Report No. CH-459

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Metallurgical Project

A. H. Compton, Project Leader

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REPORT FOR PERIOD ENDING FEBRUARY 9, 1943

HEALTH, RADIATION AND PROTECTION

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THE EFFECTS OF IRRADIATION ON THE BLOOD AND BLOOD FORMING TISSUES.

S. T. Cantril, L. Jacobson, and J. J. Nickson

R. S. Stone, Group Leader

January 11, 1943

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Abstract

A review is given of the effects of external whole body and local irradiation in man and experimental animals. Internal irradiation by radioactive substances in man and experimental animals is considered.

An abstract of pertinent findings is given in the summary and conclusions.

[redacted] GENERAL SUMMARY

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#2

R. S. Stone

Our Project Director has described the duties of the Health Division as follows:-

(1) Safeguarding the health of the personnel in the Chicago Project and its subsidiary research projects;

(2) Investigating the nature of hazards, protection against them, and the treatment of injuries associated with the radioactive and toxic materials used in our process;

(3) The precautions necessary to safeguard the public health;

(4) As an important secondary duty to consult with and give all available useful information to associated projects that are concerned with similar hazards of radioactivity and toxicity.

In line with the first of those duties:-

Dr. Cantril reports below on the physical and laboratory examinations of the personnel here in Chicago showing that a good check is being kept on all of them and few instances of even slight changes due to the hazards of occupation are found. Dr. Wollan reports on surveys made by members of his group, largely Dr. Parker, of the exposure conditions existing around the cyclotron here, in St. Louis and in Bloomington, and around Pile #1. These studies have shown that while many of the safeguards necessary have been incorporated already some further safety measures are needed and these are now being installed. The Health Director visited the project at Bloomington and was instrumental in instituting more routine examinations. He obtained health reports from the Chemistry Group in Berkeley showing no unusual blood or urine changes and he wrote to the leaders of all other subsidiary research projects advising them of the health measures that are taken here and should be taken by them.

In line with the second duty, that is "Investigating the hazards, etc.":-

Dr. Cole and his group have continued their investigations with Xenon^{127}, with fast neutrons and x-rays, attempting to find new ratios, and with animals near Pile #1; Dr. Tannenbaum has continued his studies on Uranium toxicity; Dr. Wollan and his group are continuing their efforts to build a satisfactory apparatus for separating that part of the ionization due to neutrons from that part due to gamma rays when we have a mixture of the two; The N.C.I. Group, the M.H.N.Y. project and the project at the U. of C.H. are all trying to find the effect of various doses of total body irradiation; Dr. Hamilton and his groups are investigating the metabolism of fission products and the methods of replacement therapy. Dr. Cole has spent a great deal of his time planning the experiments to be performed at the Argonne to study the effects of radioactive materials coming from the pile in the cooling air.

In line with the third duty:-

Dr. Wollan, together with the members of other divisions has spent a considerable amount of time calculating the hazards to be anticipated at the Argonne, Site X and Site W. Dr. Church, Meteorologist recently added to the project, has supplied useful data to add to the above calculations.

In line with the fourth duty:-

The Health Director has helped to set up a more complete medical program in associated projects and has consulted with the Army and Stone & Webster regarding hospital and medical facilities at Site X.

B. REPORTS FROM SUBSIDIARY PROJECTS

R. S. Stone

1. N.C.I., Dr. Carl Voegtlin, Director:

The project at Bethesda was recently visited by Dr. Jacobson who brought back the report that the animal experiments using acute and chronic exposures to x-rays and gamma rays are either under way or about ready to start, but there is little in the way of results to report. They have had some delays in getting necessary materials but everything needed is now on hand or accounted for. Doses of x-rays as low as 12.5 r given in a short period of time show a detectable change in some tissues, especially the bone marrow and lymphoid tissues. There is apparent recovery in two to three weeks. 25 r and 50 r doses produce much more severe reactions from which also the animals apparently recover in a few weeks. However, we are more interested in the late effects than the early ones.

2. M. H. N. Y., Dr. Lloyd F. Craver, Investigator:

This project was also visited by Dr. Jacobson. Two patients have been treated with the Heublein technique which consists in practically continuous x-ray irradiation from a tube operated at 185 kv. at a distance of 295 cm. from the patient when he is in bed. The radiations are filtered through 1.65 mm. of Cu and 2.07 mm. of iron. The first patient who received a total of 300 roentgen between December 5, 1942 and January 4, 1943 at the rate of 10 r per day, was a man who had a melanoma with wide spread metastases. "Clinically he withstood the treatment fairly well and there seemed to be no consistent change in his blood count". However, on February 2nd both the red and white cells had decreased in numbers to lower levels than at any previous time, and the patient will have to be followed for longer period of time before definite conclusions can be drawn. A second patient who had lung metastases from an embryoma of the testicle received 150 r at the rate of 10r per day between December 21, 1942 and January 5, 1943. On this latter date his platelet count dropped rapidly and so treatment was discontinued. The platelets returned to a fair level in two days. His red cell count has continually decreased since the start of treatment but the white cells have not decreased very much in numbers. Neither of these patients was in very good physical condition and probably their disease may account for some of the

changes noted. Dr. Craver concludes "... if it can be demonstrated that persons with as much disease as these can tolerate certain amounts of radiation, one may be justified in concluding that presumably normal people could all the better withstand it."

3. U. of C. H., Dr. Robert S. Stone, Investigator:

At this institution, more nearly normal patients are being treated than those at M.H.N.Y. The radiation used has been x-rays of 100 kv. constant potential with no filtering intervening and the treatment times have been short. The study has not gone far enough to show any but immediate results. One patient received 190 r from 19 treatments in 21 days; a second 80 r in 25 days; a third 220 r in 14 days, and a fourth 150 r in 13 days. The blood counts of all were nrmal throughout the time of treatment and at the end and no unusual symptoms developed.

4. U. of C. Radiation Laboratory and Departments of Physiology and Biochemistry, Dr. J. G. Hamilton and Associates:

(A separate report is to be issued later in the month giving the details of the material incompletely summarized here.) The following radioelements with the carriers have been prepared from material bombarded on the Berkeley Cyclotron; Krypton ^{79}, Rubidium ^{88}, Strontium ^{85}, Yttrium ^{86}, Zirconium ^{89}, Columbium ^{93}, Iodine ^{131}, Xenon ^{127} and Lanthanum ^{140}. As has been reported, when Strontium is injected into animals it goes largely to the bones. After oral administration only a small percentage (about 8) is taken up into the body and goes to the bones. It is excreted largely in the feces. Yttrium goes mainly to the bones and remains there. It is excreted in the feces. Less than .1% was absorbed from the gastro-intestinal tract. When introduced into the lungs it tended to remain there. Zirconyl chloride when injected tended to remain at the site of injection and not be absorbed. What little was absorbed was distributed throughout the body and not selectively deposited in the bones. Iodine went to the thyroid gland or was eliminated by the kidneys. Xenon distribution has been described in a previous report.

Some rats were given raw mixtures of fission products in the form of Chlorides. The fission products were obtained from a sample of uranyl nitrate bombarded at St. Louis. Study of tissues at different periods showed active materials to be largely located in the bones but an appreciable amount was also found in the liver and spleen. Most of the excreted activity came in the feces. When this mixture was given by stomach tube only 1.6% of the administered dose was found to have been absorbed at the end of 4 days. Dr. Hamilton concludes in part:

"1. The bulk of long life fission products are deposited in the bones, from which the rate of elimination appears to be much slower than the average half life.

2. It is probable that a large fraction of inhaled long life fission products is likely to be held in the lungs for an extended period of time.....

3. The oral ingestion of [illegible] fission products [illegible] is [illegible] ..... [illegible]

C. HEALTH PHYSICS

E. O. Wollan, Section Chief

5. Radiation Problems at Argonne

The radiation problems associated with the Argonne pile have been considered and calculations indicate that the 5 ft. thick concrete shield which is being built will give ample protection from both the neutrons and the gamma rays for operation up to 100 kw. If the metal is coated, which is now the plan, it seems that the present exhaust system with slight modifications will give adequate dilution of the fission products which escape the pile. If the metal is not coated it cannot be said with certainty that the radiation from the discharged air would be at a safe level. Detailed reports regarding the radiation conditions at Argonne have been furnished to those immediately concerned. The radioactivity of the exhaust air for uncoated metal was calculated from the experimental data of Conyell and Sugarman, account being taken of the relative power and metal surface of the experiment and the pile. With some uncertainty as to the average life time of the discharged fission products and of the amount of trapping of these in the channels in the pile it was found that the radioactivity in the undiluted cooling air was 4×10^{-9} curies of hard Beta-rays per cm^3. If, as seems reasonable, the gamma ray activity is of the same order of magnitude it would be the determining factor on the amount of dilution required for safety. A dilution of 100 would bring the concentration to about 4×10^{-11} curies/cm^3 which could be considered safe. This dilution is probably attainable with the present set up but the lack of certainty on this point has made coating of the metal seem desirable.

Instruments for measuring the radioactivity of the air at Argonne are now being made. These will be capable of giving readings for concentrations far less than the tolerance concentrations. A number of instruments for surveying the direct radiation in the neighborhood of the pile will also be on hand before operation begins at this site.

6. Radiation Problems Associated with the Chemical Plants

The radiation shielding for chemical plants at X and W as designed by Mr. Cooper and the DuPont engineers has been checked and found ample with a large safety factor. A chart has been made for their use which permits rapid determination of the concrete required in shielding any amount of product.

A calculation of the radioactive $_{54}Xe^{133}$ associated with the maximum product to be handled indicates that a 200 ft. stack gives a sufficient dilution to maintain the air contamination at a safe level if the Meteorological conditions are not too abnormal. The meteorological conditions which must be considered in the choice of a site must meet requirements for hazards even greater than those encountered in normal operation.

7. Air Sampling and Uranium Content Analysis

Dr. Friedell has arranged for the sampling of the air at firms under the Army's jurisdiction which handle uranium. The amount of the product present

per unit volume of air will be analysed by a measurement of the alpha-ray activity of the collected sample. The alpha-ray ionization is measured by a Dorshem electrometer with the cylinders from the electrostatic air sampler (at Dr. Friedell's suggestion) being used as the wall of the ionization chamber. The sensitivity for reasonable observation times is sufficient to determine 5 micrograms of uranium with an accuracy of 10% when the amount of other materials present is not large. This equipment is also being used by Dr. Cantril and Dr. Nickson together with Dr. Gamertsfelder in the analysis of the uranium in the urine of animals which are being studied for toxological effects of the material

8. Effect of Prolonged Beta-Irradiation on the Human Body - H. M. Parker

The permissible exposure of the body to prolonged gamma-irradiation of low intensity is not well known, although we have a provisional guide - the tolerance dose. For irradiation by beta particles it is self evident that larger doses can be accepted, but apparently no one has yet proposed a permissible figure. It has now become necessary to make such a decision. The problem has been approached by a review of those cases of Beta-ray exposure in the literature that are reasonably suitable for calculation or re-measurement. The work will be continued in collaboration with Drs. Cantril and Nickson. Preliminary calculations for exposure to radio-phosphorus have given rational results and suggest a new method of approach.

9. Pocket Chambers - H. M. Parker

Selected groups have read and recorded their own pocket ionization chambers. Despite the collaboration of the groups concerned it is evident that this is not the ideal way to obtain a record of the radiation exposure of project members. It does not function for small groups, some of which may receive the heaviest exposures, and for alarge groups it means that one person is made responsible for the readings and for the maintenance of the chambers and micrometers. The time thus spent, when integrated over the project, might better be supplied by one person.

Calibration of the chambers is being carried out [illegible] Dr. Gamertsfelder and will be reported next month.

10. Radiation Surveys - H. M. Parker

The following surveys were made to locate and eliminate potential hazards to personnel. As they will not be reported elsewhere and as the results are sometimes of interest in planning protection in other groups they are set out in moderate detail.

(a) The problem of beta-ray exposure was mentioned above. Opportunity arose to measure the radiation from an extended source of uranium metal. The dosage-rate close to the surface was .043 nominal roentgens per hour. It seemed that the hands and arms working with this material would be exposed to this dosage-rate. The rest of the body seen by the uranium probably received more than 0.01 r per hour. Glove equivalent to 0.6 gms/cm² thickness cut the radiation by a factor of 6. It is hoped to correlate these figures with other Beta ray effects later.

(b) The radiation from chemical residues in the Chemistry Department stored behind a straight 4" lead wall was checked. Dosage-rate in the vicinity of the work bench under which the residues were stored reached 0.07 r per hour. It was recommended that a 2" lead wall be built at right angles to the main wall and that a 1" lead cover be placed on the work bench. The judicious use of an L-shaped protective shield is frequently sound. If the L is used in the corner of an outside room, it should be remembered that persons in the next room or even on the next floor may be exposed. In the present case the two open sides were outside walls.

(c) The radiation from a one gram radium source confined in its lead coat was measured. At the time, men were working on an apparatus within one meter of the source, where the dosage-rate was 0.055 r per hour. It should be emphasized that the lead carts are not safe containers for the large radium sources. They are planned for reasonably safe movement of the source and for storage at a considerable distance from working positions -- certainly not less than 2 meters. The men in this case were not exposed for more than 20 minutes, but all unnecessary radiation is axiomatically above tolerance.

(d) Two surveys of the radiation around Pile #1 have been made. The relative values from point to point agree well, but the absolute magnitude is not consistent. As the output had been recalibrated between these surveys the second has been assumed to be correct. It happened that the electroscope had also just been checked at this time. The gamma-radiation only at relevant points was:

Maximum in the East corridor	0.52	roentgens	per	kilowatt	hour
Maximum on the central stairs	0.61	"	"	"	"
Maximum guards' exposure	0.022	"	"	"	"
3rd Handball court	0.025	"	"	"	"
In the street	0.02	"	"	"	"

Evidently if gamma radiation is the principal hazard the equipment as tested was safe, provided that access to certain obvious regions was prohibited.

(e) These surveys were part of a program reported elsewhere by Penneman and Parker to reduce the hazards of handling radioactive targets. The work is still incomplete.

(f) The activity of the St. Louis cyclotron and of the bombarded sample were tested approximately 30 hours after a prolonged bombardment. The gamma radiation alone in the vicinity of the cyclotron was then 0.33 r per hour. The activity of the sample was such that 10 minutes was the "safe" time of close approach. The purpose of handling it at this time was to remove representative portions. Personnel handling the sample received doses of the order of 0.1 r to the body and 0.2 to 0.4 to the hands. Most of the exposure could have been avoided by having the sample subdivided into cartons before bombardment and by preparing suitable lead containers for the cartons ahead of time. The further progress of the transfer of energy from the sample to project members is being followed.

(g) The gamma radiation around the U. of I cyclotron during the deuteron bombardment of a Be probe at about 10 microamperes was measured.

The water tanks surrounding the cyclotron were adequate to cut down the gamma radiation and presumably also the neutrons. There was no protection above the cyclotron and this led to a curious distribution of radiation throughout the room due to the large component of scattered radiation from the roof. It was safer to be against the cyclotron tanks than at any other point within 20 feet of them. This "open box" effect is a familiar one in other connections, and it is sound practice to avoid it. In some countries radium hospitals are not permitted to store radium in protective boxes without lids that close automatically. The L benches mentioned above are bad from this viewpoint . They are not planned for permanent storage. NB. the tolerance dose rate is 0.0125 r per hour, on the basis of an 8 hour day.

11. Neutron Measurements - Carl Gamertsfelder

Measurements of neutrons have been made with small paraffin lined chambers and attempts have been made to obtain an absolute calibration of these in terms of their efficiency in measuring the ionization in the body.

The chambers are made in pairs one of which has an aluminum wall and the other a paraffin wall. The two chambers should give nearly the same reading for gamma rays and the difference between their readings when irradiated by a mixture of neutrons and gamma rays should record the neutrons.

An attempt has been made to calibrate the paraffin chambers by measurements of the neutrons coming from a Ra-Be source (of known strength) shielded with sufficient lead to cut out most of the gamma rays. The difference between the readings of the paraffin wall and aluminum wall chambers gives a measurement of the neutrons.

Due to the uncertainty in the absorption of neutrons in Pb this method does not look very promising at present. More work must be done before an accurate neutron sensitivity of the paraffin wall chamber can be given.

A set of measurements made with these chambers on top of the West Stands pile is listed below. The chambers were shielded with three inches of lead on all sides.

	I	II	III	
Paraffin wall chambers	.224	.208	.192	
Aluminum wall chambers	.147	.131	.131	
Diff.	.077	.077	.061	av.= .072 r'

Time=75 minutes
Power = 12 watts

Intensity of neutrons under these conditions is .058 r'/hour where r' represents a tissue ionization unit for neutrons equivalent to an r for gamma rays.

D. BIOLOGICAL RESEARCH

K. S. Cole, Section Chief

12. Radiobiological Importance of Specific Ionization.--R. E. Zirkle. A review of the literature on specific ionization is nearly completed. The variation of amount of radiation, as a function of the ion density required to produce a given biological effect, is found to lie in about a ten-fold range for the best data available on a wide variety of biological materials and effects. This review will be issued in report form.

13. Effects of Fast Neutrons on Rabbits.--R. E. Zirkle and L. O. Jacobson. Experiments have been started to compare the fast neutrons and 200 KV x-rays for production of blood changes and lethal effects. The Be-d neutrons from the probe of the Chicago cyclotron are being used. Preliminary experiments have shown blood changes in the 5-10 n range and lethal effects in the 30-120 n range.

14. Effect of Radiations from Pile #1.--R. E. Zirkle and L.O. Jacobson. Three rabbits have been kept near Pile #1 since January 18. The accumulated dose as measured by Victoreen 0.25 r and 25 r chambers, was 3.56 r for 19 days. No significant changes have been observed

15. Drosophila.--R. E. Zirkle. Two separate series of x-ray exposures have been made to date, using graded doses and slightly over 4000 eggs. A smooth survival curve has been obtained giving a half-survival dose of 175 r. This compares favorably with 180 r found in earlier work.

16. Effects of Radio-xenon. Guinea pig #10 had 15 days exposure to about 0.1 millicurie/liter of Xe^{127}. It was removed from the gas chamber in poor condition and died after heart puncture. Blood, gross and microscopic examinations, showed effects of ammonia, dehydration and low oxygen tension but no certain effects of radioactivity. Guinea pig #14 had 14 days exposure to about 0.5 millicurie/liter of Xe^{127}. It was removed in good condition, but showed a weight loss of 140 gm. Heart puncture showed dehydration and low oxygen. The animal died the next day. Gross and microscopic examinations showed areas of collapsed lung but also indicated that heart puncture was primarily responsible for death. There were no certain effects of radioactivity.

Guinea pig #15 spent a total of 37 days in the apparatus without xenon exposure. It died from an inadvertent stoppage of oxygen supply having lost 16 gm. in weight. Guinea pig #16 was removed from the apparatus after 45 days without xenon exposure. It was in good condition with no change of weight and is being kept for observation. Guinea pig #17 died in the apparatus, without xenon exposure after 32 days. Gross examination showed no cause of death; microscopic sections have not yet been made.

During part of these experiments ammonia accumulated because spilled food prevented removal of feces and urine. The ammonia could be removed by acid, but an arrangement for daily introduction of food is simpler and apparently adequate. The CO_2 absorbers have been modified to reduce danger of leaks by distorting the flexible connections by flexure rather than torsion.

Over a period of a week two animals were each found to produce 250 cc/day of unidentified gases. Mr. Garrison found them to be methane and hydrogen. These gases are being analyzed by combustion and the technique is being developed for removing them from the animal bottles by the same means.

E. CLINICAL MEDICINE AND MEDICAL RESEARCH

S. T. Cantril, Section Chief

17. Medical Examination

Physical examinations and the accompanying x-ray examinations of the chest and laboratory examinations of the blood (including Wassermann) and urine have been done on 350 people up to the time of this report. In the month of January 1943, Dr. Nickson examined 67 new personnel. The number of people rejected as a result of the health examinations has not been high. This is not due to unusually high standards of health among applicants but rather to the scarcity of available personnel. Candidates have not been employed who have been found to have physical defects which would intefere with their work or which might be further impaired by any possible hazard of the work here.

18. Uranium Toxicity

(a) Metallurgic Laboratory. We have for the past two months been looking forward to an improvement in working conditions in the metallurgy shops under Mr. Creutz. He was finally able to move his shop to the North Stands and place an order for an adequate ventilation system for his uranium cutting and grinding operations. Just as this was to be installed, the system was taken for other work at Argonne, so that further delay in installation must now be awaited.

The machining, grinding and casting of uranium metal is becoming more and more common and operations in this work are increasing in scope. The wearing of dust collecting masks is not sufficient protection against the inhalation of metallic dust or fumes. That the working conditions are not satisfactory as yet is not the fault of Mr. Creutz, but is rather due to a succession of delays over which he has had no control. It is expected that proper equipment will again be available within this month.

Repeated urinalyses of men in this group have not shown findings consistent with evidence of uranium toxicity. Improvement in working conditions becomes all the more necessary as machining operations increase.

(b) Measurement of Uranium in Excreta and in Air Samples. Messrs. Hollan and Camertsfelder have for some time been working on an instrument which will measure small quantities of uranium (micrograms) by alpha particle measurement. They have developed this to a point which now permits preliminary surveys of the uranium content of excreta in experimental animals which have been receiving uranium in various forms (oxide, nitrate, metal dust) and by different routes (ingestion, inhalation), as well as analysis of uranium retained in the animals. Dr. Nickson has begun a preliminary study of the practability of the method in analyzing for small quantities of uranium in urine.

Measurements of known amounts of alloy added to urine have shown that the method is accurate to within 10-15%. Thus the method is clinically useful.

Preliminary measurements indicate the presence of the alloy in the urine from dogs who have had powdered alloy sprayed into their lungs; 1 gram per week has been introduced over a 10 week period, a total of 10 grams. The concentration seems to be of the order of 1 microgram per c.c.c.

The urine of one of the men who has been grinding the metal for several months was examined. No evidence of activity was found.

It has been found that the metal can be precipitated from solution by alkalinzation of the urine. This seems to offer a convenient way to concentrate any alloy that may be present in large quantities of urine or other excreta.

Dr. Tannenbaum has continued his toxicological studies of uranium poisoning in mice, as reported in CH-382,396. His program now calls for pathological studies of the animals and determinations of retained uranium in the organs. Whether a method of analysis based on physical measurement of alpha activity, or upon chemical separation and quantitative determination will work out to be more practical is still to be determined by actual tests.

The mice which were kept near Pile #1 during a portion of the pressing operations, and which breathed the same atmosphere as the men, have shown no deleterious change, as evidenced by weight loss, when compared with controls. Some of these animals will shortly be sacrificed for study

19. Studies of Urine in Uranium Workers

Mr. Waldo Cohn, who joined the Health Group in December as a biochemist spent one month in Boston investigating a problem of urinalysis which was encountered at Beverly and M.I.T. It was found that there was a more than average incidence of a slight reduction of Benedict's solution when a qualitative test for sugar was done, giving the report of "slight trace" or "trace" of reduction which is usually interpreted as due to sugar. Mr. Cohn found however that, by fermentation, the reducing substance was not sugar. Nor was it consistently correlated with an increase in nitrogenous waste products. Examination of six urine specimens for uranium showed that there was less than .02 mg per c.c.; more sensitive tests were outlined and work begun on them at M.I.T. It was Mr. Cohn's conclusion that there was some correlation between the "reducing substances" in the urine and inhalation exposure to metallic uranium dust. More sensitive tests for the presence of uranium in the urine, and in dust, were recommended as urgently needed. It appears, as previously stated, that we now have these tests available.

20. Effects of Radiation on Personnel

It is of interest to analyze the radiation effects upon the blood of personnel in relation to the origin of the radiation and the type of work concerned.

White Blood Count Below 2000: In September, one physicist was found to have a count of 2500, due to over-exposure to radium and over-exposure to X-ray prior to coming on the Project. He recovered satisfactorily within six weeks and has maintained a satisfactory level.

White Blood Count 3000 - 4000: Three physicists sustained a fall in count to below 4000; two from handling sources; one from cyclotron exposure. One chemist developed a count of 3500 from exposure to radioactive chemicals. All of these low counts were transient with the exception of one man, who required five months to reach a stable normal level and who has been removed from work with radiation.

White Blood Count 4000 - 5000: Eight physicists developed a count below 5000 from the handling of radium sources. All of these were transient leukopenias. Two chemists and one physicist developed a count within this range from cyclotron exposure. On physicist had a low white count from previous exposure at the time he came to the project. He has had no exposure on the project and his count is now normal. Three physicists in the electronics group have at one time or another had a count below 5000, although they were not using sources of high strength in their work. We have attributed these periods of leukopenia to a too close proximity to sources of radiation, in the neighborhood of work.

Fall in White Blood Count but Remaining above 5000, or Reversal of Neutrophilic and Lymphocytic Ratio: Five physicists sustained a recognizable fall in count or reversal consequent to handling of sources. This was transient in four, and in one the reversal has been intermittent despite his giving up handling of sources and all work involving possible exposure. The total white count is satisfactory. Five chemists had a noticeable fall in count or reversal which was transient. In two this was due to work with a radium source: in two to cyclotron work; in one to working with radioactive chemicals.

Summary: It will be seen that the radium sources have been the greatest factor in producing low blood counts. The majority of these over-exposures occurred prior to October 1942 and came in the work of groups concerned with measurements in paraffin or graphite geometries, water tank experiments, etc., which experiments were leading up to the completion of the first operating pile. Since October and November the incidence of over-exposure from radium sources has greatly improved.

The cyclotron effects were largely among the chemists who were irradiating samples. This has been checked and exposure possibilities reduced. A separate report on cyclotron protection from the standpoint of beta ray emission in irradiated samples will be shortly completed by Parker and Penneman.

In all but two instances the leukopenia or reversal have been transient. These two cases were discussed in Report CH-396.