabrication progresses, the following sorts of stringent precautions will be taken: all components will be carefully inspected and cleaned thoroughly inside. Silver braised joints will be heated electronically and the best state of the art applied in the choice of geometry and materials. Tubing used at flared joints will be bright annealed electronically before and perhaps after flaring. Tubing will be cut and burrs removed with power machinery designed for the purpose. And the tubing will be flared with pneumatically driven dies, which are hardened, polished, and accurately shaped to the manufacturers specifications. All flare fittings and valves will be taken up only with calibrated torque wrenches. Assembly will be done in a clean, dust-free room. Individual components, sections, and then the assembled system will be tested for leaks using helium gas and a sensitive mass-spectrometer.

THE ADDED SAFETY SYSTEMS

Mention was made in the Introduction of two new safety systems which have been added to the reactor design in order to comply with the recommendations of the Reactor Safeguard Committee. These systems are treated by the Theoretical Group elsewhere in this report in summarizing the devices contributing toward the control of the reactor.

The two vertical shot wells are located seven feet from each of the central axes of the graphite structure. The two shot wells located in the gap between the two halves of the graphite structure are at 45° to the vertical and run along the edges of two of the octants of the gap pattern. The operating mechanisms for both these sets of shot wells are identical, and are contained wholly within the shield except for the cable release which extends into the control room. The mechanisms are manually operated from that station.

The liquid safety system makes use of the pneumatic tubes to carry the poison into the reactor. There are eleven such tubes, which enter the face of the reactor opposite the charging face, and extend parallel to the metal-bearing channels as far as the gap. They are centrally located, within a circle of nine foot radius centered about the central axis of the reactor. Trichlorobenzene is to be used in this system. This liquid has a freezing point of 17°C and a boiling point of 213°C . The liquid is stored in a 14' O.D. by 18' long tank mounted on the face of the shield some 12' above the uppermost level of the pneumatic tubes. Eleven individual take-off lines are located on the underside of the tank and connect to pneumatic tubes. These lines contain check valves so that the CO_2 pressure, which operates the pneumatic tube system does not back up into the trichlorobenzene system. The liquid is fed into the tubes by gravity. There is a valve for each of the eleven lines which is manually operated from the control room by a long $1/8$ " diameter stranded steel cable running through a conduit to the tripping mechanism. The valves are of a special design to make absolutely sure there will be no leakage through the valve into the pneumatic system. On the underside of the tank there are eleven 2" pipe nipples welded into the tank with a 2" screwed 150# flange. A .029" thick stainless steel sheet is bolted between the flanges, and acts as a seal for the liquid. This seal is pierced by a specially designed spring-loaded plunger. The plunger assembly is mounted on top of the tank so that the point is approximately $1/2$ " above the steel diaphragm. When the spring-loaded plunger is tripped by the tripping mechanism it pierces the diaphragm and allows the liquid to flow through the diaphragm into the pneumatic system. The plungers is a stainless steel tube perforated with $1/8$ " diameter holes at random so that the liquid can flow into the tube and out

of the tank. There is a 35° cutting angle with the vertical axis. The spring which actuates the plunger is preloaded to 258#. At the control room a convenient pull handle is provided which requires a 25# force to actuate the mechanism.

CONTROL AND INSTRUMENTATION

Following is an itemized summary of the various components of the control system and a brief account of their present status.

Rods and Racks: one set of gear racks which drive the control rods is completely machined and the balance of the racks is complete except for the splicing. The rod-to-rack splices will be made at the Brooklyn Navy Yard.

Rod Support Structure: about 50% of the steel for the west rod support structure has been placed. After the sections are properly aligned, welding can begin. An engineer from M.I.T. is on hand to check the alignment. Work on the east structure will lag about two weeks behind that on the west structure.

Roller Supports: the roller supports for the rods are all on hand and will be installed as soon as the supporting structure is finished. This will be done by Ferguson millwrights under Ferguson supervision working in close cooperation with M.I.T.

Rod Drives: five of the hydraulic motors and gear reducers have been completed and it is expected that ten sets will be shipped by October 18.

Only one hydraulic pump has been received from Oilgear. The balance is expected momentarily. Assembly of the rest of the unit, including electric motor, tachometer, flywheel, stroke control and limit stop, is proceeding. It is estimated that the first unit will be available by Oct. 15.

The electric drives for the regulating rods have been assembled and are being tested. They are scheduled for shipment in October.

Miscellaneous Mechanical Equipment: ratchet cranks are being provided for manual insertion of rods to hold the pile down after the boron shotwells and trichlorobenzene tubes have been tripped. These cranks are now on hand.

In case of failure of the normal limit stops, the rods will be stopped by spring-type emergency overtravel stops. These include also the drive pinions and are now completed and on the site.

Rod Controls: the cabinet which contains the devices which actuate the solenoid-operated stroke controls of the emergency rod hydraulic pumps is in place in the equipment room.

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The pile power may be held level by switching on an automatic regulating system which operates on regulating rod No. 15. The control is of a simple type which runs the rod in or out at two discrete speeds. This is accomplished by means of contacts on a Brown recorder whose signal is a mixture of deviation of pile power from set power as obtained from an ion chamber and certain functions of this deviation. Studies are in progress to obtain stability of the servo loop and to minimize startup overshoot. Some construction has been started.

Boron Chambers: four 3-inch G.E. chambers will be installed in instrument holes near the top of the west face of the pile. Three of these will be connected to the power trip circuits and one will serve as spare.

Two more G.E. chambers will be installed in holes at the bottom of the east face. One of these will drive the galvanometers and the other will provide the signal for the automatic power regulator. These G.E. chambers are on hand.

In one of the lower holes in the east face there will be installed a specially-constructed boron chamber which will supply the signal to the period circuit. This chamber is constructed of materials with a low neutron cross section so as to be operable at low levels after irradiation at a high level. This instrument was redesigned at Eastman Kodak on the basis of a Clinton Labs. design and is being manufactured by Eastman for us. Delivery date has not been determined.

Fission chamber: in hole E30 on the east face there will be installed a fission chamber which will be movable along the hole by means of a motor-driven lead screw. This will operate into the counting rate system. The chamber is on hand at M.I.T. and Ferguson has designed the moving mechanism and will construct it.

BF₃ Counter: A BF₃ counter tube will be mounted on the carriage in the instrument tunnel under the pile. This will operate into a linear amplifier and scaler for low level work. The BF₃ tubes have been received.

Pile Period System: this is an electronic circuit which has two types of output; one proportional to $\log n$ or $\log$ power, the other proportional to $\frac{d}{dt} \log n$ or reciprocal of pile period. The power meter, with logarithmic scale is located on the console. The period meter, reading ∞ to five seconds is also on the console. In addition, on the control board behind the console there is a recorder which reads periods of -50 to ∞ to $+ 2.5$ seconds. This recorder will be equipped with a set of contacts for giving an audible signal whenever the period becomes less than a standard startup value. If

the period drops below a safe value, a pair of Sensitrol relays will act to trip the pile. Development on the circuit is complete and construction should be complete in October.

Counting Rate System: in order to avoid "blind" startups it is desirable to provide some neutron detector which will begin reading before the pile is started up. It has been decided to use a fission counter for this purpose operating into a circuit whose output indicator reads counting rate on a logarithmic scale. This scale will run from 1 to 10,000 counts per second. In addition to the panel meter on the console, the No. 2 galvanometer will be switched into the output of the counting rate circuit during startup in order to provide a more readable indication. For the protection of the fission chamber, when the meter reads off scale a relay acts to cause the withdrawal of the chamber into the pile shield. Construction of these circuits is essentially complete.

Emergency Shutdown System: several changes have been made in the power trips. Originally it was planned simply to use Sensitrol relays operating out of ion chambers. Several objections were raised: they would serve as high level trips only; they were too slow to prevent a damaging power overshoot; they do not fail safe. It was decided therefore to provide a fast, electronic, fail-safe, trip circuit, backed up by the simpler Sensitrol and supplemented by a Beckman amplifier for low level trip. The electronic trip circuit was developed, tested and proved very reliable. Three complete, independent systems of this sort are being provided. All of this equipment will be mounted on a special balcony high on the west face of the pile. Construction of the electronic trips is about 75% complete.

Equipment Room: all the cubicles and the galvanometer pedestal are in place in the equipment room underneath the control room. The instrument power inverters will be installed here.

Exit Filter Activity System: the ion chamber for this system has been constructed, and will be installed on the south wall of the pile building at the 110 ft. level.

Stack Air Activity System: the Kanne chamber for this system is on hand.

Instrument Power: the instrument load will be supplied from a motor-generator inverter which is continuously connected to the emergency battery. The 115 volt power from the inverter will have a frequency closely approximating that of the outside power line. By comparing two clocks driven from the two sources, it will be feasible to cause the instrument supply frequency to average the same as that of the outside supply. This will be done manually.

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In case of general power failure, the instruments will function without interruption.

Thermocouples: a change was made from iron-constantan thermocouples to chromel-alumel. This was the result of corrosion tests.

Thermopiles: the boron-coated neutron thermopiles have been ordered from General Electric. The first units delivered were rejected because of poor construction. Probable delivery date has not been determined. Four of these will be installed in various parts of the pile and connected in series to give average power.

Console and "M.I.T." Control Board: these two items are complete and will be shipped from Empire Switchboard Company when construction progress in the control room permits.

G.E. Instruments: Groups 1 and 2 of the "G.E." system have been shipped to the Long Island City plant of G.E. for wiring. Groups 3 and 4 will be shipped to the site by November. The control board will be shipped less the heat balance computer, which will be shipped at the end of November.

Wiring: no wiring has been pulled. About 25% of the conduit has been installed in the equipment room. None has been installed on the rod support structures. Wiring is expected to begin about November 20, and will require 10 to 12 weeks to complete.

Personnel: five technicians have been hired for instrument maintenance and one for special instrument development. Three technicians were sent to Foxboro for a few days' instruction on the helium system and one technician spent two weeks at M.I.T. working with the M.I.T. instruments. All the engineers in the Operating Division were given a week's instruction at the M.I.T. Servomechanisms Laboratory.

POWER RECOVERY SYSTEM

Since the inception of the reactor project, several extensive studies have been made to determine the feasibility of converting the heat energy of the hot air from the reactor into electrical energy.

Such a heat recovery plant would consist of waste-heat boilers located in the two exit air ducts and generating low pressure steam for driving a conventional turbo-generator which would operate in parallel with the 2300 volt fan house power bus of the Long Island Lighting Co. The electric power thus reclaimed would be an appreciable part of the power required to drive the large fan motors and would reduce materially the amount of power purchased.

The initial investigations centered about a coordinated system which would have included the present air-cooler units as a component part of the heat recovery cycle. Subsequent considerations dictated that coordination of the waste heat recovery project with the air coolers was not feasible, so the heat conversion study was continued separately.

The most recent investigation of such waste heat conversion is embodied in a formal report submitted by Gibbs and Cox, Inc., to the H.K. Ferguson Co., in response to the latter's request dated October 15, 1947. This report, dated June 30, 1948, concludes that it would be difficult to justify the construction of such a plant for economic reasons.

Any economic justification of this specialized heat recovery equipment is uniquely dependent on the performance of the waste heat boiler, due to the relatively low temperature threshold of the air entering the boiler--estimated at 420°F. The unit cost of purchased energy is also an obviously important factor. In the case of the Gibbs and Cox study, deductions were based on boiler performance and energy cost data which were most unfavorable. On the basis of more complete and reliable data, a critical reexamination indicates that the conversion of this waste heat to useful electric power is justifiable on economic grounds alone. Based on conservative estimates of quantity and temperature of exit air from the reactor, it appears that approximately 1250 kw can be reclaimed economically. This figure is to be compared with a maximum of 5200 kw required for the five large fans.

In view of these considerations a detailed feasibility report was prepared and submitted to the Executive Committee of Associated Universities at its September meeting. As a result of the Committee's deliberations, the Nuclear Reactor group is proceeding with the final details of submitting the feasibility report on heat recovery directly to the Atomic Energy Commission.

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HOT CHEMISTRY LABORATORY

One function of Brookhaven National Laboratory is to make available to the scientific and technical institutions of the East the major facilities required for modern research in the atomic sciences, i.e. reactors, accelerators, and hot laboratories, which because of cost and technical requirements are beyond the scope of the individual institutions. The hot laboratory is a necessary component of Brookhaven if effective utilization of the major facilities of the laboratory is to be realized, since many extremely important research and development projects involving medium and high levels of radiation can be conducted effectively and safely only with the massive shielding and remotely operated apparatus, the carefully planned ventilation and drainage, and the provisions for decontamination and handling which are embodied in such a laboratory.

During the period covered by this report the design of this building has progressed from a few general concepts to a status sufficiently detailed to permit construction to begin. Early in 1948 the size, scope, and function of the various components of the hot laboratory were crystallized into a unified whole and the result was embodied in a report dated February 26, which was submitted to the H.K. Ferguson Company for engineering development and design. The work of that company advanced to the point of issuing, on May 10, foundation drawings for immediate construction. Such construction was deferred, at the request of the AEC until very recently pending their approval of funds. By June 2, the plans and general scope of the building had received the approval of authorities within the laboratory as well as the Engineering Advisory Committee, the Physical Sciences Advisory Committee and the Executive Committee of the A.U.I. On June 30, the AEC also gave its qualified approval to proceed with the construction. During July, the building plans were re-studied and revised to reduce the estimated cost of construction. In August ground was broken and by September 30 all of the pads and footings and some of the columns had been poured and the bricklaying was about to begin.

A brief description of some of the features of design should be of interest. The building is divided functionally into the following five areas:

1. Process
2. Equipment Assembly
3. Decontamination
4. Analytical
5. Personnel

Process Area

The Process Area contains the Hot Cells, Semi-Hot Cells, and Semi-Works.

The Hot Cells are concrete-walled cubicles in which chemical processing and physical manipulations can be performed at an activity level equivalent to 50 curies of 2.0 Mev. These cells are of unique design, the outstanding feature of which is the fact that all equipment and apparatus can be pre-assembled and pre-tested as a complete unit in another room before placing it in the Hot Cell for the hot operations. Similarly the apparatus can be removed as a unit to a third room for decontamination.

The Semi-Hot Cells are laboratories in one end of each of which is a shielded bench on which work can be done by reaching over the top of the shield with appropriate tongs or manipulators. The level of activity to be accommodated in these units will be in the range of 1 mc to 1 c.

The Semi-Works Area is an open space with a 25 foot ceiling in which will be placed a shielded metallurgical bench for the physical testing of solids. Space is also provided for large equipment of the pre-pilot plant scale. Shielding will be built around the individual pieces as required.

Equipment Assembly Area

This area comprises the Equipment Assembly and Testing Room, the Cold Metal Shop, the Hot Tool Shop, the Glass Blowing Shop, the Cold Storage Room, and the Stock Room. The Equipment Assembly and Testing Room, as its name implies, is a large room in which the entire assemblies to be used in the Hot Cells and Semi-Hot Cells are completely assembled and tested even to the point of making dead and tracer-level runs in the equipment. When and only when the complete apparatus has been thus tested it is carried as a unit by a lift truck to the appropriate cell. The Hot Cell is of such a design that the apparatus can be set inside and heavy steel doors closed on it leaving all of the controls outside.

Decontamination Area

This area consists of dismantling and repair rooms, a decontamination room containing a special "dunking" tank in the floor, and the hot storage

vault. The walls of all of these rooms are shielded by a foot of concrete so that hot equipment being cleaned and repaired in them is not a radiation hazard to the rest of the building.

Analytical Area

This area consists of two Analytical Laboratories, a Physical Measurements Laboratory, a Counting Room, an Office for records, and Glass Washing Rooms. The Analytical Laboratories are of a design which, in accordance with the current tendencies in radiochemical laboratory design, minimizes places where unwanted activity can collect.

Personnel Area

This area consists of "hot" and "cold" locker rooms so arranged as to eliminate any spread of contamination, a check room, offices and conference rooms, a Health Physics Office, and a monitor station. The latter, in addition to routine counting and hand washing facilities, provides an emergency decontamination shower. Elsewhere throughout the building are the usual emergency showers for fire and acid burns.

WASTE DISPOSAL

A considerable amount of effort has been spent in the last six months in studying and defining the problem of handling the radioactive liquid wastes that accompany nuclear research. The problem of handling and disposing of the radioactive liquid wastes that will accompany nuclear research at Brookhaven is especially acute because:

- A. The laboratory is located in a highly populated area.
- B. The ground water in this area is easily accessible and is used extensively for domestic purposes.
- C. The surface streams all pass through populous communities and are used in duck farming.

Definition of the Problem:

The waste disposal problem at Brookhaven is discussed in this report in three of its major aspects.

1. Appraisal of standards of quality for natural waters contaminated with radioactive wastes.
2. Estimation of the amounts and specific activities of liquid wastes.
3. Considerations for handling wastes during initial phases of operation.

1. Appraisal of standards for water quality:

Tolerance values for radioelements are commonly given on the basis of whole body radiation from immersion in liquids. The following equation is taken from MDDC 240, "Tolerance Concentrations of Radioactive Substances", by K.Z. Morgan, and assumes a limit of 0.1 roentgen per day (Beta and Gamma radiation):

$$Q_W = \frac{1.6 \times 10^{-3}}{E}$$

Micro curies per milliliter of liquid,
where

Q_W = Total quantity of radiation.*

E = Energy of emitted particle in Mev

* Tolerance Values for Brookhaven are based on one-half this value, or .05 roentgens per day.

SECRET

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Since the tolerance levels for ingestion of liquids are known to be many times lower than for immersion it seems logical that any potential hazards from radioactive wastes should be evaluated in terms of ingestion tolerances. By way of comparison, ingestion tolerances for the following isotopes are shown along with equivalent chemical concentrations:

<u>Isotope</u>	<u>Ingestion Tolerance C/cc of liquid</u>	<u>Equivalent Chemical Concentrations p.p.m.</u>
Strontium ⁸⁹	4×10^{-3}	10^{-7}
Iodine ¹³¹	0.55×10^{-3}	10^{-8}
Lanthanum ¹⁴⁰	1900×10^{-3}	10^{-6}

Although present day information may indicate the limits below which radioactive contamination is not a demonstrable hazard to health, it should be assumed that any appeals to the courts or to the public health authorities would be on claims of health impairment. Therefore, from the legal standpoint alone, the objectives in the waste disposal program will require high standards of control. Radioactive pollution does not have to be injurious to health to be socially undesirable.

Certainly an ideal would be to reduce the activity level in the waste effluent to the level of natural activity in the local waters. Natural activity varies greatly from place to place and from time to time, but in general, it is in the order of 10^{-7} C/cc of water: a maximum upper limit would be immersion tolerance in the order of 10^{-3} C/cc of water. An operating level for the discharge of liquid wastes from our facilities has been tentatively set at 3×10^{-7} C/cc.

2. Amounts of Radioactive Wastes:

The wastes to be handled at Brookhaven have been considered under the following classifications:

Type A: Hot Metal Wastes - high in uranium content, high specific activity, low pH

Type B: Hot Process Wastes - high specific activity, moderate to high chemical concentrations, low pH

Type C: Solvent Wastes

Type D: Low Activity Wastes - low chemical concentrations, low pH

Type E: Cold Wastes, but potentially contaminated.

Type E will require temporary retention and monitoring at the source.

Estimates of the quantities of waste to be expected have been made based on a comparison with similar operations at the Oak Ridge National Laboratory and on a unit breakdown and waste volume estimates from Brookhaven facilities as now planned. These are as follows:

<u>Type of Waste</u>	<u>Gallons per Year</u>
Type A	7,800
Type B	32,000
Type C	3,900
Type D	300,000

The premises on which these estimates are based are:

Firstly, that construction of the reactor, reactor laboratories, hot laboratories, and their accompanying facilities is assumed to follow the designs as of this date. However, some allowance has been made for improvements in design and operations techniques which should result in reduction of waste volumes in comparison with those from the Oak Ridge National Laboratories.

Secondly, that these volumes are computed from rates of discharge corresponding to a normal level of operations for which the building is designed. This level may not be attained until some two years after completion of the building.

Thirdly, that these amounts are actual and to be expected under the conditions noted above with a 40-hour week. No contingency factor has been added to cover the possibility of a longer work week, and no safety factor is included to cover inaccuracies in the estimates.

3. Considerations for Handling Wastes During Initial Phases:

Two general methods of treating hot wastes have been considered, (a) by direct dilution to tolerance or natural activity levels and (b) by concentration and storage of hot wastes with consequent purification of plant effluents.

To dilute untreated Brookhaven National Laboratory liquid wastes to tolerance would require dilution volumes available only in local ground water. The lack of control, the possibility of dangerous local effects, and the low

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ground water circulation rates make this method seem unattractive. Even if wastes could be piped, or conveyed by tanker beyond the water shelf to the ocean, the possibility of concentration of active elements in fish and marine life would have to be contended with. It is in accordance with Atomic Energy Commission policy, furthermore, to avoid dilution of active material.

The best method giving positive control seems to be concentration and storage. The concentration step must provide for treatment of large volumes of water with contaminant in proportions of roughly one part per million and result in tolerable water effluents. The demand is for large-scale water treatment equipment with an efficiency up to 99.999%. It is not sufficient, for example, to specify that an ion-exchange bed must have an efficiency of 99% when the 1% of contaminant not retained is unfair to the community. Ion-exchange, adsorption, precipitation, and evaporation have been proposed and tried elsewhere, but little is known of the efficiency of any of these methods in treating small amounts of contaminants.

Prior to the development of a satisfactory concentration process, all liquid wastes at Brookhaven in which activity is above tolerance limits will be stored. To insure flexibility and control the following systems have been planned:

A. Hold-up System

The principle has been adopted that all known active solutions will be trapped and held while potentially contaminated liquids would be temporarily retained and monitored. Hold-up in the reactor labs and similar facilities will be accomplished by the use of drums and "hot" pots, while pipe lines and outside hold-up tanks will be provided in the hot labs.

B. Collection System

A piping system providing for flexible operation will be installed to transfer solutions from tank to tank and from hold-up tanks to the waste tank farm. The first major unit in the tank farm will be collection tanks for the accumulation of various wastes for analysis, classification, and distribution to subsequent treatment or storage facilities.

C. Storage System

Consideration is being given to a system of tanks that would retain at least a two year accumulation of laboratory radioactive waste. The system is intended to be flexible within itself and to include facilities for discharging tank contents into other tanks or containers which may not be part of the local storage system.

GRAPHITE TESTING

In the January 1, 1948 Progress Report a complete report was given on the testing of AGOT and AGHT graphite on hand at that time. In spring of 1948 shipments of purified graphite from Bay City, Michigan were received and a Sigma Pile was set up in the Engineering Laboratory of Building T-197 for testing two sections of this graphite. The graphite for purification was obtained from stocks of AGHT material which had a diffusion length of approximately 49.00 cm. The same polonium beryllium sources were used in this Sigma Pile as were used for the previously reported tests, necessitating thirty minute exposures and counting times. Diffusion lengths determined were as follows:

	Data Set #1	Data Set #2
1st test section	55.91 cm $\pm$.85 cm	55.58 cm $\pm$.93 cm
2nd test section	55.71 $\pm$.53 cm	54.96 $\pm$.55 cm

It is planned that this pure graphite be used for the removal core section of the pile, for removable experimental stringers and for thermal columns. To date shipments totalling 86,912 have been received and for convenience we have designated this as Grade AA graphite.

June 30, 1948 the H.K. Ferguson Company reported that insufficient amounts of AGOT material were available for completing the pile as planned, since machine losses had been underestimated in the original plan. Arrangements were made with the Atomic Energy Commission to obtain 100,000 lbs. of CS Grade Graphite from the material allotted for Hanford Engineering Works. This material was received July 8, 1948 and three tests sections have been machined and tested. Stronger Radium-beryllium sources were used in these tests so that information could be given to the H.K. Ferguson Company on the allocation of this graphite within the reactor as soon as possible. The results indicate that this material is as good or better than the graphite presently allocated for Zone A of the reactor, having diffusion lengths of 52.02 to 54.34 cm. Since a considerable amount of Zone A graphite had already been machined of AGOT material having a diffusion length of 50.36 - 52.30 cm, it was not possible to put all of this CS material in Zone A. CS graphite, therefore, will be allocated to Zones A, B, & C to fill the present shortages. As of June 30, 1948 the shortages in these zones were estimated to be as follows:

- (1) 637 bars 4 x 4 x 50" for Zone A
- (2) 608 bars 4 x 4 x 50" for Zone B
- (3) 294 bars 4 x 4 x 50" for Zone C

The graphite testing program is completed, the test piles have been disassembled and the graphite turned over to the H.K. Ferguson Graphite Machine Shop for use in the reactor.

THEORETICAL GROUP

During the period January 1 to September 30, 1948, the work of the Theoretical Group has been oriented in the following directions: refinement and extension of design calculations on the basis of more recent experimental data; anticipation of problems of initial operation; treatment of miscellaneous problems, arising from the work of other groups of the project.

The problems studied are discussed under the following headings:

- I. Revised Pile Properties Based on new Graphite Data.
- II. Revised Estimate of the Required Value of the Excess Multiplication Factor.
- III. Possible Modifications of the Metal Loading.
- IV. Further Calculations on Problems of Pile Control.
- V. The Helium System.
- VI. Problems of Initial Operation.
- VII. Miscellaneous Problems.

I. Revised Values of the Pile Constants on the Basis of New Graphite Data.

In earlier calculations, the "design" value of the diffusion length of thermal neutrons in the graphite was taken as 50.2 cm for a graphite density of 1.62 grams per cc or 50.8 cm for a graphite density of 1.60 grams per cc. The results of the sigma-pile tests indicate that the thermal neutron diffusion length may be conservatively taken to be 52 cm when corrected to a graphite density of 1.60 grams per cc. The actual density lies between 1.65 and 1.70 grams per cc. On the basis of the sigma-pile data the value obtained for k_{∞} , as compared with the "design" value, is:

	<u>Old design values</u>	<u>Values based on sigma-pile data</u>
η	1.315	1.315
ϵ	1.029	1.029
p	0.878	0.885
f	0.899	0.898
k_{∞}	1.068	1.074

Thus, the value of k_{∞} should actually be about 0.006 greater than the earlier design value.

Tests show that the purity and the density of the graphite are higher than originally assumed, and this results in a slightly lower value of the migration area, and in a higher value of the critical Laplacian.

	<u>Old design values</u>	<u>Values based on new data</u>
$(M_I)^2$	721 cm ²	710 cm ²
$(M_{II})^2$	764 cm ²	752 cm ²
$-\Delta_I$	95×10^{-6} cm ⁻²	106×10^{-6} cm ⁻²
$-\Delta_{II}$	89×10^{-6} cm ⁻²	100×10^{-6} cm ⁻²

It will be seen in the next section that the total excess k requirement of the pile is 0.021, based on the requirements of xenon, temperature effect and desired experimental facilities. A cylindrical loading 20.4 feet in diameter, with 22-foot long metal tubes should yield an excess k of about 0.023 provided the reflector saving is in agreement with the two-group theory. This would correspond approximately to 750 full length loaded channels, or 63 tons of metal. This calculation does not include the effect of aluminum in the pneumatic tubes, in the shot wells or in the anchors which will hold the metal cartridges in place. Nor does it take into account the fact that the ends of the metal cartridges will not lie flush against the central gap. These effects may increase the total number of loaded channels to about 800, or about 70 tons of metal.

The numbers quoted above must be considered with some caution since they depend very strongly on the value used for the diffusion length of thermal neutrons in graphite. Although a very serious attempt has been made to measure this quantity with good statistical precision, it has been possible to analyze only 10-12 per cent of the total graphite, and the absolute accuracy of the results is not very well known. The importance of the diffusion length is such that a variation of one centimeter in diffusion length corresponds to a variation of about 10 tons in the amount of metal required.

II. Revised Estimate of the Required Value of the Excess Multiplication Factor.

The size of the reactor and the extent of the metal loading depend on the value of the excess multiplication factor needed. The latter depends on the

conditions under which it is desired to operate the reactor. The most important of these conditions are the neutron flux, the power level, the average metal and graphite temperatures and the desired experimental facilities. The flux, power level and metal temperature are, of course, closely related, but their effects can be at least partially separated. Thus, the flux (or specific power) determines the extent of the xenon poisoning; the metal and graphite temperatures determine the (negative) temperature coefficient of the multiplication factor. We, therefore, consider three primary contributions to the excess requirement:

1. The xenon poisoning.
2. The temperature coefficient of the effective multiplication factor.
3. The desired experimental facilities.

1. The effect of xenon poisoning, including the "burning" of xenon by neutrons.

The effect of xenon poisoning in a unit cell in the reactor reduces the local value of the thermal utilization factor and hence of the multiplication factor. If Δ denotes the additive contribution to $1/f$ where f is the local value of the thermal utilization factor, then

$$\Delta = \Delta^\infty \frac{H}{H + H_x} \quad (\text{cf. CRT - 272})$$

where Δ^∞ is the limiting value of Δ as the power level (or flux) becomes very large, H is the local value of the specific power (power per ton of metal), and H_x is the particular value of H at which an atom of xenon has equal chances of being destroyed by neutron capture or by spontaneous decay. The function Δ^∞ depends on the value of the fission yield of xenon (or of its precursor iodine) and the ratio of the fission cross-section of ordinary uranium to the total absorption cross-section. The best available value of Δ^∞ is 0.032. The value of H_x depends strongly on the absorption cross-section of Xe for thermal neutrons, and a value of H_x equal to 2 megawatts per ton of metal leads to a somewhat pessimistic value for the xenon poisoning effect. The local increment is then averaged over the pile by weighting with the square of the power distribution (or flux distribution). The effect of xenon poisoning on the entire reactor can be represented by:

$$\frac{\Delta}{P} = \frac{0.032}{1 + 1.75\gamma H_x} \frac{U}{P}$$

where γ is the ratio of the average neutron flux to the maximum neutron flux, U is the total amount of uranium metal in tons and P is the total power production of the reactor in megawatts. A reasonable value to expect for γ in the Brookhaven reactor is 0.324, with $\frac{U}{P} = 4$. This yields

$$\bar{\Delta} = 0.006$$

The decrease in k is then given by

$$\delta k = -k\bar{\Delta} = -(1.07)(0.9)(0.006) = -0.0058 = -0.006$$

This value is somewhat lower than that given $-(0.008)$ in previous reports where the effect of the "burning" of xenon by neutrons was neglected in order to obtain a conservative value for the excess k requirement.

2. The Temperature Coefficient of the Effective Multiplication Factor.

The calculation of the temperature coefficient of K eff. ($=k$) is based largely on the coefficients obtained experimentally in the Clinton reactor. It was found there that the graphite and uranium temperatures contribute in different ways to the total temperature coefficient. The values obtained were:

	<u>In hours per degree</u> <u>above room temperature</u>	<u>δk per degree C.</u> <u>above room temperature</u>
Graphite	-0.8	-2.2×10^{-5}
Metal	-0.3	-0.83×10^{-5}

The temperature coefficient of k is due to several causes:

(a) The resonance escape factor decreases with increasing temperature due to the Doppler broadening of the resonance bands of uranium.

(b) The number of neutrons produced per neutron absorbed in uranium (η) decreases with temperature due to

(1) The change in the ratio of the absorption cross-section of U_{238} to the fission (or absorption) cross-section of U_{235} .

- (2) The change in the ratio of the fission cross-section of U_{235} to the total absorption cross-section of U_{235} .

(c) The thermal utilization factor increases with temperature chiefly because of the "flattening" of the thermal neutron distribution.

(d) The leakage of neutrons from the reactor increases with increased graphite temperature.

It is reasonable to assume that the metal temperature coefficient will be the same for the Brookhaven and Clinton reactors. However, analysis of the variation of the thermal utilization factor with temperature indicates that the increase in the thermal utilization factor will be somewhat smaller in the Brookhaven reactor than in the Clinton reactor. The values of the metal and graphite temperature coefficients used for the BNL reactor are:

graphite = -2.7×10^{-5} in k per degree C.

metal = -0.83×10^{-5} in k per degree C.

It is expected that the maximum metal temperature will be 350° C in each cartridge, corresponding to an average metal temperature of about 275° C. The average graphite temperature is expected to be about 200° C. The average graphite temperature calculated on the basis of heat transfer by the air stream alone would be about 150° C. To this must be added the temperature increase due to heat production in the graphite itself, the temperature increase due to conduction from the aluminum fins where they touch the graphite, and the temperature increase due to radiation from the metal to the graphite. The last three effects together may result in an increase of the average graphite temperature to about 185° C. In order to obtain conservative results, an average temperature of 200° C has been used in the present calculations. This yields for the temperature coefficient of the effective reproduction factor:

graphite effect : - 0.0047 in k

metal effect : - 0.0021 in k

total effect : - 0.0068 in k

This result is again somewhat lower than that given (-0.0075) in a previous report in which the metal temperature coefficient was calculated for the maximum metal temperature rather than for the average metal temperature in order to obtain a conservative value for the total excess k requirement.

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3. The Experimental Facilities.

It is expected that a value of 0.0075 in k will be adequate for the experimental facilities contemplated.

The total amount of excess k required is then:

xenon effect:	0.006
temperature effect:	0.0068
experiments:	0.0075
total:	0.020

In order to insure against possible doubts in the temperature effect, a total excess k requirement of 0.021 has been assumed. If it should turn out that the temperature and xenon effects involve slight over-estimates, the "surplus" excess k can be used to increase the allowable experiments or to modify the loading of the reactor. In any case, a value of the excess k of 0.021 seems to be reasonably conservative.

III. Possible Modifications of the Loading of the Brookhaven Reactor.

After criticality is reached, the experimental value of the critical Laplacian can be obtained and compared with the theoretical value. In addition, the temperature coefficients will be measured and compared with the values used in the design. With these data more accurate estimates will be made of the loading needed for the desired value of the excess multiplication factor. It is expected that on the basis of the conservative design calculations and the improved graphite quality there will be some "surplus" excess k available. If this is the case, the surplus can be used in any of several ways;

(a) to allow for more experimental facilities,

(b) to increase the reflector size, thereby saving metal and improving the air flow in the central gap,

(c) to "bow" the metal loading, i.e. decrease the amount of the metal in and near the center of the reactor. This would result in a flattening of the neutron distribution and either in an increase in the central neutron flux or a decrease in the power required to cool the reactor.

The extent to which scheme (b) or (c) can be used will depend on the amount of "surplus excess k " which will be available. This excess can be expressed in terms of the excess of the "actual pile buckling" over the geometrical buckling ($51 \times 10^{-6} \text{ cm}^{-2}$). Since the actual value of this excess cannot be esti-

mated accurately before the initial period of pile operation, values of the buckling of $60 \times 10^{-6} \text{ cm}^{-2}$ and $70 \times 10^{-6} \text{ cm}^2$ have been used to compare the possible advantages of increased reflector and bowing.

Before proceeding to the calculations some qualitative discussion may be helpful. From the viewpoint of the ease of fabrication of the metal tubes the advantage lies with the use of the larger reflector since the length of the metal cartridges, in this case would be uniform rather than varying. If a smaller number of channels are loaded the pressure drop in the gap will be decreased, while for a given central flux a smaller total amount of air and hence of pumping power will be required. Since the pumping power represents a relatively large part of the operating cost, the saving would be significant. On the other hand, in an experimental pile the greatest possible flux is desirable. In this case if the input power is kept constant the air which is not needed for the outer channels can be used to cool the loaded channels with a corresponding increase in the heat removed from these channels. Thus, a greater central flux can be obtained while still maintaining the maximum metal temperature at 350° C .

In the bowed pile, for constant input power, the shortened central tubes can take more air relative to the unshortened outer channels, with a resulting increase in the heat which can be removed from the central tubes. Hence, the central flux can again be increased.

In order to bypass the extensive calculations we first quote the results of the analysis, then indicate the assumptions on which the calculations are based. The results are given in Table 1. Case A refers to a cylindrical pile with a uniform metal tube length of 22 feet and a loading radius sufficient to give the required value of the excess k with the indicated buckling. Case B refers to a pile with a uniformly reduced metal tube length and a loading radius of 11.5 feet and is included for the sake of comparison. Case C refers to a bowed pile with the extent of the bowing determined by the buckling, and a fixed loading radius of 11.5 feet.

Results

The results of the analysis show that under the somewhat idealized conditions of the calculations, reduction of the loading cross-section, while maintaining a uniform tube length of 22 feet should require somewhat less pumping power than would be required in a bowed pile. The same maximum central power output should be obtained in the two cases. Thus, we could find no significant advantage in a bowed pile over a pile with uniform tube length under the design conditions of the Brookhaven pile. These results have been borne out by the more extensive calculations made by the Engineering Division. Therefore, in view of the greater simplicity afforded by the uniform tube length we have recommended that a uniform tube length of 22 feet be used in the pile.

TABLE 1.

SUMMARY OF CALCULATIONS WITH
MODIFIED METAL LOADINGI. Buckling $60 \times 10^{-6} \text{ cm.}^{-2}$ Cooling Required for a Central Output of
3.5 KW/ft. of Metal
(13 watts per cm.^2 at center of pile).

	<u>Loading</u>	<u>Maximum Central Power Output</u>	<u>Air Flow lbs/hr.</u>	<u>Pressure drop inches H_2O</u>	<u>Theoretical Pumping Power KW</u>
CASE A	L 22.0 feet D 21.4 feet 70.4 tons of U.	4.62 KW/ft. (17.2 watts/ cm.^2)	920,000	46.0	1,100
CASE B	L 19.0 feet D 23.0 feet 69.8 tons of U.	4.62 KW/ft. (17.2 watts/ cm.^2)	984,000	45.0	1,160
CASE C	L 17.0 22.0 ft. D 23.0 feet 75 tons of U.	4.64 KW/ft. (17.2 watts/ cm.^2)	995,000	43.7	1,140

II. Buckling $70 \times 10^{-6} \text{ cm.}^{-2}$

CASE A	L 22.0 feet D 18.7 feet 53.6 tons of U.	4.92 KW/ft. (18.3 watts/ cm.^2)	733,000	39.6	750
CASE B	L 15.1 feet	4.87 KW/ft. (18.2 watts/ cm.^2)	921,000	38.3	920
CASE C	L 12.8 19.3 ft. D 23.0 feet 61.4 tons of U.	4.85 KW/ft. (18.1 watts/ cm.^2)	950,000	37.7	940

The results of Table 1 indicate that a maximum central heat flux of 17.2 watts/cm² may be obtained with a buckling of 60×10^{-6} cm⁻². This would correspond to a central flux 5.7×10^{12} neutrons per cm² per sec. It is difficult to assess accurately the significance of this result in view of the approximations and quantitative uncertainties in the calculations. We consider that the chief value of the calculations is in the comparative results for the different cases considered, and that the "absolute" results indicate an expected, though quantitatively uncertain, gain in central flux.

Assumptions

Several assumptions and approximations were made in this study, some because of lack of better information, others to keep the labor within reasonable bounds. These are enumerated in the following paragraphs.

Heat Transfer Coefficients

The overall heat transfer coefficient between the aluminum cartridge and the cooling air - based on the maximum aluminum temperature - was taken as

$$H = 0.011 \left(\frac{W_c}{1000} \right)^{0.73} \frac{\text{KW}}{\text{ft}^2 \text{ } ^\circ\text{C}}$$

where W_c = air flow through channel in lbs. per hour. This coefficient is based on a film coefficient obtained from the usual Dittus-Boelter equation for flow in tubes. It includes an estimate of the temperature drop within the aluminum jacket based on data of J.B. Rosen of the Engineering Division. The drop through the fins was obtained in a straightforward manner from a heat diffusion equation. The efficiency of the jacket decreases with increasing film coefficient, accounting for the somewhat unorthodox exponent of 0.73.

Pressure Drop

The pressure drop, ΔP_t , in the system was broken down into two terms. The first, ΔP_c is the pressure drop through the central Channel; the second, ΔP_o , includes all other losses. They were taken as follows with units in inches of water:

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$$\Delta P_c = (9.0 + \ell) \left(\frac{W_c}{1000} \right)^{1.8}$$

$$\Delta P_o = 22 \left[\frac{W_t}{10^6} \right]^{1.8}$$

where

W_c = air flow through central channel, lbs/hr,

W_t = total air flow, lbs/hr,

ℓ = length of central cartridge, ft.

ΔP_c is based on values given by D. Bareis of the Engineering Division, with terms added for entrance losses. Strictly speaking, entrance and exit losses vary as W_c^2 , and ΔP_c depends on air temperature and pressure. Since neither W_c nor air temperature varies appreciably in the cases compared, no significant loss in precision should be introduced.

ΔP_o was estimated quoted in BNL - 4 (Status Report: July 1, 1947). Here again some of the losses should vary as W_t^2 and there is a temperature dependence. These are again ignored. About one-third of ΔP_o is in the central gap. It is apparent that this loss should depend to some extent on the distribution of the air flow through the various channels. This dependence was neglected because of lack of data.

Cooling Air Requirements

For all the cases considered, the amount of air required in each channel as a function of radius was calculated so as to give a maximum aluminum temperature of 350° C with an inlet air temperature of 20° C. The total air flow requirement was obtained by integration assuming that the ideal distribution can actually be obtained. For these ideal conditions the intersection of the pressure drop vs. flow characteristic curve for each case with the corresponding characteristic curve of the blower set gave the maximum achievable central power level. Blower data were supplied by Wm. Page of the Engineering Division.

Reflector Effect

For the purposes of the present calculations the reflector saving was calculated by the simple one-group approximation: $\delta = L_o \tanh \frac{T}{L_o}$ where T

is the reflector thickness and L_0 is the thermal neutron diffusion length in the reflector, taken as 1.60 feet. For the saving in the radial direction, the savings were averaged over the azimuth, the thickness T being taken at each point as the shortest distance to the reflector edge. It will be remembered that the calculations were based on a cylindrical metal loading in a cubical pile.

In each case reported the perturbation of the neutron flux near the edge of the metal loading and in the vicinity of the central gap was ignored. The effect of the gap is obviously negligible because the maximum jacket temperature depends only slightly on the details of the longitudinal neutron distribution. It is clear that the general conclusions drawn from our approximate calculations will hold, even individual results may be modified slightly.

Mathematical Methods

The mathematical treatment of the problem of the bowed pile followed that of Wheeler M-4220, particularly Appendices 5 and 6.

IV. Further Calculations on Problems of Pile Control.

In an earlier progress report (BNL - 14, January 1, 1948), the problems of overall-control and pile start-up were considered. In the present report, the earlier calculations are refined and extended.

A - Pile Start-up Problems

We have previously investigated the nature of an accidental over-load of the BNL reactor at start-up. This investigation was based upon a simplification of the pile kinetic equations which applies accurately only to events after prompt critical is reached. The work has now been modified so that the neutron intensity curves before prompt critical could be studied and more accurate determinations of the over-loads and the pile periods could be made.

The withdrawal rates of the control rods have now been frozen at 1 ft. per sec. At start-up the individual rods will be withdrawn only half-way through the pile. The maximum overload computed on this basis is 2.6 that of the normal operating level. The maximum pile period during overload is 0.8 sec. The overload lasts for 2 seconds.

Thus, the problem of pile start-up is actually somewhat simpler than seemed to be the case on the basis of our earlier calculations.

XENON GROWTH AND DECAY AFTER SHUTDOWN
AVERAGE FLUX - 1.5×10^{12} NEUTS / CM² SEC.

Figure 22

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B - Pile Shut-down Problems

The change in the multiplication factor of a reactor with time after shut-down depends primarily on (1) the change in temperature of the metal (2) the change in temperature of the graphite and (3) the growth and decay of Xe^{135} .

The best available figures give an increase in k of 2.7×10^{-5} per degree Centigrade fall in the temperature of the graphite and 0.83×10^{-5} per degree fall in metal temperature. At an average flux of 1.5×10^{12} neutrons/cm² sec, the concentration of Xe^{135} is practically constant for the first four hours after shutdown and then decays slowly as its shorter-lived predecessor I^{135} is used up. Actually, there will be a very slight rise in the Xenon concentration after shut-down due to the continued decay of its precursor iodine. At the neutron flux contemplated, however, the maximum Xenon concentration reached will only be about two percent greater than the equilibrium concentration. At the end of 8 hours the Xenon concentration has dropped by only 9% and at the end of 24 hours 43% of the Xenon is still present. The course of its growth and decay is plotted in Figure 22.

Under conditions of operation the total effect of Xenon poisoning at equilibrium will be 0.0006 in k . Three control rods will suffice to compensate for the disappearance of all of the Xenon, and as has been shown, then can be inserted over a period of several hours.

Figure 23 shows the fall in the average graphite temperature of the reactor as a function of time after shut-down with full cooling. Figure 24 shows the relative power output of a reactor as a function of time after shut-down for different values of the control inserted, and also experimental values obtained for the Clinton reactor. The metal temperature will drop from its operating value to that of the graphite in a minute or less, and will then remain within a few degrees of the graphite temperature as the latter decreases. The increase in k due to the drop in the metal temperature from operating to graphite temperature will be 0.0012. The increase in k involved in cooling the graphite plus metal from the operating graphite temperature to room temperature will be 0.0060.

The control rods are of two varieties, those closer and those further from the center of the reactor. The closer rods can effect a change in k of 0.0036 each; those further from the center 0.0021 each. The cumulative effect of all sixteen rods is expected to be greater than 0.040. Hence, if the cooling air is uninterrupted, a single rod will hold the reactor down for several minutes, and four or five rods (an overestimate) will be required to compensate for all temperature effect. The last two or three rods need to be inserted only at a rate of about one every ten minutes.

AVERAGE GRAPHITE TEMPERATURE AFTER FULL SHUTDOWN

Figure 23

RELATIVE POWER OUTPUT OF A PILE AFTER SHUTDOWN V.S. TIME

Figure 24

In summary, three rods may possibly be required to compensate for the total Xenon effect and four for the total temperature effect, making a total rod requirement of seven (out of a total of sixteen rods) to hold the reactor for an indefinite period. The excess reactivity used for experimental purposes, is, of course, not a transient.

In the event of a power failure or a shutdown of the cooling air blowers, the air pressure within the reactor will rise about 15%. The added nitrogen will produce a loss of k of 0.0015. This is a favorable circumstance which, together with the slower rate of heat removal, will ease the shut-down control problem. The only transient will be the drop in metal temperature since it will take many hours for the heat to be removed by the emergency air-flow. Under this condition, any single rod would hold the reactor down for a period of hours.

Because of the statistical independence and the operating safety features of the control rod system, it is certain that an ample margin of safety has been provided.

C - Additional Safety Systems.

The main control system, consisting of sixteen horizontal rods has been described earlier (Report on the Brookhaven Nuclear Reactor, June 22, 1948, pp. 28 ff). These rods will easily control the reactor during start-up and shut-down and under normal operating conditions. They will also provide enough control to handle any reasonable emergency. In the event an accident which may interfere with the proper functioning of the primary control system, additional safety devices will be available. These consist of:

(a) two boron-shot wells situated in the central gap, running diagonally from the upper edges of the east and west faces downward to the center of the reactor.

(b) two vertical boron-shot wells,

(c) a reservoir outside the shield from which trichlorobenzene can be fed rapidly into eleven pneumatic tubes.

In addition, another device can be installed if required; it will be discussed later.

The shot wells located in the central gap will be equivalent in effectiveness to at least one control rod running diagonally through the center of the pile, i.e. to $\delta k \approx 0.005$. The vertical shot wells, situated seven feet from each of two

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axes of the reactor will each add 0.001 in k. Thus, the four shot wells listed in (a) and (b) will provide 0.007 in k.

In addition to the shot wells the pile will contain eleven pneumatic tubes which enter the north face and run parallel to the direction of the metal tubes. Each pneumatic tube has an inner diameter of $2 \frac{11}{16}$ inches and is approximately twelve feet long. The lattice of pneumatic tubes may be approximated by a circular cross-section somewhat less than nine feet in radius. Under normal operating conditions the pneumatic tubes will afford a means of rapid insertion and removal of samples. For emergency purposes the tubes can be connected to a reservoir of liquid absorbing material, such as trichlorobenzene, located outside of the shield, and can be filled with material from the reservoir by means of a suitable arrangement of valves. A conservative estimate indicates that with trichlorobenzene about 1% in k could be obtained in this way. Thus, the boron shot wells together with the pneumatic tubes would be capable of supplying almost two percent in k for purposes of emergency control.

If the emergency controls discussed should be deemed insufficient, another possibility is under consideration. This involves the use of part of the channel in which a control rod moves. Each control rod has a square cross-section two inches on a side and lies in the center of a square channel four inches on a side. Thus, there is a space four inches by one inch in cross-section above the rod itself. If necessary, an aluminum tube with a rectangular cross-section slightly less than four inches by one inch could be built into the upper part of the control rod channel extending as far as the central gap. In the event of failure of the primary rod system the additional tubes could be filled with trichlorobenzene. The amount of control which may be expected from this system depends on whether or not it is used in conjunction with the pneumatic tube system. The control rod tubes if used alone would provide 0.017 in k; if used in conjunction with the pneumatic tubes, the total effect would be 0.032 in k. This apparent discrepancy is due to the fact that if used alone the control rod tubes would be operative chiefly in the south half of the pile, while the pneumatic tubes would be operative chiefly in the north half of the pile. If used together, the two systems tend to reinforce each other. It is hoped that the installation of the control rod tube system can be avoided.

V. The Helium System.

A. Contamination of the Helium System by Radioactive Fission Fragments.

The purpose of the helium system is the early detection of canning failures during pile operation. A description of the system has been given in previous

reports. In order to detect leaks the space between the uranium slugs and aluminum jacket is filled with helium gas. The gas is exposed to the hot uranium slugs in a running pile. Since the total activity in the slugs soon approaches 10^8 curies in high-level operation an investigation of the extent of pollution of the helium system by radioactive fission products was undertaken.

Radioactive fission products enter the gas both by slow diffusion and by the stoppage of fast fission fragments. The latter is essentially a surface phenomenon since the extrapolated range of fission fragments in uranium is only a quarter of a mil. It is shown that of all the fission fragments generated in a slug, the fraction $\frac{1}{4} \bar{R} S/V$ escape, where $\bar{R}$ is the mean range of the fission fragments in uranium and S/V is the surface to volume ratio of the slug. Only a minute fraction of these fragments are stopped in the gas.

The inner surface of the aluminum can is anodized, that is it is coated with a layer of Al_2O_3 to a thickness of about one mil. The vast majority of the fission fragments that escape from the slugs stop in a layer of aluminum oxide equal to the extrapolated range of the fragments, about one third of a mil. When the pile activity is 10^8 curies, the activity in this layer is some 14,000 curies. Under the same circumstances and with the present cartridge geometry the activity stopped in the gas is estimated at some 30 curies of which about 4 curies are contributed by long-lived, large yield gases.

We are interested chiefly in the equilibrium activity in the shielded trenches where the tubing from each column of cartridges is manifolded. There are two such trenches, one for each half of the pile. Under uniform mixing of the radioactive gases, there would be about 0.01 curie per linear foot of trench. Actually, there exists a favorable concentration gradient along the tubing due to the decay of the radioactive gases. When this gradient is taken into account, the computed activity is less than a millicurie per foot of trench. This amount of activity is not serious.

A more serious question is raised by consideration of the possible pollution of the helium system by diffusion processes, that is, either direct diffusion of radioactive fission products through the uranium slugs or back diffusion from the active aluminum oxide layer. The extent of diffusion depends critically upon the temperature of the metals. Numerical calculations are hampered by the lack of adequate experimental data on the diffusion coefficients of fission products as a function of the temperature and physical properties of the metals. The extrapolation of rough high temperature data by the Langmuir-Dushman formula indicated that high-level equilibrium activity due to 5.3 day Xenon alone would amount to 1 curie at $350^\circ C$ and

10 curies at 450° C. At the higher temperature this estimate exceeds that of the activity, contributed by recoil, of all the long-lived large-yield fission gases. In addition, the empirical nature of the Langmuir-Dushman formula is such that these estimates could well be off by a factor of ten.

In order to obtain quantitative data, a single slug was canned in a short cartridge filled with helium and irradiated at the center of the Clinton graphite pile. After a few days of irradiation at measured slug temperatures of 300° - 330° C, the gas in the cartridge and tubing was drawn off and the activity measured. The recorded activities were 25 - 35 mr/hr. Decay curves show that most of the activity was short-lived, suggesting that in this temperature range, the principal source of the contamination of the helium system is still the stoppage of recoil fragments. It was estimated that 0.1 millicurie of radioactive gas escapes from a slug into helium while the pile is running and one-sixth as much remains after the pile is shut down for an hour.

The theoretical investigation of the diffusion processes shows that in a pile operating at a fixed level, the diffusion of a primary radioactive fission product approaches equilibrium in a time of the order of the mean life of the product. At equilibrium, the concentration of the product in the metals is the same as if there were no diffusion except in a surface layer of thickness $\ell = \sqrt{D\tau}$ where D is the diffusion coefficient and τ the mean life of the product. For the parameters of interest, this layer is very thin being about 10^{-6} cm or so for long-lived gases in the temperature range of 350° C to 450° C.

The equilibrium activity in the helium system due to direct diffusion from the slugs is given by the fraction $\ell S/V$ of the activity of the slugs where S/V is again the surface to volume ratio of a slug. The corresponding fraction for back diffusion is $\ell S/V \left(\frac{R}{4R_1} \sqrt{D_1/D} \right)$ where $\frac{R}{R_1}$ is the ratio of the mean range of the fission fragments in Al_2O_3 and D_1/D is the ratio of the diffusion coefficients. The relative importance of back diffusion depends upon the ratio D_1/D . In the present case, direct diffusion probably dominates. If the aluminum jacket were uncoated, the situation would be reversed, since the diffusion coefficients in aluminum are of a higher order of magnitude.

Consideration of the diffusion of secondary fission products leads to similar results. The thickness of the layer in the slug where the concentration falls off now depends upon the critical lengths ℓ_1 and ℓ_2 of both parent and daughter. If $\ell_1 \gg \ell_2$, both contribute equally to the activity of the gas. If $\ell_1 \ll \ell_2$, the daughter may be treated as a primary fission product.

In order to obtain estimates of the activity in the shielded trenches, the diffusion of the radioactive gases through the helium filled aluminum tubing was treated. At equilibrium, the concentration of a primary, radioactive

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fission product falls off exponentially with distance along the tube. This sets up a favorable concentration gradient which may however be disturbed by temperature cycling and other transients. In addition, the increased volume due to the tubing and manifolds serves to dilute the fission products somewhat. However, there is a limit to the extent of this dilution since the products tend to cluster near the entrance end of the tube.

In summary, it is found both by theoretical work and experiments that the pollution of the helium system of the BNL reactor will not be too serious. However, problems of this nature will become more acute in the design of high temperature piles and the need for better experimental data on the diffusion coefficients of fission products in metals is indicated.

The Purging Problem

The efficiency of the helium system as a conductor of heat depends on the concentrations of foreign gases that are built up within the aluminum jacket with time. It is contemplated that the helium system will be purged occasionally and replenished with fresh helium to improve its thermal conductivity. The slow increase in long-lived activity may likewise require occasional purging of the system.

Since the contaminants will be concentrated in the cartridges, it will be necessary to pump the gases through at least 60 feet of small diameter tubing. The resistance to flow will therefore be considerable and this raises the important question of the time required to remove all but a small fraction of the gas from the cartridges.

A satisfactory mathematical model is that of the discharge into a vacuum of a long cylindrical capillary tube initially filled with a gas at rest under uniform pressure and temperature. The flow is assumed to be one-dimensional, unsteady, viscous and iso-thermal. The only comparable problems which have been treated to some extent in the literature lie in the field of ballistics. However the latter problems involve turbulent flow at high Reynolds numbers. The parameters involved in the purging problem lie in the region of low Reynolds numbers where the flow may be expected to be laminar.

The chief problem from the engineering view point is determination of the pressure-time curve at the rear of the tube. A mathematical formulation which assumes no slip of the gas stream at the walls leads to the simple expression

$$\frac{1}{p} = \frac{a}{\mu} \left(\frac{R}{L}\right)^2 t + \frac{1}{p_0}$$

where p is the pressure at the rear of the tube at any time $t \geq 0$, p_0 the initial pressure, R/L the ratio of tube radius to tube length μ the absolute viscosity of gas and α a constant approximately equal to $1/8$. The formula shows that more than 99% of the helium at the rear of the tubes will be evacuated in a few minutes after the pumps are started.

The accuracy of the theoretical expression was checked by the experimental evacuation of air from 100 feet of $1/16$ inch I.D. copper tubing. The result of three test runs show that the pressure at the rear of the tube falls to 1% of atmospheric pressure in two minutes. The pressure-time data were used to check the constancy of the parameter α in the above theoretical expression. It was found that α varied slightly with time, rising from an initial value of 0.11 to 0.15 after the first minute of pumping.

The effect of slip was argued by analogy with steady flow conditions. It was found that at $1/10$ atmosphere the correction to the flow equations is only of the order of 1% although the correction becomes increasingly important as the pressure is further reduced.

Under simplifying assumptions, the hydrodynamical equations of motion for the purging problem lead to a non-linear partial differential equation governing the motion of the system. A special solution is obtained which yields the pressure-space distribution as well as the pressure-time relationship already mentioned. Comparison of theoretical and experimental data will be carried out as soon as the latter are available.

VI. Problems of Initial Operation.

With the completion of most of the important problems connected with the design of the BNL reactor, the attention of the Theoretical Group has been shifted to preparation for the initial period of pile operation. The experimental program planned for this period will afford the opportunity of comparing experimental results with theoretical calculations. In order to help in the anticipation of problems which may arise and in the planning of the projected experiments, a careful study has been made of the history of the operation of the Clinton pile. In addition, work has been started on the planning of the experiments to be done on the BNL reactor and on the methods of analyzing the results.

Plans are being made for measuring the thermal neutron diffusion length in the actual graphite structure both during the stacking process and after completion of the stacking. We are investigating various methods of placing the neutron sources, and of correcting for the effect of the central gap and the empty channels. Methods of analyzing the activity data while

the metal is being loaded are also under investigation, with the object of making the best possible prediction of the actual loading.

After criticality has been achieved, experiments will be done on the effectiveness of the control systems, shadowing effects, poisoning effects, neutron distribution, delayed neutron periods, temperature and barometric effects, etc. Data will also be collected on the air flow distribution with the object of obtaining the most efficient possible distribution. The latter will depend to some extent on predictions of the final metal loading based on extrapolation from criticality data. The Theoretical Group has started work on the job of anticipating the needs of the Nuclear Reactor Project in planning and interpreting the experiments.

VII. Miscellaneous Problems.

In addition to the major problems considered, several minor problems have been considered. These will be mentioned very briefly.

A. Heating of the Control Rods.

The most important contribution to the amount of heat developed in a control rod is that due to neutron capture. Less significant contributions come from moderation of neutrons and absorption of gamma rays generated in the surrounding portion of the pile. The latter contributions are proportional in magnitude to the similar heating effects which occur in the moderator itself and should amount to about ten percent of the heat due to neutron capture. A reasonably conservative estimate of the rate of heat production in a control rod due to neutron capture yields a rate of about one KW. The problem of whether under these conditions the control rods require cooling is under consideration. If necessary, some cooling air can be made available to the rods by very slight modifications in the machining of the graphite in the neighborhood of a rod. Even this may be unnecessary.

B. The Effect of Very Highly Purified Graphite on the Pile Constants.

It seemed possible that some graphite practically free of boron might be available for the central portion of the pile, and some calculations have been made on the increase in k which would result, and on the possible effect on the final pile loading. Since it has turned out that this graphite is not available, the results are only of academic interest.

C. A memorandum by Dr. H.M. Schwartz containing tentative suggestions for a program of basic physical research using the pile has been distributed.

D. A study is under way of the possible radiation to be expected at various heights from ground level to the top of the stack under inversion conditions.

E. Studies have been made on the desired dimensions of the Brookhaven thermal column.

F. Various "dodges" have been considered for obtaining increased thermal neutron flux in some of the experimental holes.

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METEOROLOGY GROUP

Introduction

Members of this Group have continued consciously to devote their major efforts to procurement, installation, and test of facilities, equipment and supplies, and to their self-education in the essentially new methods now used in micrometeorology and atmospheric pollution studies. Virtual completion of the 160 and 420 foot meteorological towers and the recorder and operations building marks the end of this preliminary phase and the beginning of a full meteorological operating phase.

A separate report, "Summary of Current Operations of the Meteorology Group," is descriptive of the meteorological training program. Design plans and construction progress have been reported in the "Brookhaven National Laboratory Program Report," and a complete description of the meteorological facility will be submitted after its acceptance from the contractor. The Group's prime interest in the Laboratory's Radiation Protection Program is fully discussed in a report to the Reactor Safeguard Committee, dated June 22, 1948, BNL-18, and in its Supplement, dated August 30, 1948.

In addition to the more or less extensive reports listed above, special reports have been submitted and data obtained for various other purposes of the Laboratory. Still other results and data are presented here for the first time, generally in summary fashion preliminary to full publication. Up to the present these efforts have been directed toward one or more aspects of the atmospheric dispersal of cooling air (from the Reactor) problem, but the scope of the attack is far wider than is apparent on casual thought. The present report serves to suggest the breadth of the meteorologists interests in and his adaptability to such investigations, by giving a general survey of major developments and discussions of the routines established or being established in (1) observations and instruments, (2) forecasting, and (3) statistical analyses of data.

General Aspects of the Work

Among the parameters recognized to be of practical importance in determining the effective concentration of atmospheric impurities are:

A) Design Parameter of Source(s):

1. Height and diameter of stack.
2. Temperature, speed, physical nature, and mass rate of effluent.
3. Nature of surrounding structures and terrain.

B) Meteorological Parameters:

1. Wind; speed, direction, gustiness, and persistence and their derivatives.
2. Temperature; air temperature and its derivatives.
3. Precipitation.

Not all of the parameters listed are of equal importance under different circumstances. Some may be varied cheaply and easily, while others are themselves variable without action on the part of an operator. None may be omitted from consideration in dealing with the dispersion of effluent from the reactor stack.

Irrespective of design parameters, certain advantages are resultant from the operations of a polluting source when some form of "meteorological control" is invoked. By meteorological control is meant the most efficient expenditure of power and labor compatible with weather conditions and the nature of the contaminant effluent from the source. This may mean, for example, an increase in the temperature of the effluent, or the curtailment or even shutdown of the source under particular meteorological conditions. The first or design step is to determine the best estimate of operations possible with a given source in a given location in accordance with a set of design parameters and general climatological data. The second or operating problem is to predetermine by forecasts of effluent dispersion what mass rates are suitable with a given source during a given period.

Due to a variety of circumstances, the literature provides an inadequate source of information necessary to obtain a solution to the general dispersion problem. Researches must consequently be carried out to determine the actual dispersion of effluent under all possible meteorological conditions, and correlations obtained between the dispersion and the data available to the meteorologist. Extensions of the data usually available generally have to be obtained. In particular, when the source is at an elevation of some 360 feet above the general surrounding terrain, observations must give the wind and temperature in the vicinity of the source.

Wind speed is important because the concentration of effluent decreases inversely with wind speed. Wind direction and its variations are important because the effluent is carried downwind and spread over an angle which increases as the variability of the wind direction increases. Temperature is important for the obvious reason that warm and lighter gases tend to rise up through colder. The distribution of temperature in the vertical direction is of paramount importance because, in nature, warm air frequently overlies cold air. The effluent from a stack, even though the gases just above stack top are considerably warmer than any atmospheric air, is cooled as it leaves the stack by mixing with the atmosphere to such an extent that in nature the effluent will not penetrate through a strong discontinuity where warm air overlies cold (i.e., an inversion) above the top of the stack. In such a case the effluent is confined to a relatively thin layer of atmosphere near the ground, just as the now familiar cold chamber at a grocers preserves frozen food efficiently without benefit of a structural "lid". The cold air in the box will no more flow out of the top of the box than will the mixed and cooled effluent penetrate the inversion above the top of a stack.

Independent estimates of the amount of time the Nuclear Reactor at Brookhaven may operate at full power in accordance with presently set maximum permissible exposure, estimated average meteorological conditions, and the present state of knowledge concerning the dispersal of cooling air, agree that shutdown will be necessary about five percent of the time. This estimate is close to the estimate made when the Meteorology Program was initiated about one year ago. The estimate can be made more firm only after experiments with smoke dispersal at Upton and a better and longer series of climatological data are available for Upton.

The trend of organization of meteorological work is in the direction of two major units; (1) Operations, and (2) Research. The bulk of the work presently and in the visible future is directly concerned with atmospheric pollution and turbulence. The immediate work load is distributed into four categories; (a) observational and instruments, (b) forecasting, (c) statistical analyses of data, and (d) miscellaneous. A five-day week, twenty-four hour per day watch was established January 1, 1948, and a seven-day week, twenty-four hour per day watch on August 2, 1948.

A contract has been negotiated with the Cornell Aeronautical Laboratory to determine dispersal conditions close to the source in an isothermal atmosphere by a series of tests on models in a wind tunnel. Equipment is

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available and plans are well advanced for special observations using instruments elevated by balloons above the top of the tower. Special work will also be done shortly to determine inversions above the tower by anomalous transmission of sound. A variety of air sampling devices and laboratory equipment is available to study actual concentrations of oil fog smoke effluent from the stack in the high meteorology tower prior to startup of the Nuclear Reactor. Plans for the determination of effluent dispersion by photography of smoke continue in development.

The Meteorology Building will serve as a communication center for field units of the Meteorology Group and the Health Physics Officer, since a twenty-four-hour watch is essential to the meteorology program. Communication will be by means of short wave radio. Unforeseen delays in the completion of the meteorological facility necessitated making a temporary installation to obtain wind and temperature at a few levels on the high meteorological tower. This installation required funds and equipment which had been earmarked for installation on the R.C.A. towers at Rocky Point, so that the R.C.A. installation has been postponed indefinitely.

Unsatisfactory operation of the Autocall Recorders in the surface micronet required replacement by Gurley wind vanes and cups. These record presently in five of the small buildings installed by Health Physics. The records available from five off-site Gurleys promise to be adequate to study the further distribution of effluent after it attains low levels. The micronet of temperatures and humidities remains unchanged.

The general "attraction" of high places and construction activity for many people has necessitated close liaison between the Meteorology Group and the Safety Engineer with respect to routine use of the high meteorological tower. The immediate vicinity of the towers and the towers themselves will be closed to casual visitors.

Travel to other Atomic Energy Plants and to other micrometeorological installations has been made as frequently as pressing duties permitted. Of particular benefit was a visit by one scientist and one technician to the Army Chemical Center, Maryland, whereby meteorological personnel learned how to operate the standard Army Smoke Generators. The Group has in turn been visited regularly by its Consultants in Meteorology for periodic reviews of the Program, and also by scientists from the Hanford Engineer Works, the Navy Aerological Office, the American Meteorological Society and elsewhere.

In addition to a close cooperation with the newly established U.S. Weather Bureau Office, Upton, varying degrees of cooperative work are in force between meteorological personnel and the Marine Division, Suffolk County Highway Department; Long Island Vegetable Research Farm; New York State Conservation Department, and the U.S. Navy. Continued assistance from the Electronics Division, and the Health Physics Officer, Brookhaven National Laboratory, are also of aid in execution of the Program.

"Operations" personnel and equipment of the Group were removed from 57 Pascal Place to the new, modified and renovated Meteorology Building at 19 West Brookhaven Avenue in mid-July. Research personnel and equipment of the Group and the U.S. Weather Bureau Office, Upton, continue to be housed at 57 Pascal Place. Activity at the new location was in full force as of August 1, 1948. Standby power and the continuous watch which has been established will insure continuity of record.

Final installation of the Faraday Cage atop the Nuclear Reactor Stack, to study earth-atmosphere electric current and to provide some direct measure of the dispersal of cooling air has been postponed, but mounts for the device will be installed by the chimney contractor as the stack reaches its full height. The installation of cables between the two towers and the operation of a horizontal traveller on it await completion of the towers themselves. Aeronautical engineers who have reviewed plans for the traveller express interest in the data from it for use in gust alleviation studies.

Observations and Instruments

"While everybody pays lip service to the vast importance of measurement in scientific investigation, Campbell (Physics: The Elements.) alone seems to have thought seriously about the process."

A.D. Ritchie, "Scientific Method," 1923.

Scientific literature now contains many excellent papers and books which contradict Ritchie's 1923 opinion, but few appear in the literature offered as standard meteorological fare. The inevitable results of this situation are further aggravated by the successes of Bjerknes' Norwegian School, the necessity in 1941-45 to train many nonscientists in the elements of weather forecasting for military purposes, and very recently the considerable space devoted to claims and counterclaims by Langmuir and Schaeffer on the one hand, Gunn and his followers on the other,

concerning the "artificial production of rainfall." There are exceptions it is true, but the great majority of meteorologists remain content to leave meteorology where Lindsay and Margenau find the first physics, "largely observational in nature and did not involve the control which was later introduced through the medium of experiment."

Replace "mathematics" by "forecasting" in the following quotation, again from Ritchie in writing of the early Greeks, and one finds a statement applicable to the great majority of modern meteorologists, at least if the use of pencil and eraser in map analysis is not considered working with one's hands. "Mathematics, they thought, was an occupation for gentlemen, but using tools or working with your hands simply wasn't done." Fortunately the applicability is only partial. The majority of meteorologists do not work with tools and/or with instruments because the majority either prefers the (questionable) security of the status quo or is by experience incapable of designing and setting up an experiment. Moreover the bulk of meteorological installations are standard service "weather stations" wherein only the simplest instrumentation is employed, and this given but routine maintenance by technical personnel whose rights are somehow felt to be usurped when the "professional" enters in.

The first step taken to change this state of affairs at Brookhaven National Laboratory was the design and procurement of an installation essentially nonstandard. The second step was the assignment of weather technicians to preparation of the general weather forecast, a duty usually reserved for professional meteorologists, in the language of the United States Weather Bureau and of the American Meteorological Society. These preliminaries have cleared the way for increased activity by all personnel in all phases of the work, and it is expected that each member of the Group will engage in observations and instruments in some fashion best fitted to his abilities, not only as they presently appear but also as they may be developed through exposure to other scientists and technicians at the Laboratory.

It is premature to lay claim to success in this effort to stimulate action and thought for measurement and its processes in meteorology, a field in which the controlled experiment is frequently inapplicable to nature. The pressure exerted for immediate results is familiar to meteorologists who prepare a daily forecast, and early estimates from inadequate data are necessary in effluent dispersion studies as well. The Meteorology Group will persist in regarding these as estimates, and in seeking improvement in its attack on the dispersion problem by every conceivable means at its disposal with the installation, equipment, and personnel available. If the successes of scientists with observations and instruments match the successes of technicians in general weather forecasting, the final results will speak

for themselves. The progress to report up to the present is mainly the establishment of a route whereby the data of meteorology will be subject to fresh scrutiny in their acquisition and interpretation.

By no means all the observations of meteorology are instrumental in character. State of the sky and cloud forms are best determined by the eye, as are presently visibility and the nature of precipitation. Wind is usually best observed by instruments, although it is customarily reported on teletype circuits in a code first used from visual estimates alone, and such estimates are still excellent and within code ranges when made by a skilled observer at sea. The first observations of wind on the high tower at Upton were simply that its speed was too great for riggers to work on the tower above 150 feet. Temperatures are notoriously difficult to estimate with any accuracy, the usual reason given being that humidity and wind speed cannot be accounted for in their effects on the senses. More recently it is also recognized that air temperatures vary rapidly with time and position, and that a thermometer of small mass and specific heat is essential if the variations are to be determined. Whether or not the smaller variations or fluctuations are of any consequence in studying the problem at hand is another matter entirely.

Whatever observations are made and irrespective of how they are made, whether by reading the pointer of an indicating instrument or by preserving the record from some form of automatic recording device, it is essential to develop a number of forms and sheets on which the record is first entered. The variety of such forms is smaller than one might anticipate. The United States Weather Bureau, Army, and Navy have adopted a number identical for all three services. These are designated in general as "WBAN" forms. Other forms differ from service to service because of their special requirements, and similarly a number of new forms have been developed for use at this Laboratory. Some of the B.N.L. forms are shown in Figures 25, 26, & 27. Other forms in use by the Meteorology Group are obtained from the U. S. Weather Bureau Office, Upton. Still other forms will be necessary as smoke operations begin with the meteorology tower and stack.

A number of special instruments have been or are being developed. Among these are (1) a device to indicate the start and end of precipitation, credited primarily to personnel of the U. S. Weather Bureau Office, Upton, and constructed in Laboratory shops, (2) photoelectric smoke densitometers designed and built in the Electronics Division as an improvement on the instrument used similarly at the Hanford Engineer Works, as reported orally to the Group by duPont engineers in Wilmington, Delaware, (3) low lag wheatstone bridge type resistance thermometer, designed and built by meteorology personnel in association with the Electronics Division, from an early model reported by A. Raspet of Aerophysics Institute, (4) a device to hold and carry

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records from standard recording instruments past a computer as he abstracts required data, being built in Laboratory shops, and (5) a winch of special design to raise and lower Kytoons (kite-balloons) for observations above the top of the 420 foot tower. In addition a specially designed air sampler has been obtained on temporary loan from the Atomic Energy Office, New York City.

A knowledge of both the amount and distribution of solar radiation is important to the meteorologist. The amount of energy that reaches the surface of the earth after reflection, scattering, and absorption have taken place is directly related to the state of the atmosphere. To obtain this knowledge, a pyrhelimeter has been installed by the personnel of Meteorology on top of the Meteorology Tower Building. A recorder in the building gives a continuous record of radiation in terms of gm cal per cm sq. per sec. The pyrhelimeter develops an emf of 2.00 millivolts per gm cal min⁻¹ cm⁻².

Mobile weather and smoke sampling stations are being designed for and built in vehicles on assignment to the Group. Each vehicle will carry instruments to make standard weather observations of temperature, wind, and humidity. Each will also be equipped with a smoke densitometer, of the air sampling variety either by filter paper or photoelectric effects, a 1000 watt motor-generator set, flood lights, and a bench fitted with such tools and equipment as may be necessary. One of the units will be further equipped to make observations of sound intensity and wave for, another means of investigating temperature conditions above the top of the 420 foot meteorology tower. Communication between the mobile units and between them and the towers will be by short wave radio. Certain equipment, light in weight, will also be installed temporarily in an airplane which is available by purchase requisition from the Mastic Air Service.

Photographic equipment for detailed study of smoke effluent from the meteorology stack is on order for use of the Group by the Photography and Graphic Arts Group. The Electronics Division is building an intervalometer to trigger two cameras almost simultaneously when they are up to 3000 feet apart; the resulting negatives when studied in a Recordak Viewer will determine velocities of significant whorls and eddies of smoke, and thus of the air that carries the smoke along. Photographic studies already completed for several months at Upton, using coal smoke effluent from stacks on the site, have clarified concepts and phraseology used in such studies to personnel of the Group.

Close liaison is maintained between the Group and the Patent Engineer on all developments in instruments, the items having been reported in some detail to date number three.

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**METEOROLOGY GROUP
BROOKHAVEN NATIONAL LABORATORY
HOURLY OBSERVATIONS**

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SIX-HOURLY OBSERVATIONS						
TIME	MID TO 0130	0130	0730	1330	1930	1930 TO MID
PRECIP						
SNOWFALL						
SNOW DEPTH						
MAX TEMP						
MIN TEMP						
R.H. %						
STATE QND.						

[illegible]

24-HOUR SUMMARY							
TEMPERATURES					PRECIPITATION		
MAX	TIME	MIN	TIME	MEAN	24-HR. PCPN	24 HR SNO	
MAX INVERSION				MAX LAPSE		TIME CHANGE OVER	

MONTH _____ DAY _____ YEAR _____

Figure 25:

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Date: _____ ACE DATA

Surface wind 410' wind Gust. Micromax
Time Dir. & Speed Dir. & Speed Char. Sfc. 410' Character Remarks and Significant Data

00_							
02_							
04_							
06_							
08_							
10_							
12_							
14_							
16_							
18_							
20_							
22_							

Gustiness Character

75°
Direction
(Degrees)

6
Speed
(MPS)

Figure 26

DAILY MICROFORECAST

 Date: _____
 Time: _____
 Fcstr: _____
Wind - 410 Foot Level

	1330E	1930E	0130E	0730E
Forecast				
Observed				

Gustiness - 410 Foot Level

	1330E	1930E	0130E	0730E
Forecast				
Observed				

Surface Wind, Sky Cover, Present Weather

Time							
Forecast	○	○	○	○	○	○	○
Observed	○	○	○	○	○	○	○

Lapse Rate

	<u>Periods of Lapse or Inversion</u>		<u>Character of Lapse or Inversion</u>
	<u>Nature</u>	<u>Period</u>	
Forecast	From: From: From:	To: To: To:	
Observed	From: From: From:	To: To: To:	

 Time of Max Lapse $T_{410} - T_s$ Time of Max Inversion $T_{410} - T_s$

Forecast			
Observed			

Smoke Behavior

	<u>Qualitative:</u>	<u>Quantitative:</u>
Forecast		
Observed		

Figure 27

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DECLASSIFIED

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Meteorological instruments indicate or record some characteristic of the instrument itself, e.g., the temperature of the mercury in a thermometer, the number of revolutions per minute of cups on an anemometer, etc. If the instrument is properly designed and calibrated it may be installed so that the indication or record is also representative of the temperature or speed of the air at the location of the instrument. If the location is such that this reading is applicable to a considerable mass of air in the vicinity of the instrument, the reading is said to be "representative". The desire to obtain representative records leads one to mount instruments on slender poles or booms (as on the towers) as far away from solid objects as possible. The instrument is said to have good or bad "exposure" according as the reading is or is not representative. The exposures of several of the meteorological installations in the vicinity of or at Upton are as shown in Figures 28 to 30 inclusive. It must be understood that representation readings may not include all significant variations of the meteorological element, according to what the problem under investigation may be.

Irrespective of the instrument's exposure the readings will not be reliable, either as representative readings or to show significant variations, unless they are periodically compared with a standard. Calibration of instruments mounted on towers has been accomplished by comparison between the readings of standard mercurial thermometers and the resistance type "thermohms" installed, the mercurial thermometer being placed alongside the thermohm after climbing the tower. The method requires further development. One check was made on August 6, 1948 when the recorder at 410 feet read 59.3°F (15.2°C) while the mercurial in a slow flying airplane indicated 59.5°F, at the same elevation but a few hundred feet away from the tower in the horizontal. Wind instruments are usually calibrated in wind tunnels.

Minor and routine maintenance of standard instruments will be performed by the Group. Spare instruments are available in quantity sufficient to insure an adequate supply of data in all except the most complete breakdowns. Major repairs will be made when feasible either by the Group or with the cooperation of the Electronics Division, or by return of the instrument to its manufacturer. Teletype machines on which synoptic data are received are of course maintained by the Western Union and New York Telephone Companies from whom the machines are on lease.

An Army surplus M-1 smoke generator was first put into operation by the Group on June 22, 1948. The "run" was for a few minutes and on the ground. On July 8, 1948 an extended run was made for the purpose of determining whether the sensitivity of the smoke densitometer No. 1 was satisfactory. Tests showed that the instrument indicated full scale on the next to most sensitive range when the oil fog smoke was so thin that one could scarcely distinguish its presence by looking through less than about 100

Figure 28

Figure 29

Figure 30

yards of the air-smoke mixture. The final stage of sensitivity was then removed since at very high dilutions, or low concentrations, of the smoke the instrument will not distinguish between smoke particles from the generator and the normal dust in the atmosphere.

It had been anticipated that smoke runs would be made with regularity prior to August from the stack in the 420 foot tower. The motor necessary to turn the blower was long delayed in arriving on the site; therefore, a temporary 30 H.P. motor was installed by laboratory personnel. A 51 minute test run, using the tower & pit facilities, was made on August 23. Smoke was seen to emerge from the 355 foot stack within the tower for 27 minutes. During this time a mobile unit toured the laboratory site making measurements with a smoke densitometer. Another unit made a series of photographic observations. The smoke run of August 23 was fruitful in that equipment was tested and personnel learned procedure.

The data on hand are tabulated in another part of this report. A complete description of the various installations of temperature and wind instruments will be presented elsewhere. The three most significant installations made during the period are the wind and temperature instruments on "Princess", a pole east of 57 Pascal Place, and the one wind and three temperature recorders put into temporary use on "Ace", the 420 foot tower, near the end of July. In addition, a temperature difference recorder (Micromax, Model R) has been installed by group personnel. At a glance, one can read a continuous record of the difference in temperature between the 410' level on the tower, and the instrument shelter at the Meteorology Towers Building.

Statistical Analyses of Data

The statistical work of the Meteorology Group provides summaries of the data in a form to permit ready application to the study of the dispersion of the effluent from the Nuclear Reactor stack.

As of October 1, 1948, the data obtained are:

1. Upper air measurements of temperature and wind over the Laboratory site.
2. Continuous records of air temperature, wind speed and direction on the site at various levels from the surface to 80 feet. On July 28, 1948 a preliminary installation on Ace has extended the elevation to 410 feet above surface.

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TABLE 2
Summary of Meteorological Data Obtained by the
Meteorology Group, August 1, 1948
METEOROLOGY TOWERS

Designation	JACK	QUEEN		PRINCESS		ACE		ROCK HILL
Elements Measured	Wind Velocity	Wind Velocity	Temperature	Wind Velocity	Temperature	Wind Velocity	Temperature	Wind Velocity
No. Instruments	1	1	5	2	6	1	3	1
Elevation of Instruments above ground	30 ft.	87 ft.	4, 9, 18, 75 ft. 2" below soil	40, 80 ft.	4, 9, 18, 37, 75, 2" below soil	410 ft.	150, 350, 400 ft.	114 ft.
Start of Record	5/13/47	11/7/47	11/7/47	2/18/48	2/7/48	7/28/48	7/28/48	6/22/48
End of Record	12/27/47	1/13/48	12/31/47	still operating		still operating		
Missing data	23 days	1/2 day	unknown	2 days	2 days	none	none	16 days

MICRONET INSTALLATIONS

Designation	No. 1		No. 2	No. 3	No. 4		No. 5	No. 6		No. 7	No. 8	No. 9		No. 10	West-hampton
Elements Measured	Wind Vel.	Temp. & Rel Hum.	Temp. & Rel Hum.	Temp. & Rel Hum.	Wind Vel.	Temp. & Rel Hum.	Temp. & Rel Hum.	Wind Vel.	Temp. & Rel Hum.	Temp. & Rel Hum.	Temp. & Rel Hum.	Wind Vel.	Temp. & Rel Hum.	Temp. & Rel Hum.	Wind Velocity
No. Instruments	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Start of Record	6/15	1/15	1/15	1/15	6/15	1/15	1/15	6/25	6/25	1/15	1/15	6/15	1/15	1/15	3/15
End of Record	---	---	---	---	---	Still Operating			---	---	---	---	---	---	---
Missing data	9 days	9 days	none	1 day	5 days	12 days	6 days	none	none	1 day	1½ days	7 days	20 days	8 days	none

Location:

JACK: Northwest corner of building T-197 at B.N.L.
 QUEEN: Fire Tower on Rutherford Hill
 PRINCESS: The telegraph pole adjacent to 57 Pascal Place
 ROCK HILL: No. 12 on map in Figure 38.
 MICRONET: See map in Figure 38. All installed 1948
 WESTHAMPTON: Drawbridge between Westhampton and Westhampton Beach.

3. Continuous records of air temperature and relative humidity on the site and at nine micronet stations in the vicinity.
4. Continuous records of surface wind speed and direction at five stations within a twenty-mile radius of the Laboratory and at an elevation of 374' M.S.L. on the Rock Hill tower.
5. Continuous records of rainfall at two stations within the Laboratory grounds and at two micronet stations.
6. Normal weather stations hourly observations of weather conditions, dry and wet bulb temperature, pressure, and cloudiness.

A summary of the data is given in Table 1, showing the dates when the various recording instruments began operation and the length of the record.

The upper-air observations of temperature over the Laboratory site are obtained from airplane flights made twice daily, five days per week, beginning October 14, 1947, and seven days per week after June, 1948. One flight is made within an hour after sunrise, the other at the time of maximum heating, generally about 1400 E.S.T. The temperatures are read at 225, 450, 750, 1,000, 1,500, and 2,000 feet above sea level and at intermediate points when there is a significant change in the vertical temperature gradient. Figure 31 is a summary of 220 airplane flights made between October 14, 1947 and July 31, 1948. The morning and afternoon flights are shown separately. Each curve represents a type of temperature gradient and the mean difference between the temperature at 225 feet and the lowest point of inflection or 2,000 feet if there is no point of inflection. The conditions above a point of inflection are of little significance in the dispersion of effluent and are now shown.

Reading from left to right in Figure 31 we find:

1. 17 of the 86 morning soundings showed a uniform lapse between 225 and 2000 feet with a mean difference of -6.9°F. , or $-3.9^{\circ}\text{F./1,000 ft.}$
2. 5 soundings showed a lapse from 225 to 1,500 feet with an inversion above, the mean difference between 225 and 1,500 feet being -3.8°F. , or $3.0^{\circ}\text{F./1,000 ft.}$
3. 7 soundings showed a lapse from 225 to 1,000 feet with an inversion above and a mean gradient of $-3.7^{\circ}\text{F./1,000 ft.}$
4. 4 soundings showed a lapse from 225 to 750 feet with an inversion above and a mean gradient of $-5.3^{\circ}\text{F./1,000 ft.}$

5. 3 soundings showed a lapse from 225 to 450 feet with an inversion above and a mean gradient of $-4.9^{\circ}\text{F}/1,000\text{ ft.}$

6. 16 soundings showed an inversion between 225 and 450 feet with a lapse above and a mean gradient of $+6.2^{\circ}\text{F}/1,000\text{ ft.}$

7. 11 soundings showed an inversion from 225 to 750 feet with a lapse above and a mean gradient of $+8.4^{\circ}\text{F}/1,000\text{ ft.}$

8. 12 soundings showed an inversion from 225 to 1,000 feet with a lapse above and a mean gradient of $+8.4^{\circ}\text{F}/1,000\text{ ft.}$

9. 7 soundings showed an inversion from 225 to 1,500 feet with a lapse above and a mean gradient of $+4.4^{\circ}\text{F}/1,000\text{ ft.}$

10. 4 soundings showed uniform inversion conditions extending from 225 to 2,000 feet with a mean gradient of $+2.0^{\circ}\text{F}/1,000\text{ ft.}$

The afternoon soundings are plotted in a similar manner. The few cases of inversions in the afternoon indicate the thorough mixing typical of afternoon situations while in the morning, there is a rather even division between inversion and lapse conditions.

Three types of vertical temperature gradient have an important effect on the dispersion of an effluent: (1) a uniform lapse; (2) an inversion; (3) a lapse from the ground to some point above the top of the stack with an inversion above. Thorough mixing occurs under lapse conditions. When there is an inversion, stack gases tend to be confined to a thin layer at or slightly above the top of the stack and rarely reach the ground. But when an inversion overlies a lapse, the base of the upper inversion acts as a lid to confine the effluent to the mixed layer. Such a condition is called a "ground duct" when the mixing layer extends no higher than 1,000 feet. A ground duct has occurred on 33 soundings at Upton, or 15% of the total. Of these, 11 persisted for less than 18 hours; for 9 occurrences the persistence is unknown, and there were 5 instances when the persistence was greater than 24 hours. These 5 cases totalled 12 days or 4.1% of the total number of days between October 14, 1947 and July 31, 1948. This figure is a minimum, since flights were made on but 47% of the days and those days can in no sense be considered a random sample.

Continuous records of temperature at 2 inches below the ground and at 4, 9, 18, 37, and 75 feet above the ground have been made on Princess, the telegraph pole in the field adjacent to the Meteorology Building at 57 Pascal Place, beginning February 7, 1948. The measurements are recorded on a ten-point Micromax wheatstone bridge manufactured by Leeds and Northrup

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SUMMARY OF 220 AIRPLANE SOUNDINGS

FROM 225 TO 2000 FEET ABOVE SEA LEVEL
OCTOBER 14, 1947 TO JULY 31, 1948

Figure 31

with a cycling rate of 4 minutes, 48 seconds. A similar recorder with twelve points and a cycling rate of 5 minutes, 46 seconds, began operation on Ace, the 420-foot meteorology tower on July 28, 1948 with elements at 150, 350, and 400 feet. A graph of the latter record for 0700 - 0800 E.S.T., July 29, 1948 is shown in Figure 32. On September 22, 1948 a continuous record of the temperature difference between the shelter atop the Meteorology Building (approximately 35 feet above the ground) and the 400 foot level on Ace was begun.

The data on Ace and Princess have been summarized in two ways: (1) A plot of the hourly temperatures at all levels has been made by reading the values recorded for the cycle nearest the hour; (2) the time of change-over in the morning from inversion to lapse, the time and amount of the greatest lapse observed during the day, the time of change-over from lapse to inversion in the evening and the time and amount of the greatest inversion, using the 4-foot and 75-foot levels on Princess and the 4-foot level on Princess with the 400-foot level on Ace. The resistance thermometer used is accurate to $\pm 0.5^{\circ}\text{C}$. so that it is impossible to distinguish between adiabatic and isothermal conditions on Princess. The time of change-over, therefore, has been defined as a positive temperature difference between 4 feet and 75 feet of greater than 0.5°C .

Table 3 is a summary of the inversion data from March through August, 1948 for Princess, and August and September for Ace. The decreased frequency of inversions during the early summer can be attributed to the greater cloudiness, the decrease in the number of calm nights, and the larger percentage of southerly winds bringing warm moist air over the Laboratory area. The data here presented must be used with caution for the thermometers are not aspirated, but only protected from direct sunlight by 18-inch metal shields.

The wind speed and direction at 40 and 80 feet above the ground on Princess have been continuously recorded since February 18, 1948, the 410 feet on Ace since July 28, 1948. A sample of the trace at 80 feet is shown in Figure 33. For comparison, a sample of the wind speed and direction trace for the same period of time at the 410-foot level on Ace is given.

The wind speed and direction have been tabulated as hourly means: the speed to ± 0.5 meters per second, the direction to eight points of the compass. After June 1, 1948, the direction has been read to the nearest 3 degrees and the range of speed in meters and direction in degrees has also been recorded. Monthly summaries are then prepared giving the percentage frequency of each direction and the frequency of speeds in six classes: 0.2-0.5, 0.6-1.0, 1.1-1.5, 1.6-2.0, 2.1-2.5, 2.6-3.0, 3.1-3.5, 3.6-4.0, 4.1-4.5, 4.6-5.0, 5.1-5.5, 5.6-6.0, 6.1-6.5, 6.6-7.0, 7.1-7.5, 7.6-8.0, 8.1-8.5, 8.6-9.0, 9.1-9.5, 9.6-10.0, 10.1-10.5, 10.6-11.0, 11.1-11.5, 11.6-12.0, 12.1-12.5, 12.6-13.0, 13.1-13.5, 13.6-14.0, 14.1-14.5, 14.6-15.0, 15.1-15.5, 15.6-16.0, 16.1-16.5, 16.6-17.0, 17.1-17.5, 17.6-18.0, 18.1-18.5, 18.6-19.0, 19.1-19.5, 19.6-20.0, 20.1-20.5, 20.6-21.0, 21.1-21.5, 21.6-22.0, 22.1-22.5, 22.6-23.0, 23.1-23.5, 23.6-24.0, 24.1-24.5, 24.6-25.0, 25.1-25.5, 25.6-26.0, 26.1-26.5, 26.6-27.0, 27.1-27.5, 27.6-28.0, 28.1-28.5, 28.6-29.0, 29.1-29.5, 29.6-30.0, 30.1-30.5, 30.6-31.0, 31.1-31.5, 31.6-32.0, 32.1-32.5, 32.6-33.0, 33.1-33.5, 33.6-34.0, 34.1-34.5, 34.6-35.0, 35.1-35.5, 35.6-36.0, 36.1-36.5, 36.6-37.0, 37.1-37.5, 37.6-38.0, 38.1-38.5, 38.6-39.0, 39.1-39.5, 39.6-40.0, 40.1-40.5, 40.6-41.0, 41.1-41.5, 41.6-42.0, 42.1-42.5, 42.6-43.0, 43.1-43.5, 43.6-44.0, 44.1-44.5, 44.6-45.0, 45.1-45.5, 45.6-46.0, 46.1-46.5, 46.6-47.0, 47.1-47.5, 47.6-48.0, 48.1-48.5, 48.6-49.0, 49.1-49.5, 49.6-50.0, 50.1-50.5, 50.6-51.0, 51.1-51.5, 51.6-52.0, 52.1-52.5, 52.6-53.0, 53.1-53.5, 53.6-54.0, 54.1-54.5, 54.6-55.0, 55.1-55.5, 55.6-56.0, 56.1-56.5, 56.6-57.0, 57.1-57.5, 57.6-58.0, 58.1-58.5, 58.6-59.0, 59.1-59.5, 59.6-60.0, 60.1-60.5, 60.6-61.0, 61.1-61.5, 61.6-62.0, 62.1-62.5, 62.6-63.0, 63.1-63.5, 63.6-64.0, 64.1-64.5, 64.6-65.0, 65.1-65.5, 65.6-66.0, 66.1-66.5, 66.6-67.0, 67.1-67.5, 67.6-68.0, 68.1-68.5, 68.6-69.0, 69.1-69.5, 69.6-70.0, 70.1-70.5, 70.6-71.0, 71.1-71.5, 71.6-72.0, 72.1-72.5, 72.6-73.0, 73.1-73.5, 73.6-74.0, 74.1-74.5, 74.6-75.0, 75.1-75.5, 75.6-76.0, 76.1-76.5, 76.6-77.0, 77.1-77.5, 77.6-78.0, 78.1-78.5, 78.6-79.0, 79.1-79.5, 79.6-80.0, 80.1-80.5, 80.6-81.0, 81.1-81.5, 81.6-82.0, 82.1-82.5, 82.6-83.0, 83.1-83.5, 83.6-84.0, 84.1-84.5, 84.6-85.0, 85.1-85.5, 85.6-86.0, 86.1-86.5, 86.6-87.0, 87.1-87.5, 87.6-88.0, 88.1-88.5, 88.6-89.0, 89.1-89.5, 89.6-90.0, 90.1-90.5, 90.6-91.0, 91.1-91.5, 91.6-92.0, 92.1-92.5, 92.6-93.0, 93.1-93.5, 93.6-94.0, 94.1-94.5, 94.6-95.0, 95.1-95.5, 95.6-96.0, 96.1-96.5, 96.6-97.0, 97.1-97.5, 97.6-98.0, 98.1-98.5, 98.6-99.0, 99.1-99.5, 99.6-100.0, 100.1-100.5, 100.6-101.0, 101.1-101.5, 101.6-102.0, 102.1-102.5, 102.6-103.0, 103.1-103.5, 103.6-104.0, 104.1-104.5, 104.6-105.0, 105.1-105.5, 105.6-106.0, 106.1-106.5, 106.6-107.0, 107.1-107.5, 107.6-108.0, 108.1-108.5, 108.6-109.0, 109.1-109.5, 109.6-110.0, 110.1-110.5, 110.6-111.0, 111.1-111.5, 111.6-112.0, 112.1-112.5, 112.6-113.0, 113.1-113.5, 113.6-114.0, 114.1-114.5, 114.6-115.0, 115.1-115.5, 115.6-116.0, 116.1-116.5, 116.6-117.0, 117.1-117.5, 117.6-118.0, 118.1-118.5, 118.6-119.0, 119.1-119.5, 119.6-120.0, 120.1-120.5, 120.6-121.0, 121.1-121.5, 121.6-122.0, 122.1-122.5, 122.6-123.0, 123.1-123.5, 123.6-124.0, 124.1-124.5, 124.6-125.0, 125.1-125.5, 125.6-126.0, 126.1-126.5, 126.6-127.0, 127.1-127.5, 127.6-128.0, 128.1-128.5, 128.6-129.0, 129.1-129.5, 129.6-130.0, 130.1-130.5, 130.6-131.0, 131.1-131.5, 131.6-132.0, 132.1-132.5, 132.6-133.0, 133.1-133.5, 133.6-134.0, 134.1-134.5, 134.6-135.0, 135.1-135.5, 135.6-136.0, 136.1-136.5, 136.6-137.0, 137.1-137.5, 137.6-138.0, 138.1-138.5, 138.6-139.0, 139.1-139.5, 139.6-140.0, 140.1-140.5, 140.6-141.0, 141.1-141.5, 141.6-142.0, 142.1-142.5, 142.6-143.0, 143.1-143.5, 143.6-144.0, 144.1-144.5, 144.6-145.0, 145.1-145.5, 145.6-146.0, 146.1-146.5, 146.6-147.0, 147.1-147.5, 147.6-148.0, 148.1-148.5, 148.6-149.0, 149.1-149.5, 149.6-150.0, 150.1-150.5, 150.6-151.0, 151.1-151.5, 151.6-152.0, 152.1-152.5, 152.6-153.0, 153.1-153.5, 153.6-154.0, 154.1-154.5, 154.6-155.0, 155.1-155.5, 155.6-156.0, 156.1-156.5, 156.6-157.0, 157.1-157.5, 157.6-158.0, 158.1-158.5, 158.6-159.0, 159.1-159.5, 159.6-160.0, 160.1-160.5, 160.6-161.0, 161.1-161.5, 161.6-162.0, 162.1-162.5, 162.6-163.0, 163.1-163.5, 163.6-164.0, 164.1-164.5, 164.6-165.0, 165.1-165.5, 165.6-166.0, 166.1-166.5, 166.6-167.0, 167.1-167.5, 167.6-168.0, 168.1-168.5, 168.6-169.0, 169.1-169.5, 169.6-170.0, 170.1-170.5, 170.6-171.0, 171.1-171.5, 171.6-172.0, 172.1-172.5, 172.6-173.0, 173.1-173.5, 173.6-174.0, 174.1-174.5, 174.6-175.0, 175.1-175.5, 175.6-176.0, 176.1-176.5, 176.6-177.0, 177.1-177.5, 177.6-178.0, 178.1-178.5, 178.6-179.0, 179.1-179.5, 179.6-180.0, 180.1-180.5, 180.6-181.0, 181.1-181.5, 181.6-182.0, 182.1-182.5, 182.6-183.0, 183.1-183.5, 183.6-184.0, 184.1-184.5, 184.6-185.0, 185.1-185.5, 185.6-186.0, 186.1-186.5, 186.6-187.0, 187.1-187.5, 187.6-188.0, 188.1-188.5, 188.6-189.0, 189.1-189.5, 189.6-190.0, 190.1-190.5, 190.6-191.0, 191.1-191.5, 191.6-192.0, 192.1-192.5, 192.6-193.0, 193.1-193.5, 193.6-194.0, 194.1-194.5, 194.6-195.0, 195.1-195.5, 195.6-196.0, 196.1-196.5, 196.6-197.0, 197.1-197.5, 197.6-198.0, 198.1-198.5, 198.6-199.0, 199.1-199.5, 199.6-200.0, 200.1-200.5, 200.6-201.0, 201.1-201.5, 201.6-202.0, 202.1-202.5, 202.6-203.0, 203.1-203.5, 203.6-204.0, 204.1-204.5, 204.6-205.0, 205.1-205.5, 205.6-206.0, 206.1-206.5, 206.6-207.0, 207.1-207.5, 207.6-208.0, 208.1-208.5, 208.6-209.0, 209.1-209.5, 209.6-210.0, 210.1-210.5, 210.6-211.0, 211.1-211.5, 211.6-212.0, 212.1-212.5, 212.6-213.0, 213.1-213.5, 213.6-214.0, 214.1-214.5, 214.6-215.0, 215.1-215.5, 215.6-216.0, 216.1-216.5, 216.6-217.0, 217.1-217.5, 217.6-218.0, 218.1-218.5, 218.6-219.0, 219.1-219.5, 219.6-220.0, 220.1-220.5, 220.6-221.0, 221.1-221.5, 221.6-222.0, 222.1-222.5, 222.6-223.0, 223.1-223.5, 223.6-224.0, 224.1-224.5, 224.6-225.0, 225.1-225.5, 225.6-226.0, 226.1-226.5, 226.6-227.0, 227.1-227.5, 227.6-228.0, 228.1-228.5, 228.6-229.0, 229.1-229.5, 229.6-230.0, 230.1-230.5, 230.6-231.0, 231.1-231.5, 231.6-232.0, 232.1-232.5, 232.6-233.0, 233.1-233.5, 233.6-234.0, 234.1-234.5, 234.6-235.0, 235.1-235.5, 235.6-236.0, 236.1-236.5, 236.6-237.0, 237.1-237.5, 237.6-238.0, 238.1-238.5, 238.6-239.0, 239.1-239.5, 239.6-240.0, 240.1-240.5, 240.6-241.0, 241.1-241.5, 241.6-242.0, 242.1-242.5, 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281.1-281.5, 281.6-282.0, 282.1-282.5, 282.6-283.0, 283.1-283.5, 283.6-284.0, 284.1-284.5, 284.6-285.0, 285.1-285.5, 285.6-286.0, 286.1-286.5, 286.6-287.0, 287.1-287.5, 287.6-288.0, 288.1-288.5, 288.6-289.0, 289.1-289.5, 289.6-290.0, 290.1-290.5, 290.6-291.0, 291.1-291.5, 291.6-292.0, 292.1-292.5, 292.6-293.0, 293.1-293.5, 293.6-294.0, 294.1-294.5, 294.6-295.0, 295.1-295.5, 295.6-296.0, 296.1-296.5, 296.6-297.0, 297.1-297.5, 297.6-298.0, 298.1-298.5, 298.6-299.0, 299.1-299.5, 299.6-300.0, 300.1-300.5, 300.6-301.0, 301.1-301.5, 301.6-302.0, 302.1-302.5, 302.6-303.0, 303.1-303.5, 303.6-304.0, 304.1-304.5, 304.6-305.0, 305.1-305.5, 305.6-306.0, 306.1-306.5, 306.6-307.0, 307.1-307.5, 307.6-308.0, 308.1-308.5, 308.6-309.0, 309.1-309.5, 309.6-310.0, 310.1-310.5, 310.6-311.0, 311.1-311.5, 311.6-312.0, 312.1-312.5, 312.6-313.0, 313.1-313.5, 313.6-314.0, 314.1-314.5, 314.6-315.0, 315.1-315.5, 315.6-316.0, 316.1-316.5, 316.6-317.0, 317.1-317.5, 317.6-318.0, 318.1-318.5, 318.6-319.0, 319.1-319.5, 319.6-320.0, 320.1-320.5, 320.6-321.0, 321.1-321.5, 321.6-322.0, 322.1-322.5, 322.6-323.0, 323.1-323.5, 323.6-324.0, 324.1-324.5, 324.6-325.0, 325.1-325.5, 325.6-326.0, 326.1-326.5, 326.6-327.0, 327.1-327.5, 327.6-328.0, 328.1-328.5, 328.6-329.0, 329.1-329.5, 329.6-330.0, 330.1-330.5, 330.6-331.0, 331.1-331.5, 331.6-332.0, 332.1-332.5, 332.6-333.0, 333.1-333.5, 333.6-334.0, 334.1-334.5, 334.6-335.0, 335.1-335.5, 335.6-336.0, 336.1-336.5, 336.6-337.0, 337.1-337.5, 337.6-338.0, 338.1-338.5, 338.6-339.0, 339.1-339.5, 339.6-340.0, 340.1-340.5, 340.6-341.0, 341.1-341.5, 341.6-342.0, 342.1-342.5, 342.6-343.0, 343.1-343.5, 343.6-344.0, 344.1-344.5, 344.6-345.0, 345.1-345.5, 345.6-346.0, 346.1-346.5, 346.6-347.0, 347.1-347.5, 347.6-348.0, 348.1-348.5, 348.6-349.0, 349.1-349.5, 349.6-350.0, 350.1-350.5, 350.6-351.0, 351.1-351.5, 351.6-352.0, 352.1-352.5, 352.6-353.0, 353.1-353.5, 353.6-354.0, 354.1-354.5, 354.6-355.0, 355.1-355.5, 355.6-356.0, 356.1-356.5, 356.6-357.0, 357.1-357.5, 357.6-358.0, 358.1-358.5, 358.6-359.0, 359.1-359.5, 359.6-360.0, 360.1-360.5, 360.6-361.0, 361.1-361.5, 361.6-362.0, 362.1-362.5, 362.6-363.0, 363.1-363.5, 363.6-364.0, 364.1-364.5, 364.6-365.0, 365.1-365.5, 365.6-366.0, 366.1-366.5, 366.6-367.0, 367.1-367.5, 367.6-368.0, 368.1-368.5, 368.6-369.0, 369.1-369.5, 369.6-370.0, 370.1-370.5, 370.6-371.0, 371.1-371.5, 371.6-372.0, 372.1-372.5, 372.6-373.0, 373.1-373.5, 373.6-374.0, 374.1-374.5, 374.6-375.0, 375.1-375.5, 375.6-376.0, 376.1-376.5, 376.6-377.0, 377.1-377.5, 377.6-378.0, 378.1-378.5, 378.6-379.0, 379.1-379.5, 379.6-380.0, 380.1-380.5, 380.6-381.0, 381.1-381.5, 381.6-382.0, 382.1-382.5, 382.6-383.0, 383.1-383.5, 383.6-384.0, 384.1-384.5, 384.6-385.0, 385.1-385.5, 385.6-386.0, 386.1-386.5, 386.6-387.0, 387.1-387.5, 387.6-388.0, 388.1-388.5, 388.6-389.0, 389.1-389.5, 389.6-390.0, 390.1-390.5, 390.6-391.0, 391.1-391.5, 391.6-392.0, 392.1-392.5, 392.6-393.0, 393.1-393.5, 393.6-394.0, 394.1-394.5, 394.6-395.0, 395.1-395.5, 395.6-396.0, 396.1-396.5, 396.6-397.0, 397.1-397.5, 397.6-398.0, 398.1-398.5, 398.6-399.0, 399.1-399.5, 399.6-400.0, 400.1-400.5, 400.6-401.0, 401.1-401.5, 401.6-402.0, 402.1-402.5, 402.6-403.0, 403.1-403.5, 403.6-404.0, 404.1-404.5, 404.6-405.0, 405.1-405.5, 405.6-406.0, 406.1-406.5, 406.6-407.0, 407.1-407.5, 407.6-408.0, 408.1-408.5, 408.6-409.0, 409.1-409.5, 409.6-410.0, 410.1-410.5, 410.6-411.0, 411.1-411.5, 411.6-412.0, 412.1-412.5, 412.6-413.0, 413.1-413.5, 413.6-414.0, 414.1-414.5, 414.6-415.0, 415.1-415.5, 415.6-416.0, 416.1-416.5, 416.6-417.0, 417.1-417.5, 417.6-418.0, 418.1-418.5, 418.6-419.0, 419.1-419.5, 419.6-420.0, 420.1-420.5, 420.6-421.0, 421.1-421.5, 421.6-422.0, 422.1-422.5, 422.6-423.0, 423.1-423.5, 423.6-424.0, 424.1-424.5, 424.6-425.0, 425.1-425.5, 425.6-426.0, 426.1-426.5, 426.6-427.0, 427.1-427.5, 427.6-428.0, 428.1-428.5, 428.6-429.0, 429.1-429.5, 429.6-430.0, 430.1-430.5, 430.6-431.0, 431.1-431.5, 431.6-432.0, 432.1-432.5, 432.6-433.0, 433.1-433.5, 433.6-434.0, 434.1-434.5, 434.6-435.0, 435.1-435.5, 435.6-436.0, 436.1-436.5, 436.6-437.0, 437.1-437.5, 437.6-438.0, 438.1-438.5, 438.6-439.0, 439.1-439.5, 439.6-440.0, 440.1-440.5, 440.6-441.0, 441.1-441.5, 441.6-442.0, 442.1-442.5, 442.6-443.0, 443.1-443.5, 443.6-444.0, 444.1-444.5, 444.6-445.0, 445.1-445.5, 445.6-446.0, 446.1-446.5, 446.6-447.0, 447.1-447.5, 447.6-448.0, 448.1-448.5, 448.6-449.0, 449.1-449.5, 449.6-450.0, 450.1-450.5, 450.6-451.0, 451.1-451.5, 451.6-452.0, 452.1-452.5, 452.6-453.0, 453.1-453.5, 453.6-454.0, 454.1-454.5, 454.6-455.0, 455.1-455.5, 455.6-456.0, 456.1-456.5, 456.6-457.0, 457.1-457.5, 457.6-458.0, 458.1-458.5, 458.6-45

from
back
from

100

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Air Temperature in degrees centigrade

Figure 32

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TABLE 3

Monthly Summary of Inversions

1948

<u>Data from 4 and 75-foot levels on Princess</u>							<u>Data from Meteorology Bldg. Shelter and 400-foot level on Ace</u>	
	<u>March</u>	<u>April</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>August</u>	<u>August</u>	<u>September</u>
No. nights with inversions	17	14	10	5	10	17	22	24
No. inversion hours	176	121.7	85	58.5	73.6	169.5	277	315
Mean daily no. inversion hours per inversion day	10	8.7	8.5	11.7	7.3	10.0	13	13
Mean time of start of inversion	1909	1959	1951	2000	2100	1950	1900	1850
Earliest time of start of inversion	1730	1810	1850	1900	1320	1805	1700	1700
Mean time of end of inversion	0730	0611	0430	0545	0429	0645	0800	0800
Latest time of end of inversion	0820	0700	0645	0630	0635	0810	1000	1200
% of time with inversion	24	17	11	8	10	22	37	44

Inversions are counted only when the 4-foot temperature is about $\frac{1}{2}^{\circ}\text{C.}$ more or less than the 75-foot temperature. This precaution is taken because of inadequate calibration and accuracy of the thermohms used.

Figure 33

the percentage frequency of speeds within each direction class, and the frequency of directions within each speed class are obtained. Table 4 shows the percentage frequency of each wind direction and the frequency of the various speed classes by months from March to September, 1948 at 80 ft. on Princess. Note the increasing frequency of southerly and south-westerly winds during this period. It is a characteristic of the summer season along the Atlantic coast. Attention should also be called to the variability of the wind direction. In no case has a frequency greater than 25% occurred in the five month period. Table 5 gives a breakdown of the wind summary for August and September, 1948, inversion and lapse conditions.

A monthly summary of wind speed and direction is a normal weather station procedure. But the Meteorology Group has need for summaries over a shorter time interval. Since the level of permitted off-site radiation has been set on a weekly basis, a seven-day period has been selected as the shorter time interval in which to summarize the variability of the wind direction. The method has been to compute a seven-day moving total of the number of hours of wind from each of eight directions and of light and variable winds from the 80-foot level on Princess. A sample of the resulting chart is given in Figure 34, showing the moving total of hours recorded on the seventh day for four wind directions in April, 1948. The scale to the left is the average intensity of radiation in multiples of the permitted design value that could be tolerated when the wind blew from the particular direction. Thus if the wind blew continuously from the same direction for seven days, the maximum radiation level allowable at the ground would be one times the permitted level; if the wind blew from that direction for 3.5 days, the maximum level would be twice the weekly level. Should there be but one hour of wind from a particular direction, 168 times the weekly level might safely reach the ground. Thus the effect of one of the many factors involved in the dispersion of stack gases is summarized here, the weekly variability of the mean wind direction.

A convenient summary of the data for the five months, March - July, 1948 is given in Table 6. This Table shows the number of days per month when, during the preceding seven days, the wind has blown from a given direction for more than 24, 48, and 72 hours (corresponding to a radiation level of 7, 4.7, and 2.3 times the permitted value). The great variability of the wind direction during the spring months is clear from the data in Table 6. There were only three seven-day periods when a given wind direction persisted for more than 72 hours. It was otherwise in July. For 21 seven-day periods, the wind was southwest for more than 72 hours. The maximum persistence was 109 hours, or 65% of the time, from July 7 - 13, 1948.

In addition to summaries obtained from the normal wind records, the Meteorology Group has analyzed short-term gustiness by means of speed runs. The appearance of the speed and direction traces during a speed run is shown in Figure 35. The paper speed in a normal wind record is 4 inches per hour. In a speed run, the paper runs at 4 inches per minute. The method of analysis is to count the number of intersections of the speed and direction trace with each speed line or direction line on the chart. A frequency distribution is thereby obtained from this count of gustiness exceeding 1 meter per second and 3 degrees. One purpose for this study was to determine the length of time necessary to obtain a distribution representative of conditions during an hour or so. It was found that there was little change in the parameters of the distribution after ten minutes. Accordingly, ten minutes has been chosen as the slowest cycling rate of a totalizing wind gradient recorder presently under construction for the Laboratory by the Freiz Instrument Division of the Bendix Aviation Corporation. An interesting feature of the gustiness of the speed trace has been its linear relation to the mean wind speed. The dimensionless measure of variability that measures this effect is the coefficient of variation which is tabulated for various mean winds in Table 7.

Directional gustiness has also been of interest for it has been conjectured that it is a measure of the horizontal variation of the trail of a stack effluent. Study of the directional variability is still in the preliminary stage and no substantiated conclusions can be drawn at this time.

A qualitative measure of the effect of the vertical temperature gradient on the directional gustiness is given in Figure 36. Four types of gustiness are shown. "A" is an example of the typical inversion conditions when there is practically no turbulence. "B" is a typical adiabatic condition where the mean width of the trace is roughly 15 degrees. "C" is an example of extreme instability (large lapse) when the trace is irregular and the gustiness exceeds 90 degrees. "D" shows the effect of a change-over from inversion to lapse after sunrise on a clear day. The sudden increase in turbulence at 0730 should be noted.

The temperature and humidity measured at nine micronet stations are tabulated hourly together with a similar installation established on the Laboratory site for comparative purposes. A sample record is given in Figure 37, showing the deviation of the mean hourly temperatures at five of the stations from the mean hourly temperatures measured at the Laboratory. The differences are marked and result from the radically differing exposures of the various micronet sites. The data in Figure 35 were for the month of July. It is to be expected that stations near the water in the winter will consistently show higher mean temperatures than stations only a few miles inland, and the fact is clearly shown by a comparison of Figure 37 with

Figure 34

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TABLE 4

Monthly Summary of Wind Speed and Direction from the 80' Level on Princess
Percentage Frequency of Wind Direction

1948

	March	April	May	June	July	August	September	Average
North	16	8	10	9	6	9	14	10
Northeast	9	10	14	10	4	11	4	9
East	7	8	8	8	1	5	1	5
Southeast	5	9	12	10	2	8	3	7
South	17	13	15	12	10	11	12	13
Southwest	18	21	17	28	48	19	26	25
West	7	7	7	5	10	13	14	9
Northwest	17	18	9	10	12	16	21	15
Variable	4	6	8	7	6	9	6	7

Percentage Frequency of Wind Speeds
 1948

	March	April	May	June	July	August	September	Average
0 - 2.0	10	17	27	24	17	29	33	22
2.5 - 3.5	25	23	24	42	44	44	38	34
4.0 - 5.5	26	25	24	24	26	18	19	23
6.0 - 8.5	25	23	23	10	13	6	6	15
9.0 - 11.5	12	9	2	0	0	3	4	4
12.0 -	2	3	0	0	0	0	0	1

TABLE 5
WIND SUMMARY AT 410' ON ACE

August, 1948

Percent of Time From

Direction	N	NE	E	SE	S	SW	W	NW	Var.
During Inversions	7.0	2.9	1.6	1.7	2.0	3.1	4.7	9.3	0.8
During Lapse	5.2	8.7	7.3	4.8	7.6	12.5	9.5	8.0	2.8
Total	12.2	11.6	8.9	6.5	9.6	15.6	14.2	17.3	3.6

Percent of Time

Speed in Meters Per Second	_ 2.0	2.1 to 5.5	5.6 to 10.9	_ 11.0
During Inversions	3.0	11.8	16.4	1.9
During Lapse	5.7	29.4	27.6	3.8
Total	8.7	41.2	44.0	5.7

WIND SUMMARY AT 80' ON PRINCESS

August, 1948 (23 hours missing)

Percent of Time From

Direction	N	NE	E	SE	S	SW	W	NW	Var.
During Inversions	3.3	2.6	1.1	1.4	1.1	4.6	7.1	8.0	5.1
During Lapse	5.9	8.0	4.0	5.9	9.8	14.1	5.5	8.1	3.8
Total	9.2	10.6	5.1	7.3	10.9	18.7	12.6	16.1	8.9

Percent of Time

Speed in Meters Per Second	_ 2.0	2.1 to 5.5	5.6 to 10.9	_ 11.0
During Inversions	15.1	19.3	0	0
During Lapse	14.1	42.3	9.1	0
Total	29.2	61.6	9.1	0

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TABLE 6

Number of Days per Month when the Wind Direction persisted more than
24, 48, and 72 hours during the preceding 7 days.

(Data from 80' Level on Princess, March - July
from 410' Level on Ace, August - September)

1948

[illegible]

TABLE 7

Gustiness Distribution for 10-Minute Interval

Mean Speed m.p.s.	Standard Deviation	Coefficient of Variation
4.51	1.31	0.29
7.90	1.34	0.17
8.31	1.25	0.15
8.60	1.38	0.16
10.55	2.46	0.23
10.92	2.26	0.21
11.02	2.66	0.24
12.60	2.33	0.19
13.82	2.83	0.20

Selected examples from speed runs made at 87-foot level on Queen and 80-foot level on Princess.

TABLE 8

Estimated Percentage Frequency of Wind Direction and
Speed at the Top of the Nuclear Reactor Stack

Isobar Direction at B.N.L., Backed $22\frac{1}{2}$ Degrees (Data from 0130 and 1330 E.S.T. Daily Weather Map of U.S. Weather Bureau, January 1 to December 31, 1947.)					
Direction	Dec.Jan.Feb.	Mar.Apr.May	Jun.Jly.Aug.	Sept.Oct.Nov.	Annual
North	27	7	4	10	12
Northeast	9	14	15	22	15
East	12	8	7	1	7
Southeast	4	5	6	5	5
South	2	10	10	6	7
Southwest	10	18	26	14	17
West	12	10	10	3	9
Northwest	16	18	7	19	15
Variable	8	11	14	19	13

70 Percent of Geostrophic Wind Speed at B.N.L., plus 1 meter per second for Anticyclonic Curvature, minus 1 meter per second for Cyclonic Curvature (Data from 1330 E.S.T. Daily Weather Map of U.S. Weather Bureau, January 1, to December 31, 1947.)					
Speed m.p.s.	Dec.Jan.Feb.	Mar.Apr.May	Jun.Jly.Aug.	Sept.Oct.Nov.	Annual
0 - 2.0	10	14	17	21	15
2.1 - 5.5	17	23	38	18	24
5.6 - 10.9	37	38	38	37	38
11.0 -	36	25	7	24	23

Figure 35

TYPICAL WIND SPEED AND DIRECTION RECORDS
(From 430-foot level on 400)

- A. 2100-2300 R.L.T., July 30, 1964.
- B. 0900-1000 R.L.T., July 30, 1964.
- C. 2100-2300 R.L.T., July 30, 1964.
- D. 0900-0950 R.L.T., August 1, 1964.

Direction in degrees, speed in meters per second.

Figure 36

TYPICAL WIND SPEED AND DIRECTION RECORDS

(From 410-foot Level on Ace)

Wind direction in degrees, speed in meters per second.

A. 2100-2300 E.S.T., July 29, 1948

<u>Hour</u>	<u>Wind Direction</u>	<u>Wind Speed</u>	<u>T(410) - T(4)°C</u>
2100	246	9.0	+2.4
2200	246	9.5	1.6
2300	258	9.0	1.5

B. 0800-1000 E.S.T., July 30, 1948

<u>Hour</u>	<u>Wind Direction</u>	<u>Wind Speed</u>	<u>T(410) - T(4)°C</u>
0800	Variable	1.0	-1.8
0900	Variable	1.0	-2.4
1000	Variable	4.0	-2.4

C. 2100-2300 E.S.T., July 30, 1948

<u>Hour</u>	<u>Wind Direction</u>	<u>Wind Speed</u>	<u>T(410) - T(4)°C</u>
2100	243	11.5	-0.2
2200	246	11.0	-0.4
2300	244	11.0	+0.1

D. 0630-0900 E.S.T., August 8, 1948

<u>Hour</u>	<u>Wind Direction</u>	<u>Wind Speed</u>	<u>T(410) - T(4)°C</u>
0630	321	7.5	+2.2
0700	321	8.0	0.4
0730	318	6.5	-1.5
0800	324	4.5	-3.1
0900	318	4.5	-1.0

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Figure 37

METEOROLOGICAL MICRO-NET and HEALTH PHYSICS MONITORING STATIONS

Figure 38

TABLE 9
WIND SUMMARY AT 410' ON ACE

September 1948

Percent of Time From

Direction	N	NE	E	SE	S	SW	W	NW	Variable
During Inversions	5.3	6.2	1.8	.8	4.3	6.0	10.4	6.6	.4
During Lapse	8.7	12.0	3.5	1.1	3.2	12.3	9.4	5.0	2.1
Total	14.0	18.2	5.3	1.9	7.5	18.3	19.8	11.6	2.5

Percent of Time

Speed in Meters Per Second	≤ 2.0	2.1 to 5.5	5.6 to 10.9	≥ 11.0
During Inversions	4.1	14.2	20.2	3.6
During Lapse	4.5	20.7	26.4	5.9
Total	8.6	34.9	46.6	9.5

WIND SUMMARY AT 80' ON PRINCESS

September 1948

Percent of Time From

Direction	N	NE	E	SE	S	SW	W	NW	Variable
During Inversions	5.6	.8	.4	1.7	4.4	10.2	8.2	7.8	3.1
During Lapse	8.6	2.5	.3	1.4	7.8	16.1	5.4	13.0	2.7
Total	14.2	3.3	.7	3.1	12.2	26.3	13.6	20.8	5.8

Percent of Time

Speed in Meters Per Second	≤ 2.0	2.1 to 5.5	5.6 to 10.9	≥ 11.0
During Inversions	20.9	21.2	0.1	0.0
During Lapse	12.0	35.4	10.3	0.0
Total	32.9	56.6	10.4	0.0

Figure 38, a map of the locations of the micronet stations by number.

The wind records at Rock Hill, the bridge at Westhampton Beach, and four of the micronet stations have not been in operation a long enough time for the data to be meaningful.

The rainfall records and the normal weather station records are tabulated on a monthly summary form which is in the process of development. Its purpose will be to enable immediate comparisons to be made for the various synoptic and micrometeorological elements existing at the Laboratory during a given day. In addition, the general summary will contain the direction and speed of the wind resulting from the pressure gradient force at the Laboratory. This computation is made from the daily weather maps drawn by the Meteorology Group.

Besides the summaries of the data obtained locally, the Meteorology Group does not neglect data obtained from outside agencies which may be of value in its work. An example is the wind speed and direction resulting from the pressure gradient force at the Laboratory, the so-called geostrophic wind. In the absence of any measurements of wind at the level of the top of the Nuclear Reactor stack, an approximation can be obtained by measuring the geostrophic wind on the weather map and applying small corrections for frictional effects. Using the Daily Weather Map of the United States Weather Bureau for the year 1947, an estimate of the seasonal frequencies of wind directions and speeds for an entire year can be obtained. Table 8 is a summary of the frequencies obtained from this data using the same methods as previously described for the Princess wind data.

Forecasting

The forecasting program of the Meteorology Group is essentially divided into two closely related portions; the preparation of special forecasts of micrometeorological factors to be used in predicting the dispersion of effluent from the Nuclear Reactor stack, and the preparation of forecasts of general meteorological conditions over the entire northeastern United States. The micrometeorological forecast is the primary aim, but the general weather prediction is necessary prerequisite to the preparation of the micrometeorological prediction whenever the latter is to exceed one or two hours.

Until the establishment of temporary instrumentation on the 420-foot "Ace" tower, the basic observational data necessary for the development of accurate micrometeorological forecasts was largely unavailable, since the "Princess" and aircraft observational information necessarily has left

large physical and chronological gaps in the data pertaining to the lower levels of the atmosphere. This situation made the preparation of micro-meteorological forecasts difficult, and accurate verification of the results very nearly impossible. Thus, during the period from January 2, 1948, to August 1, 1948, our primary forecasting effort has been directed toward improvement in the quality of the general weather forecasts. Since the completion of the temporary installation on the "Ace" tower more emphasis has been placed on the micrometeorological forecast.

This problem has been approached from two aspects; improvement in the utilization of available weather information, and improvement in application of analysis and forecasting techniques. In the earlier stages of the forecasting program, the Meteorology Group completed the analysis of four surface synoptic weather charts and one upper-level chart daily. The surface synoptic charts include the United States, Canada, and the adjacent ocean areas in their scope, and the upper-level chart has been confined to the area of the United States only, because of the lack of adequate upper air data outside that area.

On July 15, 1948, the daily preparation of additional upper-level charts was established. These charts are now plotted and analyzed for the 850-, 700-, and 500-millibar levels twice daily to provide as full a picture as possible of the vertical structure of the various meteorological situations encountered from day to day. These charts delineate the patterns of wind, temperature and moisture at altitudes of approximately 5,000, 10,000 and 20,000 feet above mean sea level at the latitude of Upton, and are of significant value in the understanding and forecasting of surface weather conditions.

In addition, arrangements were made in late July for the daily receipt of selected Canadian radiosonde and wind observations, which are necessary in the preparation of upper-level charts, in order to extend the area of the analysis to correspond with that of the surface synoptic chart, so that the three-dimensional structure of all meteorological factors that may affect the Brookhaven area can be clearly determined.

In order to make the presentation of all meteorological data most useful to those concerned, the Meteorology Group has prepared a new synoptic weather chart that is being used for both surface and upper-level analysis. This chart consists of a base map covering the United States, Canada, Alaska and the eastern Pacific Ocean, the Gulf of Mexico and the western Atlantic Ocean on a scale of 1:10,000,000. Combined with this chart in the form of a sectional insert is a detailed map of the northeastern United States on a 1:5,000,000 scale. This chart will make it possible to present general weather information for all levels in a standard and comparable fashion, and

will also provide a direct comparison of the general features of the weather pattern with the detailed features over the northeastern portion of the United States.

It is the present policy of the Meteorology Group to have the weather technicians prepare the general weather forecast under the supervision of the scientists. This policy serves the dual purpose of providing excellent training for the technicians in one of the most important aspects of meteorology, and allowing the scientists additional time to devote to the study of micrometeorological forecasting.

Discussions are held weekly among all meteorological personnel to investigate the peculiarities of the meteorological situations encountered during the preceding week. By this means it is possible to bring current examples of general meteorological conditions to the attention of all hands. The emphasis of these training discussions up to date has been on the relationship of constant pressure (upper-level) charts to the overall field of weather analysis, and on the forecasting of typical summer meteorological conditions, such as convective and frontal thunderstorms, sea fog, and low stratus cloudiness.

Progress has also been made on the project of utilizing climatological data in the preparations of general and special forecasts. Certain climatological data relating to temperature, wind, cloudiness and precipitation have been displayed in such a form that it is possible to use the data directly in determining forecast probabilities. This is accomplished by entering elements of the forecast on a form containing climatological data arranged to show the probability of occurrence of a given meteorological condition during the month in question.

The micrometeorological forecasts are being prepared by the professional meteorologists of the Group. These currently consist of predictions of minute details of wind and temperature structures over the Brookhaven area, and until August 1, 1948 they were based on the 80-foot "Princess" data and aircraft observations. Now that observations are being recorded on the 420-foot "Ace" tower, it is possible to concentrate on this phase of the meteorological problem, and accurately to verify the predictions.

In addition to the daily general and micrometeorological forecasts, the Group has provided forecasts of a special nature on numerous occasions. Perhaps the best illustration is the set of forecasts made in April for flights to 25,000 feet by the Navy for the Physics Department, B.N.L. Many other forecasts within the limits imposed by our teletype licences, have been provided to interested groups on weather conditions seriously affecting transportation or construction operations.

Verification of the general weather forecasts has been conducted since the beginning of the program by the use of an accepted verification system, both for the purpose of checking the accuracy of the predictions and to serve as a training aid to all personnel. To date, the forecasts have proved to be 84.1% accurate during the first twelve hours after issuance, and 69.7% accurate during the overall 36-hour forecast period. Since early August the micrometeorological forecasts have also been verified, but the record has been too short to obtain significant results.

It is anticipated that the verification system now in use will be replaced by a combined forecast-verification form that will be based on climatological data for this area. Such a form will provide the forecaster with a direct reference to climatological data, each time he prepares a forecast, and will use these data as a basis for the scoring of the forecaster's proficiency.

HOT CHEMISTRY RESEARCH

During the summer of 1948 the first research problem involving highly radioactive materials was carried out in the Nuclear Reactor Project, although our facilities for doing such work were nonexistent. A makeshift laboratory was devised where controlled conditions were imposed, and the Health Physics Section monitored the work.

The samarium problem is of interest to the Nuclear Reactor Project because there exists a wide discrepancy between the observed long-term poisoning effect in a reactor and the effect calculated from the known neutron capture cross-section and fission yield of Sm^{149} . A reasonable explanation of this discrepancy is that a metastable isomeric state of Sm^{149} may exist, with a long half-life and low cross-section. The problem then was to prepare a very intense fission sample of Sm of high purity for radioactivity, neutron cross-section, and mass spectrographic studies. This research is being conducted by Messrs. L.E. Glendenin and J.A. Marinsky of M.I.T., and they conducted the initial steps of the problem in the Project Chemistry Laboratory. They separated the rare earth fraction from a portion of a uranium slug which had been irradiated in the Oak Ridge reactor for about a year and cooled for about a year and a half. This rare earth fraction, free of plutonium, was then sent to M.I.T. where further work on chemical isolation and purification of the Sm is in progress. The radioisotopes of Ce and Eu are to be completely removed, after which the sample will then be subjected to a very thorough ion-exchange separation using a column of Dowex-50 resin to separate Sm in high purity from Y, Pm and any other rare earth activities remaining. The final carrier-free sample of Sm will be examined for radioactivity (Sm^{151} and Sm^{149} (?)). Then it is planned to send this sample to Oak Ridge for neutron-capture cross-section measurements. Finally the sample is to be sent to Dempster at Chicago to determine by mass spectrographic analysis whether there is any peak present at mass number 149.

A second problem started was the preliminary separation of rubidium from U_3O_8 which had undergone reactor irradiation for four weeks and cooled for three weeks. Here the problem is to redetermine the fission yield of the shielded nuclide 19.5 day Rb^{86} . This work was also transferred to M.I.T. where the sample was completely purified and its fission yield determined to be $3.1 \times 10^{-5}\%$. This value is important to the question of the division of nuclear charge in fission, and supports the postulate of equal chain length (See Clinton Lab Memo CL-LEG-1).

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