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THE AIRCRAFT NUCLEAR PROPULSION PROGRAM AND GENERAL REACTOR TECHNOLOGY

QUARTERLY PROGRESS REPORT

FOR PERIOD ENDING NOVEMBER 30, 1949

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
CARBIDE AND CARBON CHEMICALS DIVISION
UNION CARBIDE AND CARBON CORPORATION
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ORNL 528

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Contract No. W-7405, eng. 26

THE AIRCRAFT NUCLEAR PROPULSION PROGRAM
AND
GENERAL REACTOR TECHNOLOGY

QUARTERLY PROGRESS REPORT
for Period Ending November 30, 1949

A. M. Weinberg, Program Director

Report Edited by
C. B. Ellis

DATE ISSUED: JAN 10 1950

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SUMMARY

Reactor Design. Exploratory studies are underway on some possible new cycles not previously considered for aircraft reactors. New mathematical methods are also being investigated for analysis of reactor cores having intricate internal geometry.

Shielding. Possible designs are being studied for a new testing facility to measure attenuations up to 10^8. This should probably be in some form of a critical assembly which will operate at power levels up to 10 kw.

On the lid tank, bulk shielding measurements of iron and water are now underway.* It is hoped to begin two-shift operation shortly.

Theoretical analysis is in progress on (a) thick shields composed of a mixture of pure scatterers,* (b) neutron penetration of a water shield, using Monte Carlo techniques, and (c) neutron streaming in ducted geometries.*

A new instrument for measuring fast neutron flux is being developed.* This consists of a thin Pd film fired on a ceramic core. The proton recoils from the neutrons bombard the Pd in such a way as to change the electrical resistance of the film.

The NEPA neutron spectrometer, based on counting proton recoils from a radiator, is now installed at ORNL and is being calibrated.*

In the work on shielding materials, combinations of Pb, H_2O, and B or B_4C are being studied, and irradiation tests on Boral have been made. The tensile strength of the latter appears to increase under irradiation. Also, a new plastic has been developed which contains 50% boron by volume. It may be made into strong, flexible sheets, mechanically similar to leather, which can be easily glued onto metal surfaces for thermal neutron shielding. Work on improved concretes for shielding also continues.

Heat Transfer. The summary of atomic energy heat transfer work, ORNL 156, has been brought up to date and abridged for declassification. A new empirical relation has been developed for heat transfer in annuli which will hold for all cases where the liquid wets the walls—including liquid metals. It has been shown that the supposed phenomenon of "polarized turbulence" does not exist. The thermal conductivity and heat capacity of molten NaOH have been measured at 900° F.

Equipment is being designed for work on handling methods and heat transfer properties for liquid metals at aircraft reactor temperatures.

* These projects are being conducted in collaboration with NEPA.

Metallurgy and Materials. A program is being set up for testing the corrosion and mechanical properties of many metals when exposed to high temperature liquid bismuth or lithium. Molybdenum has the best corrosion resistance to Bi at 1800° F found so far, with Be also good; however, Ni and stainless steel are attacked. Larger vacuum furnaces suitable for work with molten Bi and Li are being built.

Radiation Damage. Five people from NEPA have now been trained in radiation damage techniques at ORNL. The principal tests on reactor core materials now underway are on Be_2C. Changes during irradiation of such properties as electrical resistivity, modulus of elasticity, hardness, coefficient of thermal expansion, and thermal conductivity are being measured with the ORNL reactor.* Exposures of Be_2C to Hanford flux will be made in the near future. Work on other possible ANP materials will be begun shortly.

Because of its interest as a possible shield material, TiH_2 has been tested for decomposition under a neutron flux of 0.5×10^{12}. No radiation-induced decomposition could be observed during 1800 hours exposure at temperatures from 160° to 340° C.*

Decomposition of numerous commerical plastics under irradiation was observed. The most resistant was polystyrene.

As an adjunct to the radiation damage work, the fast flux in Hole 19 of the ORNL reactor was measured, using a series of threshold detectors. A curve of the measured spectrum is presented. The total flux above 1 Mev was found to be 0.11 neutrons/(cm^2)(sec)(watt).

A high intensity gamma source free of neutrons, is being prepared by irradiating cylinders of gold in the reactor. From these cylinders it is expected that gamma fluxes above 10^6 r/hr can be obtained.

Irradiation of special lubricants for possible aircraft reactor use is being continued in the ORNL reactor.*

* These projects are being conducted in collaboration with NEPA.

INTRODUCTION

The program looking toward the development of a nuclear propelled aircraft is now a joint project of three Government agencies—the Department of Defense, the National Advisory Committee for Aeronautics, and the Atomic Energy Commission. On September 26, 1949, the Atomic Energy Commission designated the Oak Ridge National Laboratory as the agency for carrying on the AEC's share of the joint technical program. The other two working agencies are the NEPA Division of Fairchild Engine and Aircraft Corporation (as a contractor of the Air Force) and the Cleveland laboratory of NACA. The division of effort between the three laboratories has not yet been defined in detail. However, the Oak Ridge National Laboratory has been asked in general to investigate the nucleonics aspects of the project.

To meet this responsibility, the Laboratory is expanding its present work in all Divisions on experiments likely to aid the ANP program, and is also planning the establishment of new projects with high priority. A number of pieces of work already underway were initiated at the request of NEPA and so apply directly to the ANP program. For at least the immediate future, most of the experimental ANP work of the Oak Ridge National Laboratory is expected to fall into four categories:

- Shielding
- Heat Transfer
- Metallurgy and Materials
- Radiation Damage

No preferred reactor type, coolant mechanism, or shielding material for the nuclear airplane has yet been definitely chosen by any agency. Therefore, the experimental program must still be exploratory in nature. To guide this work throughout ORNL, a small ANP Design Group is being formed within the Technical Division. This group will carry out reactor calculations and will survey and compare the possible overall designs, and recommend those materials and processes most worthy of study by the Laboratory at any time.

A continuous and close liaison at all levels will be maintained with NEPA and NACA to avoid unwise duplication and to effect mutual progress. Joint experiments with shared personnel and facilities are expected to be of increasing importance. At present, the personnel at ORNL cooperating in such work number 21 from NEPA and 3 from the U. S. Air Force. About 10% of the ORNL reactor usage based on the allocation of operating costs, is devoted to experiments directly for NEPA.

The following sections describe present and planned work bearing on the Aircraft Nuclear Propulsion Program throughout the Laboratory. Some of this work originated at NEPA and is being carried out at ORNL now as part of the integrated ANP effort. Approximately 42 persons are now doing work directly related to this program; in addition to work specifically for ANP there is contained in this report some material affecting reactor technology in general.

REACTOR DESIGN

OVERALL DESIGN STUDIES

C. B. Ellis, Technical Division*

Some preliminary and exploratory work has been carried out on a few possible aircraft reactor designs. These have been chiefly of unusual types not previously surveyed for the purpose. Included are (a) a reactor moderated and cooled by molten NaOH, (b) reactors using liquid uranium alloys, and (c) systems containing boiling liquids, either as coolants or as control agents. None of these studies are yet complete, however it does appear that the active core for an NaOH aircraft reactor might be no larger than two feet in diameter.

It is planned to concentrate the design studies on those heat transfer systems and reactor types which show promise of permitting very high power densities in the reactor core. Such work may permit a decision as to which new cycles, if any, should be attacked experimentally at ORNL in addition to those already under study by NEPA.

CRITICALITY THEORY

L. Nelson, Mathematics and Computing Panel

The Mathematics and Computing Panel is investigating new methods of analyzing the neutron distributions and criticality conditions for reactor cores of intricate geometry. Special attention is being given to systems having gaps and ducts within the core, of the sort which may be necessary in a gas-cooled aircraft reactor. Advantage will be taken of high speed computing machine methods. One approach to be tried is the three dimensional relaxation technique.

* U. S. Air Force personnel.

SHIELDING

The shielding program at ORNL is designed to study simultaneously the feasibility of shielding mobile reactors—particularly nuclear-powered aircraft or ships—and the more long-range problem of understanding the shielding processes so that nearly ideal shields can be designed. The experimental work will center about two bulk shield testing facilities, one already in operation, the other only recently decided upon and hence in the early design stages. The results of both experimental programs will be analyzed by a theoretical section which will be responsible for the guidance of the work. Many of the proposed experiments will correspond closely to the proposals of H. A. Bethe[1], and as recommended by him, emphasis will be placed on the neutron attenuation, which shows little promise of becoming calculable in the near future.

DESIGN OF NEW ATTENUATION TESTING FACILITIES

W. M. Breazeale and E. P. Blizard, Technical Division

Although the lid-tank adjacent to the pile is operating satisfactorily and is yielding the expected data, it has been evident for some time that another bulk shield testing facility with somewhat different characteristics should be built. Specifically, the new facility should be capable of measuring attenuations of some 10^8 in fast neutrons, should have a variable intensity source and should permit measurements through various shapes of shields (i.e., cylindrical or possibly spherical in addition to flat plates). The present lid-tank is not capable of such a large attenuation range.

Various designs have been or are being considered. A fission plate excited by thermal neutrons from the pile obviously will not meet the above requirements. Some type of critical assembly which can be operated at power levels up to 10 kilowatts should be satisfactory. The three possibilities which we have considered are: (a) building a "water boiler"; (b) modifying the MTR Mock-Up, when scheduled tests are finished, to make it into a bulk shield testing facility, and (c) assembling a number of fuel elements, similar to those now in the Mock-Up, into a small reactor. This last seems to be the quickest and cheapest procedure. The assembly would be operated in a pool of

[1] Report on the Status of Shielding Information for the NEPA Project, H. A. Bethe, June 10, 1949.

water both for cooling and shielding purposes. Detail designs are now being studied with a view toward predicting costs, and time of construction, and a specific proposal will be made in the near future. Suggestions similar to the above have also been made by R. Echols and J. Bair of NEPA.

LID TANK BULK SHIELDING MEASUREMENTS

Clifford, Flynn, Lewis, Hullings, Martin; Technical Division*

A. *Experimental Program.* In order to expedite the proposed bulk shielding measurements, additional personnel have been assigned to this program. R. H. Lewis, Jr. Physicist, with the assistance of M. K. Hullings, Jr. Mathematician, and K. Martin, Jr. Mathematician, are now responsible for all measurements involving foils, and also for operation and maintenance of the counter room, Building 105. J. D. Flynn, Chemical Engineer, assisted by D. J. Kirby, Technician, and V. L. DiRito, Technician, are now responsible for operation of the lid tank and measurements taken in the tank by the various methods other than foils.

The first of a series of attenuation measurements of iron and water is now underway. This is the attenuation of water alone. Measurements along a line perpendicular to the source, (28 in. diameter—2×10^8 incident flux) and integral measurements will be made for both neutron and gamma rays through 210 cm of H_2O.[2] Following this, the attenuation of a shield containing 80% iron by volume in the form of 7/8 in. iron plates will be measured.

Other attenuation measurements planned for the future will include about two more iron-water shields to fix the optimum ratio for that combination, both with and without an iron thermal shield. This data will be used to help specify requirements of wolfram for later attenuation test specimens.

After iron and water, the other two-component systems of interest will be measured, to wit:

Lead-water
Wolfram-water
Iron-boron
Lead-boron
Wolfram-boron

* NEPA personnel.

[2] For thermal neutron distribution along centerline of tank see ORNL 480 p. 12.

All of these are to be measured with and without metal thermal shields. Each system will take several months to measure even with the tank operating on two shifts—although this time estimate cannot be very accurate without more experience on the facility.

B. *Status of Tank and Equipment.* The source plate, consisting of 200 X-10 slugs, has been placed in the tank. In an effort to calibrate the source directly, three thermocouples were each welded to a slug in the central row in order to determine the temperature increase in the source plate caused by the energy released in it from fissions. The voltage from these thermocouples is being determined with a vibrating reed electrometer, the maximum sensitivity of which is 5 microvolts full-scale. Measurements are now being taken.

To increase the range of the gamma measurements a methane-argon gamma proportional counter has been installed outside the rear face of the tank on a line perpendicular to the center of the source. It will remain in a fixed position and surrounded by a four-inch lead shield.

To avoid excessive loss of time due to maintenance of electronic equipment, two proportional counter setups, i.e., two A-1 amplifiers, four scalers, and two A-1-A preamplifiers have been acquired. These are all new or recently remodified by the Instrument Department and are now in operation.

SHIELDING ANALYSIS

W. K. Ergen, F. H. Murray, S. Podgor*; Technical Division*

The first part of the reporting period coincided with the latter part of the Summer Shielding Session. The following four reports were issued with a member of the Shielding Analysis group as an author or coauthor:

- ORNL 424 "Approximate Analysis of Penetration of Neutrons through a Thick Shield of Non-Hydrogenous Material", by F. H. Murray
- ORNL 426 "Total Cross Sections of Light Elements as Obtained from the University of Minnesota", by W. K. Ergen
- ORNL 427 "Program for the ORNL Bulk Shield Testing Facility", by E. P. Blizard, C. E. Clifford, W. K. Ergen, G. Young
- ORNL 435 "Neutron and Gamma Attenuation through Tungsten Carbide and Boron Carbide", W. K. Ergen, C. E. Clifford

* NEPA personnel.

A great part of the time of the Shielding Analysis group was spent in assisting in the issuing of Summer Shielding Session reports, after the authors had left Oak Ridge. Some time was also dedicated to the design of a new bulk shield testing facility at the MTR site.

F. H. Murray is investigating thick shields composed of a mixture of elements, some of which may be considered pure scatterers. Consideration of a large number of spherical harmonics representing the neutron flux as function of angle leads to a mixed set of equations:

$$(1 - g_0)K_0 - kK_1 = 0,$$

$$(1 - g_n)K_n = [\ k/(2n+1)\ ]\ [\ nK_{n-1} + (n+1)K_{n+1}\ ], n \leq N$$

$$(d^2K/dw^2) + (1/w)(dK/dw) + [2 - 2k^{-1}\gamma(w)]K = 0, w = n + \tfrac{1}{2} > N$$

$$\gamma(w) = 1 - g(w).$$

The corresponding Boltzmann equation is

$$(1 - k \cos\theta)K = Q/4\pi\,\sigma_t + \sum \left\{\frac{2n+1}{4\pi}\right\} g_n\ K_n\ P_n\ (\cos\theta).$$

K represents the Fourier transform of the flux, and is represented by the series on the right with g_n replaced by unity; g_n is defined by the scattering as function of angle by the various nuclei, and k is an eigen value such that $1/k\sigma_t$ is the relaxation length in many idealized problems. The recurrence equations do not seriously add to the computer's work and can be used for shielding problems for mixtures to which Wick's methods are not applicable.

Identities useful in the calculation of eigen functions of a Schrödinger equation have been developed for this system when the cross sections are constant; for the case of variable cross sections a method of perturbation is being developed.

Also a short memorandum was issued by W. K. Ergen on shielding of small reactors. This memorandum discusses the fact that for small reactors short relaxation length becomes more important for minimum shield weight than low g/cm^2.

Samuel Podgor of NEPA has been assigned to the group.

MONTE CARLO SHIELDING CALCULATIONS

L. Nelson, Mathematics and Computing Panel

A Monte Carlo computation (described in ORNL 439) of neutron penetration of a water shield is currently underway. This problem was suggested by the Summer Work Session on Shielding and has two purposes: (a) the results will be of intrinsic value in shielding considerations, and (b) the results will indicate a more efficient design of subsequent Monte Carlo computations in solving similar problems in shielding.

DUCTED SHIELD THEORY

D. Whitcombe, Physics Division*

The report "Solution to the Diffusion Equation with Streaming for Three Basic Geometries", by D. Whitcombe and N. Smith, has been released as ORNL 403. The report contains the solution to the Helmholtz equation $\nabla^2 \phi - k^2\phi = 0$ for various two medium geometries where the boundaries are not coincident with an equi-flux surface. When this general condition exists there is a net current parallel as well as perpendicular to the boundary; and this condition is designated as "streaming". This report presents many solutions of this type for three basic geometries encountered in practice, which are sufficient to obtain an approximate answer to a general problem in this class.

Pd FILM FAST NEUTRON DETECTOR

B. Gossick, Technical Division*

Preliminary information has been obtained on resistance variations of a palladium film fired on a ceramic core, due to recoil-proton bombardment. In view of the large magnitude of resistance changes, it is proposed here that this resistor might be employed to measure the energy absorbed per gram of tissue as a result of a fast neutron flux, after L. H. Gray.[3] It seems rather certain that the effect is produced by hydrogen occluded in the palladium.

* NEPA personnel.

[3] L. H. Gray, Proc. Cambridge Phil. Soc., *40*, 72 (1944).

The resistors which have been exposed thus far were manufactured by Continental Carbon, Inc., according to a process described in "Printed Circuit Techniques", National Bureau of Standards Circular #468, November 15, 1947, page 16. Through the courtesy of Dr. J. W. Jira, of Continental Carbon, resistors with exposed palladium films were obtained before the protective coats of vitreous enamel and paint were applied. One of these resistors was coated with paraffin and placed in an air cooled hole in the Oak Ridge pile. A fifteen-hour exposure at full power reduced the resistance from 48,300 to 234 ohms. A similar resistor in a chamber evacuated to approximately nine microns showed a resistance change of from 51,000 to 252 ohms within two minutes after 44 centimeters of hydrogen was applied to the system. The resistors were maintained at approximately room temperature during both the proton-recoil and hydrogen gas experiments.

The palladium film resistors normally exhibit a negative temperature coefficient of resistance. After bombardment with recoil-protons, or exposure to a hydrogen atmosphere, the temperature coefficient of resistance is positive. Investigations of R. H. Kernohan[4] show that a palladium wire will absorb approximately two hydrogen atoms per atom of palladium. The effect is to increase the resistance by a factor 1.735 and increase the length by approximately 3%. On the basis of the above information, the following mechanism is suggested. The thin palladium film is non-uniform on the rough ceramic surface, and this is so to the extent that the resistance depends largely on the cross section of many small contact points in the metal film. In the normal resistor thermal expansion brings the large metal surfaces adjacent to these contact points closer together, increasing the cross section at the junctions. In this manner a negative component of the temperature coefficient is provided which normally overrides the intrinsic positive coefficient of metal palladium. When the hydrogen is occluded in the palladium, an analogous expansion within the rough metal film permanently increases the cross section at the junctions and reduces the resistance despite the accompanying increase in resistivity. Having become more homogeneous, the film exhibits the temperature coefficient of a metallic conductor.

This phenomenon was first observed in the fall of 1947 at Argonne National Laboratory, when NEPA conducted radiation damage tests on electronic components under the direction of Mr. E. S. Bettis and Dr. E. R. Mann. In these tests, and again recently at the Oak Ridge pile, the vitreous enamel covered palladium film

[4] 'Notes on the Charging of Palladium with Hydrogen', R. H. Kernohan, Memorandum Report PL-MR-1, E. E. Dept., University of Illinois, Urbana, Ill.

resistors of Continental Carbon were exposed in jackets of paraffin, polystyrene, graphite, cadmium and aluminum. The resistance decreased substantially in the case of the hydrogenous covered resistors, sometimes to 4% of the initial value. The agreement in the results between resistors of the same value exposed under identical conditions was poor, and it seems probable that this was due to variations in the thickness of the protective vitreous enamel. Under the same bombardment the resistors covered with graphite, aluminum and cadmium did not suffer an appreciable change in resistance.

A resistor which had been irradiated within polystyrene so that its resistance had been reduced to 16,500 from 50,000 ohms was removed from the polystyrene, and placed within a thick aluminum jacket, and irradiated again in the Oak Ridge pile. In six days the resistance had dropped to 1,200 ohms. The Argonne tests also show that when a paraffin coated resistor is placed within the pile, the resistance commences to fall only after the pile power is brought up, but after the pile is shut down, the resistance continues to decrease. Apparently once a resistor has been bombarded by recoil protons, a migration of the hydrogen trapped within the ceramic is sustained by gamma radiation after the neutron flux is cut off.

NEUTRON ENERGY SPECTROMETER

B. R. Gossick, K. Henry*; Technical Division*

The NEPA proton recoil neutron energy spectrometer has now been installed at ORNL (Fig. 1). Protons emerging from a hydrogeneous radiator are detected with a proportional counter. The counting rate is recorded with different thicknesses of aluminum absorbers interposed between radiator and counter, and the neutron flux distribution in energy is obtained by a mathematical analysis of these data. Calibration measurements with Pu^{239} alpha particles in a proportional counter designed for an average collimation error of 2.7% gave good agreement with measurements made at NEPA. A similar counter is now being built in which resolution is sacrificed in favor of increased sensitivity. This tube will have an average collimation error of 9.1%.

Table 1 has been calculated to illustrate the order of resolution which can be obtained with this instrument. The first column gives the number of counts per hour to be expected, per cm^2 of radiator, when the instrument is

* NEPA personnel.

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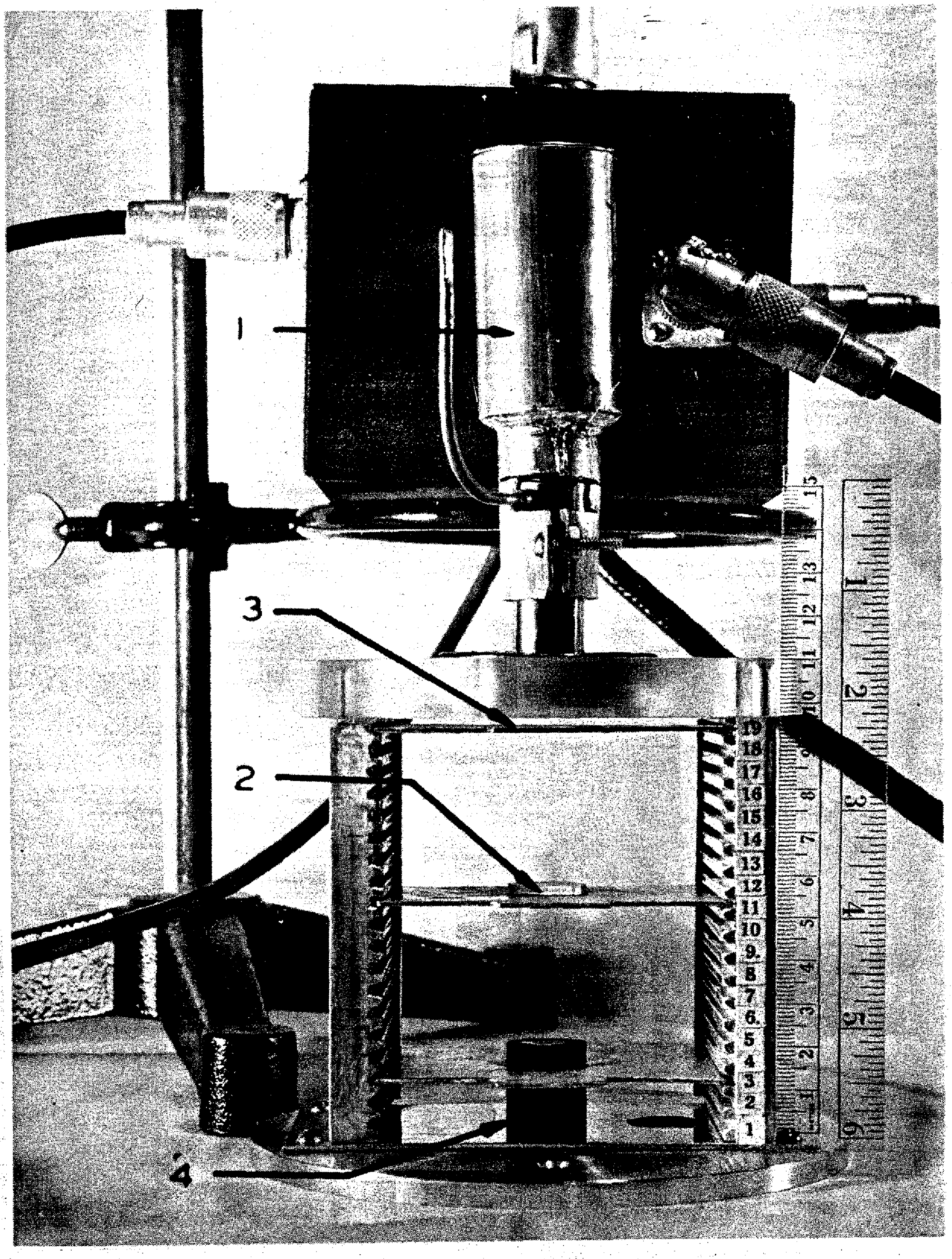

FIGURE 1. NEPA PROTON RECOIL DETECTOR ASSEMBLY

Protons from the hydrogeneous radiator (2) are detected in the proportional counter (1). The counting rate is recorded with different thicknesses of aluminum absorbers (3) interposed between the radiator and the counter. From these data the neutron energy distribution is inferred. In this photograph the instrument is being calibrated with neutrons from a Po-Be source (4).

TABLE 1

Energy Resolution in the Neutron Recoil Spectrometer

COUNTS PER cm^2 per hr	AVERAGE ERROR COLLIMATION	ENERGY SPREAD RADIATOR	MEV ENERGY INTERVAL
$.026 \int_{0.8}^{1.0} \phi(E)\, dE$	9.1%	10%	0.8 - 1.0
$.156 \int_{4.5}^{5.5} \phi(E)\, dE$	"	"	4.5 - 5.5
$.38 \int_{9.0}^{11.0} \phi(E)\, dE$	"	"	9.0 - 11.0
$.0066 \int_{0.8}^{1.0} \phi(E)\, dE$	2.7%	"	0.8 - 1.0
$.040 \int_{4.5}^{5.5} \phi(E)\, dE$	"	"	4.5 - 5.5
$.096 \int_{9.0}^{11.0} \phi(E)\, dE$	"	"	9.0 - 11.0

placed in a neutron flux $\int \phi\ (E)\ dE$. From this the standard deviation can be obtained, after a choice is made of the time which can be allowed for a desired count and of the area over which the flux can be measured.

Calculations of energy spread due to thickness of the hydrogenous radiator are based on the stopping power calculations for paraffin by Hirschfelder and Magee (MDDC 115). However, polystyrene radiators are being used because of their more uniform thickness. Preliminary measurements of the relative stopping power of polystyrene, made by Mr. Keith Henry, indicate that 1.2 mg/cm^2 thickness of polystyrene is equivalent to 1 cm of air, which checks within 6% of the corresponding value based on the proton-energy curves of Livingston and Bethe, *Rev. Mod. Phys*. *9*, 245 (1937) for air, and the tables of Hirschfelder and Magee for paraffin.

SHIELDING MATERIALS

T. Rockwell, Technical Division

Pb-B-H_2O System. It seems reasonably certain at this time that a nearly miniweight shield will consist of a heavy metal, hydrogen, and boron. *Lead* seems to be enough better than iron and not unequivocally inferior to tungsten, gold, and other more exotic materials so that attention can be profitably focused on it for some time to come. *Boron* and B_4C (80% B) have very similar properties and the latter, costing only 2% as much as boron, can be used as a stand-in for it in fabrication studies. *Hydrogen* has been the subject of considerable investigation: hydrides, hydroxides, hydrates and organics have been studied at NEPA, in this group, and elsewhere. Most of them have little more hydrogen density than water, and the problem of stability under operating conditions of temperature, radiation, and atmosphere, is a serious one. Water, flowing through a lead-boron compact, makes a shield which is radiation-stable, heat dissipating, and reasonably easy to fabricate.

Therefore, preliminary exploration of the Pb-B-H_2O system was begun this quarter. A ternary diagram, with lines of constant density (Fig. 2) shows the possibilities of the system. Several methods of fabrication suggest themselves. Lead and boron can be co-pressed hot to form a material similar to "Boral". Several such compacts were made, and cooling channels were placed in some, to give a shield specimen approximately 15% H_2O, 30% B, and 55% Pb by volume.

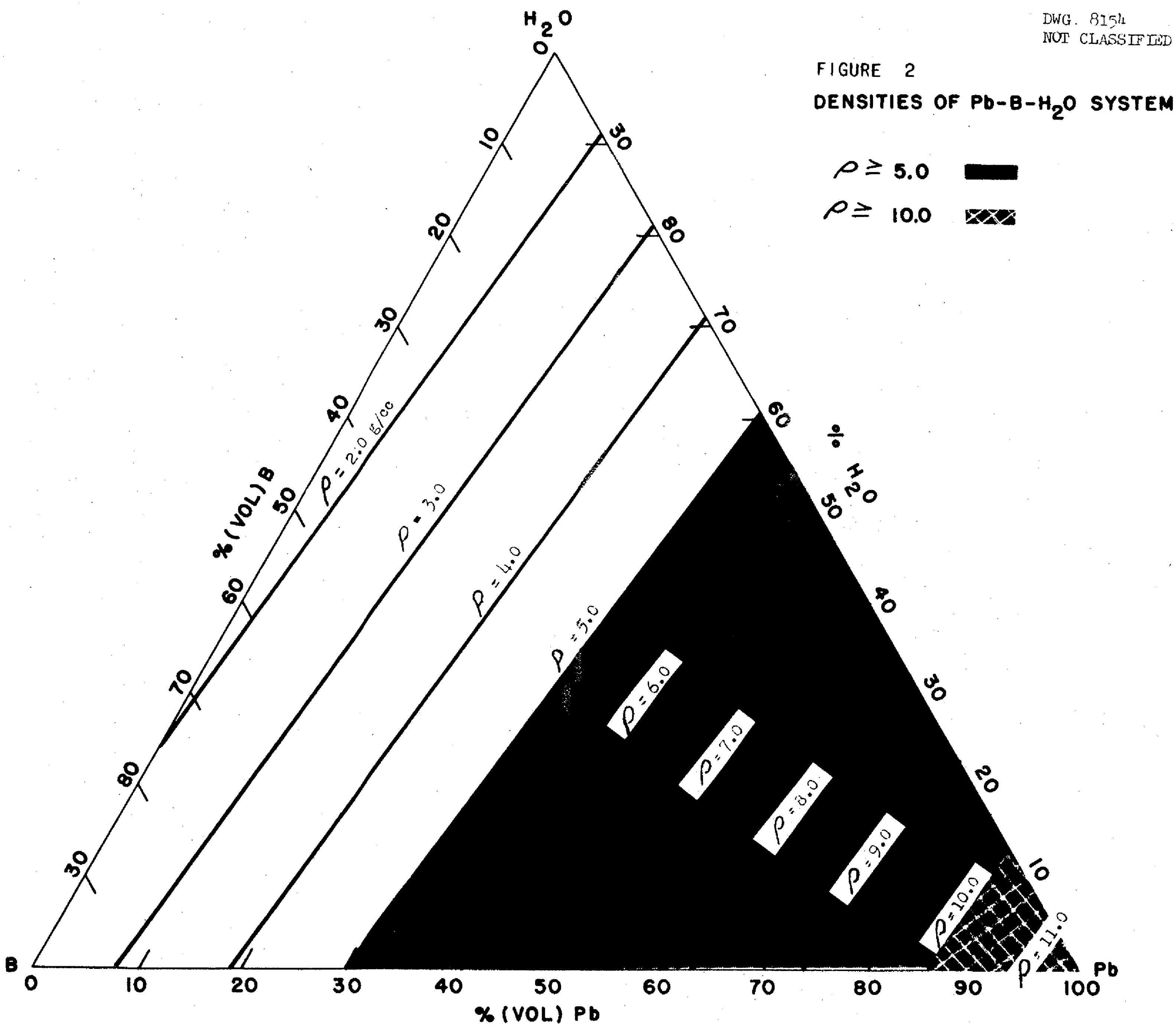

FIGURE 2

DENSITIES OF Pb-B-H_2O SYSTEM

22

Somewhat higher boron concentration and, of course, any water fraction can be obtained. It is believed that similar systems could be built up of tungsten rods flash-sintered together, with water cooling channels between them, and that metallurgical grade B_4C "gravel" could be used with mercury cooling. The stability of such systems, contrasted with chemical compounds, is a marked advantage.

Boral. The 250 sq ft sheets which were to be rolled at Lukens Steel Co. this quarter were delayed by the steel strike, and are now scheduled for completion during November. Some difficulty has been encountered in fabricating specimens for the precise thermal conductivity tests, but it is hoped that this will be completed this quarter. The irradiation of three tensile specimens has been completed up to nearly 4×10^{18} *nvt* (three months in the ORNL isotope stringer) and the only change has been a continuous increase in strength, up to 150% of the original. New specimens are being irradiated and a request for irradiation at Hanford has been filed. This material seems destined to play an important role in many reactors and a report covering the above three phases will be issued soon, to supplement ORNL 242, the first topical Boral report.

One of the group has been working at NEPA, learning new techniques of hot-pressing and other fabrications appropriate to boron and boron carbide in combination with soft metals such as lead and aluminum.

The first irradiation specimen of "Boroxal" (B_2O_3 and Al) does not seem to be faring as well as Boral, which is not surprising, since B_2O_3 is the continuous phase in the former, whereas Boral derives its structural strength from a continuous aluminum matrix. The Boroxal specimen showed a significant decrease in strength, which will be reported after later specimens are examined.

Boron Plastic. A mixture of clear Tygon (a plastic paint) and B_4C has been made to form a sheet mechanically similar to leather, containing 50% B by volume. Sheets five feet square and one-eighth inch thick are being fabricated for the lid-tank attenuation testing facility, to study the effect of coating the metal in a metal-water system, with a thin coat of boron to absorb the neutrons which have been degraded in the metal and immediately thermalized in the water. These sheets can be glued to iron, lead, or tungsten sheets, and removed at will. They are strong, light, and flexible and should find use in many places throughout the project. A topical report will be written.

Boron Production and B^{10} Separation. The literature was surveyed and a few runs were made to produce BCl_3 from B_2O_3 with HCl and a dessicant, and later with Cl_2 and C as chlorinating agents. Temperatures up to 1000° F were tried without interesting yields and the project was shelved for lack of manpower. At the request of this section, some rough calculations were made by R. Zirkind of BuAer, USN, of the effect of increasing the B^{10} content in a boron shield. Preliminary results are encouraging and the survey of the possibility of producing cheap tonnage-lot B^{10} was also promising.

Concretes. Of general interest to reactor technology is the work on concretes. Laboratory tests on barytes concrete (density 3.5) for hot laboratory shielding have been completed by the group and by the Skidmore-Owings-Merrill testing staff. Field tests have been carried out by J. A. Jones and the Austin Company, and results at this date seem very satisfactory. A topical report will be issued by ORNL Engineering Division.

Several trial pours of MO concrete test slabs, 3 in. × 56 in. × 66 in. for the attenuation testing facility, have been made, with increasing success each time. Vibration placement, as is planned with field pours, has been made possible by procurement of a small electric internal vibrator. A satisfactory technique now appears to be available and will be used when samples are requested by the attenuation group. Density can be varied within quite a wide range (~ 5.0 to 6.3 g/cc) by varying the ratio of steel punching to steel curlicues (turnings), which prevent the punchings from packing as compactly. Densities up to 7.0 are anticipated (if desired) on thicker slabs.

Work on silica gel (97% H_2O) was continued, then shelved for lack of manpower. If kept wet, silica gel seems to have most of the desirable properties of water (high-hydrogen content, thermal stability, probable radiation stability, negligible cost) with some mechanical strength. Various tests, with and without aggregate, were performed.

Aggregate studies, including cost, availability, density, and strength of concrete, were run on Birmingham limonite Montana taconite, and Tennessee barytes.

Steel bricks have been ordered for shielding the MTR Mock-Up. Samples 2 in. × 4 in. × 8 in. with various surface treatment are also being prepared as possible alternates for lead bricks. Intensive follow-up on cost estimates have lowered the price from $9.00 to $1.45 per brick, in quantities, delivered.

Fundamental work on concretes and cements was continued at a very low manpower level. Shrinkage and expansion tests, aggregate grading calculations, moisture content under different conditions of temperature and humidity, are being studied.

ORNL 243, an extensive survey of cheap shielding materials, is being issued. A "final" report on oxychloride concretes will follow. The material originally written for the special shielding issue of *Nucleonics* is being published as a classified report prior to declassification.

HEAT TRANSFER

Technical Division

Work on heat transfer during the past quarter has included an abridgment of ORNL 156, a theoretical study of heat transfer in annuli, and a small experimental study which disproved the existence of "polarized turbulence". The physical properties which control the heat transfer characteristics of molten sodium hydroxide have also been investigated. Experimental liquid metal heat transfer studies, which were inactive this quarter will be resumed next quarter.

HEAT TRANSFER SUMMARY

*W. B. Harrison**

The summary of atomic energy heat transfer work, ORNL 156, has been brought up to date and abridged for publication as an unclassified document. It was felt that much of the information contained in the original report should be made available to industry and the entire engineering field. This was impossible in its original form, but by deletion and rewording, the major portion has been converted to a useful source book which discloses no classified information. The revised manuscript is being given its final editing, and then will be submitted for declassification.

HEAT TRANSFER IN ANNULI

R. Bailey

Heat transfer in annuli was studied by Dr. Raymond Bailey who was on leave to the Laboratory this summer from the University of Mississippi through the Oak Ridge Institute of Nuclear Studies. As a result of his work a new heat transfer relationship is available which satisfies experimental results with liquid metals for the first time for all cases where liquid wets the wall. The studies have important implications for heat transfer in annuli with all fluids. In the course of his investigation it was necessary for Dr. Bailey to develop a knowledge of the flow distribution in annuli with very meager data. A final report on this work will be issued shortly as ORNL 521.

* Consultant, from Department of Chemical Engineering, University of Tennessee.

Bailey's equation is:

$$Nu = Nu_s + .0106\ R^{.37}\ (Pe)^{.86}\ ,$$

where

$$1/Nu_s = \{1/[8B(R+1)^2]\}\ \ [-3-12B-14B^2-4B^3+4(B+1)\ \ln R].$$

B = Inner radius of annulus divided by the difference between inner and outer radius.

R = Outer radius divided by inner radius of annulus.

POLARIZED TURBULENCE

E. Sparrow

Reports by other investigators have indicated that under certain conditions the turbulence in rectangular channels of large width to thickness ratio might be polarized; that is, the turbulence might occur only in planes parallel with the width of the channel and having no component parallel with the thickness. Should polarized turbulence be possible a way would open for a number of fruitful hydrodynamics studies. Experiments were conducted to prove or disprove this conclusion, and it was found that no polarized turbulence occurs. In addition, it was found that the mixing depthwise in the channel occurs at approximately the same linear rate as does the mixing across the width of the channel. Photographs of ink threads in the channel from two points of view were obtained simultaneously which illustrate the result of the experiment. The report, ORNL 471, has been issued covering this work.

PHYSICAL PROPERTIES OF MOLTEN SODIUM HYDROXIDE

A. S. Kitzes

Interest in liquid NaOH as a pile coolant has raised the question as to its heat transfer characteristics. A review of the literature revealed data on the density and viscosity of liquid NaOH, but no data on thermal conductivity or heat capacity. Therefore, the thermal conductivity and heat capacity for liquid NaOH were determined experimentally. The data are summarized in the following table. Density and viscosity data which were abstracted from the literature are also included as reference material.

DENSITY (gm/cc)	TEMP. (°C)	VISCOSITY (centipoise)	TEMP. (°C)	THERMAL CONDUCTIVITY (BTU/hr ft^2 °F/ft)	TEMP. (°F)	HEAT CAPACITY (BTU/lb - °F)	TEMP. (°F)
1.786	320	4.0	350	1.9	720-	0.27	800-1000
1.771	350	2.8	400		900		
1.746	400	2.2	450				
1.722	450	1.8	500				
		1.5	600				

The density and viscosity data were determined by Arndt and Ploetz, *Z Phys. Chem.* 121, 439 (1926).

The reported values are averages of a number of runs and are believed accurate within 20%. The set-up for the thermal conductivity measurements was calibrated by determining the thermal conductivity of water at 95° C. Good agreement was found between our values and those reported in the literature for water. The heat capacity set-up was checked by determining the specific heat of lead. Again good agreement was found with reported values.

The heat transfer coefficient of liquid NaOH was not determined. However, the coefficient can be predicted approximately from Lyon's equation (ORNL 361) for high Reynolds' number and from the Dittus-Boelter equation for low Reynolds' number.

It was also noticed during the course of the thermal conductivity and heat transfer experiments that liquid NaOH in the presence of oxygen corrodes 303 and 304 Stainless Steel. Fe_2O_3 was found in the NaOH and also, green and yellow deposits were found on the walls of the equipment. The NaOH apparently attacks and removes the chromium from the stainless steel.

THE LIQUID METALS PROGRAM FOR ANP

R. N. Lyon

One of the proposed systems for reactor powered aircraft is to transfer the heat generated in a nuclear reactor to air passing through a turbojet engine by circulating a liquid metal. The development of such a system can be broken down into a number of problems which are listed below, not necessarily in the order in which they should be attacked:

1. Selection of liquid metal;
2. Selection of container and component materials;
3. Development of handling and flow control methods,
    a. Pumps,
    b. Valves,
    c. Pipe Joints;
4. Study of heat transfer characteristics of liquid metals;
5. Preliminary design of system;
6. Mock-Up and testing of preliminary design;
7. Final design.

The selection of the liquid metal appears to be between bismuth or lead-bismuth alloy and the mass seven isotope of lithium. Other possible contenders have been eliminated largely on the basis of their induced activity which would require shielding of the piping and liquid-to-air heat exchanger.

The selection of container materials must be made on the basis of high temperature strength and corrosion resistance to the liquid. In addition, materials to be used in the reactor itself must have a low capture cross section for neutrons.

The development of pumps for this system involves a number of considerations not previously encountered. Electromagnetic pumps, which show considerable promise in handling sodium and sodium-potassium, are less efficient when used for lead-bismuth or lithium, because of the lower electrical conductivity of these liquids. In addition, large electrical generating equipment will be required while mechanical pumps can be driven directly by a power take-off from the turbojet rotor. Thus it appears that mechanical pumps are to be favored over the electromagnetic type.

While considerable progress has been achieved at other installations in the development of pumps for sodium alloys at high temperatures, the consideration of lightness, compactness, and the higher temperatures required together with the attack of nickel alloys by lithium and lead-bismuth, indicate the need for a relatively independent program for ANP.

To a large extent, the development of a suitable mechanical pump depends on the development of suitable bearings and/or a suitable shaft seal. It is in this direction that work will first proceed.

The same situation applies to the development of valves and pipe joints, although to a lesser degree. Temperatures up to 1800° F are currently being considered for the aircraft power plant, while temperatures of only 1000 to

1200° F are planned in other liquid metal cooled reactors. As a result, more intensive development is needed to provide satisfactory solutions to the valving and joining problems in the aircraft system.

To work on these mechanical handling problems, a new group is being set up in the Technical Division. Space is being set aside and technical men are being recruited for this work. Study of the heat transfer characteristics of liquid metals is being resumed with increased emphasis, both on a theoretical and on an experimental basis.

The liquid metal heat transfer group is being enlarged and design of a relatively high pressure-high flow heat transfer system will be started almost immediately. The theoretical study of liquid metal heat transfer, which has proved remarkably fruitful in the past, will be resumed and intensified. Close liaison will be maintained between the theoretical and experimental work, however.

Design and construction of a Mock-Up of the heat transfer system at one of the cooperating sites will permit testing of the components under more nearly true operating conditions as well as determining conclusively the feasibility of the overall system.

METALLURGY AND MATERIALS

J. H. Frye, F. Kerze, E. C. Miller; Metallurgy Division

The Metallurgy Division is undertaking the development of aircraft reactor materials for use at high temperatures in the presence of liquid metals or other potential coolants. Close liaison is being maintained with NEPA to coordinate the programs and to avoid duplication of effort. It is believed that this Division can make its most effective contribution by concentrating on fundamental liquid metal corrosion studies, mechanical testing of materials in molten metals at elevated temperatures, and investigating the fabrication and cladding of selected materials.

In the initial phases of this work, selected elements with high temperature possibilities—iron, nickel, cobalt, molybdenum, chromium, zirconium, titanium, beryllium, tungsten, tantalum, columbium, vanadium, and silicon—will be corrosion tested in molten lithium and in molten bismuth at 1800-2000° F and higher, to effect a sorting on the basis of relative corrosion behavior. The work may be extended later to include other coolants such as lead-bismuth alloy, sodium hydroxide or gases.

On the basis of the preliminary tests, the more promising metals and their alloys will be subjected to quantitative corrosion tests to investigate the influence of such factors as atmosphere composition, contamination of liquid metal, surface condition, wetting behavior, and dynamic corrosion.

The selected metals and their alloys will also be investigated to determine their high temperature mechanical properties and the feasibility of their *fabrication*. This will involve creep and stress-rupture tests in liquid metal and other environments, as well as methods of shaping, welding, and other means of joining. Molybdenum and low carbon iron already appear to have good corrosion resistance in bismuth, and probably in lithium. Because of this and its high-temperature strength, molybdenum will be the first metal studied in this manner. The unfavorable high temperature oxidation behavior of molybdenum will also require corrosion investigation at low oxygen pressures, and a study of the possibility of reducing this oxidation by addition of alloying elements.

The ideal constructional material would be a single metal or alloy possessing a combination of high temperature strength, oxidation resistance, and freedom from corrosion by the liquid metal coolant (plus, of course, the desired nuclear and heat transfer properties). Every effort will be made to find such a material, but recognizing that this may not be possible, concurrent efforts will attempt to develop a composite material in which a protective coating of a coolant resistant metal is applied to one of the more conventional or recently developed high temperature and oxidation resistant alloys. Diffusion, forming, and joining of these composite materials will also be investigated.

In the first experimental work, immediately available materials have been used to set up a resistance tube furnace in which specimens can be corrosion tested in a crucible of molten bismuth at about 1800° F in either vacuum or argon. This furnace is not adaptable to lithium.

Preliminary qualitative tests were made, primarily to establish furnace techniques, using beryllium, nickel, and stainless steel No. 309. Beryllium appears to have good resistance to molten bismuth; nickel, as was expected, dissolved completely; and S.S. 309 showed some signs of attack. However, the set-up proved cumbersome, the maximum attainable temperature was too low, and the desired variety of samples was not immediately available.

Efforts are now being concentrated on a procedure to charge the specimens into sealed evacuated iron capsules containing the coolant metal. The capsules will then be charged into a conventional tube furnace with available temperatures up to 2500° F. This should be in operation by the first week of December.

Steps are also in progress to design and build suitable equipment for wettability tests, controlled atmosphere and dynamic corrosion tests, and stress-rupture and creep investigations.

Three of the Laboratory's consultants, Professors E. C. Creutz of Carnegie Institute of Technology, J. L. Gregg of Cornell, and N. J. Grant of Massachusetts Institute of Technology, are actively assisting in the collection and evaluation of data on the fabrication and cladding of high-temperature alloys for resistance to liquid metals.

RADIATION DAMAGE

D. S. Billington, Metallurgy Division; M. Bredig, Physics Division

REACTOR CORE MATERIAL STUDIES

Personnel. The Radiation Damage group of the Laboratory has had a group of 5 men from NEPA for well over a year. In the course of this time they have acquired considerable experience in various aspects of radiation damage, such as radiation hazards and safeguards, hot laboratory operation, design and operation of remote-controlled apparatus for use in a hot laboratory, techniques for "in pile" experiments, cooperation in design of "in pile" experiments, investigation of radiation effects in certain selected materials, and an introduction to the theory of radiation damage through lectures by various staff members, plus a current lecture series by Dr. Evans on Solid State Theory. In addition to practice in the use of a nuclear reactor, some of the trainees have gained experience in designing experiments for supplementary studies using accelerators such as the Van de Graaff and the cyclotron. Finally, some of the trainees have participated to some extent in the design criteria for a new hot laboratory facility.

In a recent augmentation of this training program, three additional men from NEPA will join the staff of the Laboratory. The above training program has engaged the attention of many of the ORNL group and has involved all of them at one time or another. It is a pleasure to acknowlege that the NEPA personnel have contributed in large measure to the solution of numerous problems of the ORNL Radiation Damage Program.

Cooperative Program. NEPA has been investigating certain ceramic combinations that appear feasible for use as fuel elements, provided the elements will hold up under reactor conditions. ORNL has undertaken to make radiation damage studies on these proposed fuel elements. The first ceramic body now under test is beryllium-carbide (the moderator that ultimately is expected to be combined with uranium compounds to make up the fuel element for the air-cooled reactor). It is important to learn if this material will prove suitable, as its other properties appear excellent.

Preliminary experiments are underway in the ORNL reactor studying the electrical resistivity during irradiation and such properties as modulus of elasticity, hardness, and coefficient of thermal expansion before and after irradiation.

A NEPA-designed thermal conductivity apparatus is at present being studied in the ORNL reactor. This and similar experiments will serve as feasibility experiments for more elaborate experiments making use of the Hanford Reactors.

Exposures of Be_2C bodies to Hanford flux will be made in the near future. These bodies will be studied before and after irradiation at Hanford. Properties to be measured are: stored energy, modulus of elasticity, annealing characteristics, coefficient of thermal expansion, dimensional stability, surface effects (semi-conductor properties) and thermal conductivity. Should the damage characteristics of Be_2C appear suitable, then UO_2 and/or UC will be added and the mixture studied as an active fuel element.

The complete program calls for the study of a number of possible components for fuel elements, each of which will eventually be studied both separately and together. A fuel element normally consists of three essential components: the fuel, the moderator and the coating. The study of the best form (physically and chemically) for each of these is a complex problem and involves an immense number of variables. Combinations under consideration are:

1. Carbon bonded graphite - uranium bodies
2. Beryllium carbide matrix - uranium bodies
3. Metal-ceramic bodies containing uranium
4. Beryllium oxide matrix - uranium bodies
5. Materials above plus suitable coatings such as iron-chromium or metallic Si.

To augment this essentially engineering approach, the ORNL group plans to make a study of the general problem of high temperature damage. It is felt that single crystal studies should be particularly useful; not only of the materials mentioned above, but also of compounds that may lend themselves more readily to experimental manipulation. Also, the data may be more amenable to theoretical and practical interpretation. These studies would include metallic systems.

In addition, experiments with the Van de Graaff accelerator are underway with the objective in mind of studying separately the various types of damage to be expected.

Facilities. The following facilities are available to the ANP Radiation Damage Program:

1. The X-10 reactor
2. Hot laboratory in Building 105
3. Hot chemistry cells in Buildings 706-C and 706-D

4. The Van de Graaff accelerator - electron and proton beams
5. Brookhaven reactor - an investigation of the practicability of using this reactor has been made and when this reactor is in service, use will be made of certain facilities
6. Hanford reactors
7. Metallographic and fabrication facilities of the Metallurgy Division
8. Shop facilities in Physics Building, Metallurgy Building, plus general Machine Shops.

AUXILIARY MATERIAL STUDIES

O. Sisman, C. D. Bopp, Technical Division

Metal Hydrides. In cooperation with NEPA, the radiation induced dissociation of titanium hydride was determined by comparison of the dissociation pressures obtained under radiation with those obtained under normal conditions for a series of temperatures.

The apparatus consisted essentially of a furnace for heating the sample above normal pile temperatures, and gauges for observing the pressure. A sample of stoichiometric titanium hydride (TiH_2) contained in a stainless steel reaction tube was placed in the furnace, which was then inserted in the pile. Small bore tubing was used to connect the reaction tube to the gauges outside the pile.

After the apparatus had been evacuated and flushed several times with purified hydrogen, measurements were begun. The furnace temperature was maintained at a constant value and the sample allowed to decompose until it appeared that equilibrium was established. Observations of the dissociation pressures were made in this manner over the temperature range from 160° C to 340° C during 1,800 hours in the pile at an estimated average flux of 0.5×10^{12} neutrons/(cm^2)(sec).

Results indicate that little, if any, radiation-induced decomposition occurred with this hydride.

Similar experiments are now underway to determine the effect of pile radiation on the stability of lithium hydride and zirconium hydride, and to get further data on two compositions of titanium hydride ($TiH_{1.78}$ and TiH_2).

Plastics. The changes in physical properties of commercial plastics are being studied because of the desirability of plastics in reactors as instrument insulators, flexible tubing, protective coatings and components of experimental and testing equipment. The importance of this program has increased greatly with the possibility of radio and electronic controls in the relatively intense radiation field in proposed remotely controlled mobile reactors.

Quantitative information on the tensile strength, impact strength, elastic modulus, percent elongation, hardness, density, and water absorption after various irradiation dosages in the ORNL reactor has been obtained for a wide range of commercial plastics, and these tests are continuing in order to provide sufficient information for graphs of properties versus dosage for all of the materials.

Electrical properties such as resistivity, dielectric strength and arc resistance are also being determined.

Table 2 provides an indication of the wide range in the resistance of various plastics to irradiation by neutrons. Except where the material becomes unusable the ratings in this table are based on change in strength with radiation rather than actual strength. Thus for a given purpose Bakelite reinforced with paper or linen might be preferred to polystyrene, even though the latter undergoes essentially no change.

The following plastics crumbled after irradiation by 10^{18} n/cm^2:

Casein
Cellulose Acetate
Cellulose Acetate Butyrate
Cellulose Nitrate
Ethyl Cellulose
Fluorothene
Lucite
Teflon

It is expected that within the next four to six months, sufficient data will have been accumulated to permit publication of the quantitative information in a topical report which will include graphs and tables to present the physical and electrical properties of plastics after a wide range of reactor exposures.

Sodium Hydroxide. Interest in sodium hydroxide as a possible pile coolant has raised the question of the stability of molten sodium hydroxide to pile radiation. For a quick exploratory test, six 0.5 gm samples of sodium hydroxide pellets were sealed in 3.5 cc glass ampules and placed in the pile. Three ampules were kept in the pile for one week, and three were kept in for

TABLE 2

Change in Strength upon Irradiation
by 1-2 × 10^{18} n/cm^2 at 40° C

	RESISTANCE TO CHANGE IN TENSILE STRENGTH	RESISTANCE TO CHANGE IN IMPACT STRENGTH	REMARKS
Polystyrene	Excellent	Excellent	
Styron	Excellent		
Furfuryl Alcohol Polymer	Excellent	Good	
Haveg (asbestos and Bakelite)	Good	Excellent	
Nylon	Excellent	Fair	
Poly Ester Plastic	Excellent	Fair	Initial tensile strength low, but increased by factor of 5 on irradiation.
Allyl diglycal carbonate	Fair	Excellent	
Vinyl chloride Acetate	Fair	Good	
Melamine Plastics	Fair	Good	
Bakelite (paper reinforced)*	Fair	Fair	Initial tensile and impact strength very high after irradiation. Impact strength similar to polystyrene. Tensile strength higher than polystyrene
Bakelite (linen reinforced)*	Fair	Fair	
Saran	Poor	Poor	Unlike most plastics, Saran softens on irradiation.

Excellent - essentially no change; Good - reduction by less than 50%; Fair - reduction by more than 50%; Poor - unusable after irradiation.

* Presence of water during irradiation causes complete breakdown of bakelite.

four weeks. The one week samples showed no gassing, but the 4 week samples produced a considerable quantity of gas. Results are given in Table 3.

These samples were not molten during irradiation, but, for each set of three samples, one was melted before sealing the ampule, one was melted after irradiation, and the third was not melted. All three ampules were sealed at atmospheric temperature and pressure. The samples were tested for gassing by breaking the ampules in a sealed container and measuring the volume of escaping gas on a manometer.

Fast Flux in Hole 19. To compare the radiation damage done in Hole 19 of the ORNL reactor to the damage done in other reactors it is necessary to know the neutron flux spectrum in Hole 19. This spectrum (Fig. 3) has been determined by a method employing threshold detectors. From this spectrum the fast flux (above 1 Mev) was evaluated as 0.11 neutrons/(cm^2)(sec)(watt). The epithermal flux was evaluated, by a method employing cadmium ratios, as 5.3×10^5 neutrons/(cm^2)(sec)(watt).

Threshold detectors are isotopes that react only with neutrons having kinetic energy above an individual threshold energy for the detector. Above this threshold energy the probability for the reaction increases until it reaches a constant value. The effective energy for the reaction is the fictitious threshold energy arrived at by assuming that the cross-section curve has a square cut-off at a minimum energy, instead of the actual gradual decrease to zero.

The threshold reactions listed in Table 4 were employed to plot the spectrum of Fig. 3 by a method of successive approximations. (This method will be described in ORNL 525.) In Table 4 the average cross section of the isotope for the flux above 1 Mev is also listed. In Fig. 3 the ratio of the specific flux nv_E to the total thermal flux nv' is plotted against energy. Points are plotted at the effective energies of each of the threshold reactions as given in Table 4.

The $1/E$ region of the spectrum in Fig. 3 was determined by the method given in CP 3781 from the cadmium ratios given in MonC 398. (This method also will be described in ORNL 525.)

The thermal flux in Hole 19 was determined by activation measurements of cobalt foils. Several measurements gave an average value of 3.0×10^5 neutrons/(cm^2)(sec)(watt).

High Intensity Gamma Source. In order to intelligently design reactor auxiliaries, electrical control systems and radiochemical processing equipment,

TABLE 3

Radiation Stability of NaOH

SAMPLE	THERMAL NEUTRON DOSAGE (n/cm^2)	THERMAL FLUX $[n/(cm^2)(sec)]$	GAS PRODUCED cc/gm AT 25° C, 760 mm Hg
Melted before irradiation	1.35×10^{17}	0.27×10^{12}	None
Not melted	1.35×10^{17}	0.27×10^{12}	None
Melted after irradiation	1.35×10^{17}	0.27×10^{12}	None
Melted before irradiation	5.80×10^{17}	0.27×10^{12}	19.8
Not melted	5.80×10^{17}	0.27×10^{12}	67.5
Melted after irradiation	5.80×10^{17}	0.27×10^{12}	ampule exploded while being heated

DWG 8155
[redacted]

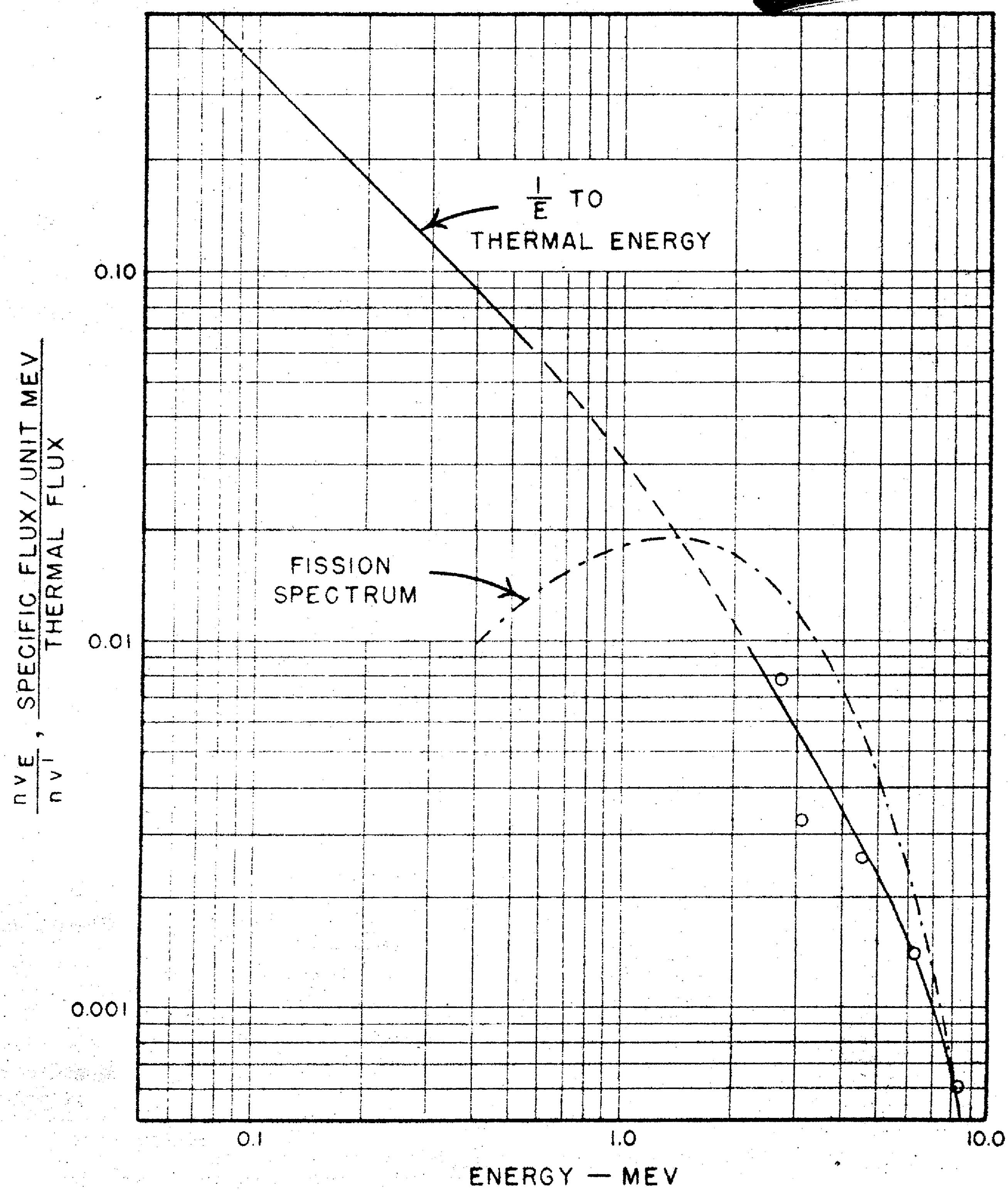

FIGURE 3 NEUTRON SPECTRUM FOR HOLE 19
ORNL REACTOR

TABLE 4

Reactions Used to Determine Fast Flux

REACTION	EFFECTIVE THRESHOLD IN MEV FOR PILE SPECTRUM	σ_{av} IN BARNS FOR PILE SPECTRUM	RATIO FOR THE PILE SPECTRUM OF THE FLUX ABOVE 1.0 MEV TO THE THERMAL FLUX	REFERENCES FOR CROSS-SECTION DATA
Al^{27} (n, α) Na^{24}	8.1	0.0010	0.039	CF 3574
Mg^{24} (n, p) Na^{24}	6.5	0.0017	0.035	"
Al^{27} (n, p) Mg^{27}	4.5	0.0035	0.033	"
S^{32} (n, p) P^{32}	3.1	0.14	0.022	LA 515
P^{31} (n, p) Si^{31}	2.7	0.029	0.042	MDDC 360
By integration of the pile spectrum curve			0.036	

a knowledge is needed of the effect of gamma irradiation free of neutrons. To obtain such information, equipment for producing a high intensity gamma source by irradiating cylinders of gold in the pile has been built and is now being assembled in the laboratory for testing.

It is expected that this apparatus will be installed in the pile and be in operation before the first of the year. Gamma ray fluxes above 10^6 r per hour are expected.

Beta versus Gamma Dosage. The effort to correlate beta and gamma irradiation effects has been continued. It is hoped that with such a correlation, the effects caused by large gamma dosage can be predicted from the behavior of materials under beta irradiation. This will greatly aid in conducting and interpreting irradiation experiments using sources which emit both gamma and beta emanations.

The experimental tests have now been completed and the correlations for a final report are underway.

Lubricants (California Research Corporation). The ORNL reactor has also been used by the California Research Corporation for an extensive series of irradiations of special oils and other possible lubricants for aircraft reactor accessories, under a NEPA contract. The results of this work are given in NEPA reports.