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PHYSICS OF SOLIDS INSTITUTE

QUARTERLY PROGRESS REPORT

FOR PERIOD ENDING JANUARY 31, 1951

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J. H. Frye, Jr., Director

PHYSICS OF SOLIDS INSTITUTE

D. S. Billington, Acting Director

QUARTERLY PROGRESS REPORT
for Period Ending January 31, 1951

Edited by

D. S. Billington and J. T. Howe

DATE ISSUED:

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INTRODUCTION AND SUMMARY

This report covers work performed in the Physics of Solids Institute of the Metallurgy Division for the period Dec. 1, 1950 to Jan. 31, 1951.

Building Status

Occupation. The new building was occupied during the latter part of December although construction and modification will continue for some time.

Hot Cells. None of the cells are at present complete. Some of the remote-control equipment has been brought to the building preparatory to installation.

Solid-State Reactions

New Pile-Loading Facility. A new pile-loading facility which will permit exposures of samples with leads attached for periods of ½ hr or greater has been installed in the X-10 reactor. A cable-driven cart carries the sample in and out during reactor operation. External shielding has been substituted for the graphite stringer formerly used.

Bombardment of Cu_2O Plates. Former data reported on the effect of pile bombardment on the electrical properties of Cu_2O have been shown to be affected by changes in the lead wire insulation used in the experiments. Latest experiments now indicate that for pile exposures up to 15 days the resistance of Cu_2O increases monotonically and approaches a high saturation value. The initial slope of the conductivity-vs.-bombardment curve has been shown to be somewhat linear although not so linear as in the case of germanium.

Bombardment of Cu_2O Rectifiers. Cuprous oxide rectifier experiments have been continued.

Single-crystal Cu-Cu_2O rectifiers are being prepared to study the effects of crystallographic orientation on the rectifier properties. It is hoped that a knowledge of the anisotropy of the chemical potential of copper can be correlated with the conductivity changes observed in Cu_2O on neutron bombardment.

Low-Temperature Bombardment of P Type Germanium. Investigation has been made into the temperature dependency of rate of conductivity change for P type

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germanium under bombardment. Rate of conductivity change was found to be dependent on temperature as indicated by the theory of semiconductors. Rate of conductivity change is thought also to be dependent on the initial carrier concentration.

Fast-Neutron-Flux Determination. Fast-neutron flux relative to center pile measurements has been determined for hole 51 using N type germanium plates.

Efficiency of Bombardment-Introduced Acceptors for Carrier Production. A more quantitative idea of the efficiency of bombardment-induced acceptors was obtained by studying the initial slopes of the conductivity curves of N type germanium both before and after conversion by bombardment. The slope ratios of samples irradiated at room temperature are found to be dependent on the initial electron concentration, n_e^0. Since the initial slope is essentially constant, the slope after conversion is dependent on the initial donor concentration, being inversely proportional to n_e^0.

Magnetic Properties Research. A large electromagnet capable of producing fields up to 37 kilogauss at a power of 125 kw over a gap of 2 in. has been ordered. This magnet will make possible an extension of Hall effect studies from semiconductors to the metals. A small magnet of similar design is also being constructed at the Laboratory.

Cryostat for Pile Irradiations. A cryostat for in-pile radiation damage studies at temperatures between 100 and 300°K has been built and bench tested. It is now ready for pile installation.

Lithium-Iron Cyclotron Bombardment. Two attempts were made to irradiate lithium in iron capsules using the Berkeley 60-in. cyclotron. In both cases heater failure prevented finishing the experiment.

Crystal Physics

Radiation Effects on Metal Crystals. A study is being conducted of property changes of single crystals of copper under irradiation. Tensile tests, electrical resistivity, and density comparisons were made between irradiated and unirradiated identical crystals. An exposure of one month in the X-10 pile increases the crystal shear stress of a copper single crystal by a factor of 8.

Hardness measurements were made on single crystals which were irradiated and then annealed at various temperatures. Complete recovery occurred above 425°C without the appearance of recrystallization. X-ray- and electron-diffraction studies are being made to investigate crystal imperfection changes due to irradiation.

86-in. Cyclotron Studies. Copper samples have been bombarded with protons in the Y-12 86-in. cyclotron, and effect on hardness has been noted.

A rotating cylindrical sample which will be liquid-metal cooled is being prepared for exposure to the beam while under tension.

Purdue Cyclotron Irradiation. The Purdue group has begun a study of the properties of unirradiated molybdenum. Properties under study are grain size, density, microhardness, and resistivity.

Instruments for creep experiments under deuteron bombardment are being built. Control circuits are complete.

Thermal Conductivity. Apparatus has been designed for measuring thermal conductivity changes during irradiation. Beginning of bench testing was planned for February.

Apparatus for before-after thermal conductivity measurements is also being designed.

Coloration Studies on High-Density Glass. Light-transmission characteristics of high-density glass have been measured after various time exposures to a Co^{60} gamma source. Effects of light on recovery were also studied. It is concluded that the glass tested may be very well suited for shielding window material.

Development of Hot-Cell Apparatus. Remote-controlled electrical resistance equipment for use in the hot cells has been completed.

The following remote-controlled equipment for use in the hot cells has either been completed or is in process of manufacture: electrical resistance apparatus, vacuum furnace, general purpose vise, and instrument panels for the cell faces.

Radiation Metallurgy

Effect of Radiation on Pure Metals and Simple Solid-Solution Alloys. Investigations have been conducted on the radiation hardening of copper alloys and subsequent removal by annealing at various temperatures. X-ray studies have also been included in these investigations.

Resistance changes due to irradiation appear to be real but are inconsistent. Resistance changes due to heat treatment have also been noted in some alloys.

Radiation Damage in Unstable Alloys. Copper alloys which previously indicated a resistivity decrease due to neutron bombardment have been found to show an aging behavior similar to that of precipitation alloys. New alloys are being made by techniques which eliminate the precipitation-hardening phenomena. Investigation of radiation damage to precipitation-hardening alloys has been continued and extended to other alloy systems.

Apparatus for Fundamental Investigations. Apparatus has been designed or constructed to (1) produce homogeneous shear; (2) perform vacuum annealing, aging, and diffusion; and (3) age samples in a salt bath.

Creep Under Irradiation. Work has been concerned with improving methods of construction and checking components of the cantilever-creep apparatus.

A tensile-creep apparatus is being built. The specimen will be tubular so that it may be filled with a liquid metal for stress-corrosion studies during creep.

Examination of Irradiated Strain Gauges. Stress-strain curves were run on samples containing bonded strain gauges both before and after irradiation. About half the gauges continue to operate after exposure. It is concluded that if sufficient number of gauges can be applied they can be used for before-after dimensional change investigations as low as 1×10^{-6} in./in. Further investigation will be necessary, however, for a complete understanding of strain gauges.

Naval Reactor

Thermal Conductivity of Uranium-Bearing Materials. No significant changes have been observed to date in thermal conductivity of BeU and ZrU under irradiation.

Thermal conductivity of uranyl nitrate hexahydrate—impregnated carbon at 550°C showed less rapid changes than impregnated graphite samples previously have shown.

Engineering Properties

Irradiation Effects on Beryllium Metal. A study has been made of change in density, electrical resistance, and dimensions caused by exposure of beryllium in the Hanford pile. Results are given.

Irradiation Effects on Kovar. Effects of Chalk River pile irradiation on the dimensions, density, hardness, and electrical resistance of kovar stock are being studied. Some information on results obtained thus far are given.

Personnel Addition to the Engineering Properties Section. The Engineering Properties of Irradiated Materials Group of the Reactor Technology Division will be combined with the Engineering Properties Section of the Physics of Solids Institute on March 1.

1. BUILDING STATUS

Occupation. Physics of Solids Institute personnel occupied the building during the latter part of December. Owing to the great increase in personnel, two people now share each one-man office. Other changes include alteration of some of the benches to accommodate special apparatus and other needs. A staff shop is being set up. The "dirty" side of the building (cells and cell entrances) is to have a strippable coat of paint. Blinds will be installed in the near future in all the laboratories.

Hot Cells (S. E. Dismuke). Work to date has been concentrated on cells 1, 2, and 3. Preliminary tests have shown that the chip collection system is not adequate, and the Special Design Section of Engineering is remodifying the unit. Barrier transfer units and the wall transfer device have been installed. The manipulator tracks and power supply are in place and the mechanical parts of the manipulator are essentially complete. The end-wall transfer unit is near completion. The four windows that have been welded in place will be grouted in and will receive their final coat of paint in the near future.

Design of cells 4, 5A, 5B, and 6 has been completed; the high-density concrete blocks have arrived and the first pair of master-slave manipulators should be here in February. Construction of these cells will be started soon.

The pieces of remote-control apparatus which have been moved to this building are listed below.

1. Analytical balance. Very slight changes will be made on the control panel.
2. Tukon hardness tester. This apparatus is being used outside the cells. From the experience gained it is planned to add a dynamic breaking circuit to the control motors.
3. Electrical resistivity tester.
4. Profile recorder.
5. Length and thickness gauges.
6. Impact tester.

All these instruments will need extension cables to connect them from inside the cells to their control panels.

A vacuum furnace has been designed and is now under construction in our machine shops.

2. SOLID-STATE REACTIONS

New Pile-Loading Facility (J. C. Pigg, J. H. Crawford, and J. W. Cleland). A large number of experiments of interest to the Semiconductor Group require pile exposures ranging from ½ to 12 hr. Since in the majority of these experiments it is necessary to bring leads out of the pile for in-pile measurements, the pneumatic tube facility cannot be used. In order to make efficient use of available pile space and exposure time it was decided to design and install a device with which samples could be loaded into and removed from the pile without requiring a pile shutdown. The design shown in Fig. 1 was arrived at in collaboration with H. G. Duggan, C. H. Odum, and J. R. Gissell of the Engineering and Maintenance Division. The device consists of a track extending into the pile on which a sample-carrying cart runs. The cart is driven in and out by means of a small cable and a crank. External shielding is necessary since the graphite stringer plug formerly used can no longer be employed to stop the neutron and gamma beam. This shielding is built up of alternate layers of 4-in. masonite slabs and 2-in. layers of lead in the form of bricks to a total thickness of 16 in. of masonite and 8 in. of lead. The hole in which the device is installed contains an enriched uranium doughnut and, consequently, a high fast-neutron flux. The shielding described above, however, is adequate. The background, both neutron and gamma, around the hole is comparable with the general background in the immediate vicinity. Access to the sample cart is through a hole on the top of the shield at right angles to the beam which is closed by a removable plug of the same composition as the shield proper. With the plug out and no source at the bottom of the hole, the activity at the mouth of this hole rarely exceeds 40 mr/hr and the neutron count is well below tolerance.

This facility is now in use and is found to be entirely satisfactory. The advantage of such a device for short-term exposures lies in the fact that special pile shutdowns need not be scheduled for short irradiations and that pile space need not be tied up for long periods, i.e., between regular pile shutdowns, thus allowing a more efficient use of the pile.

Bombardment of Cu_2O Plates (J. H. Crawford, J. C. Cleland, J. C. Pigg, F. W. Young, and K. Lark-Horovitz*). The experiments on the effect of pile bombardment on the electrical properties of Cu_2O discussed in two previous

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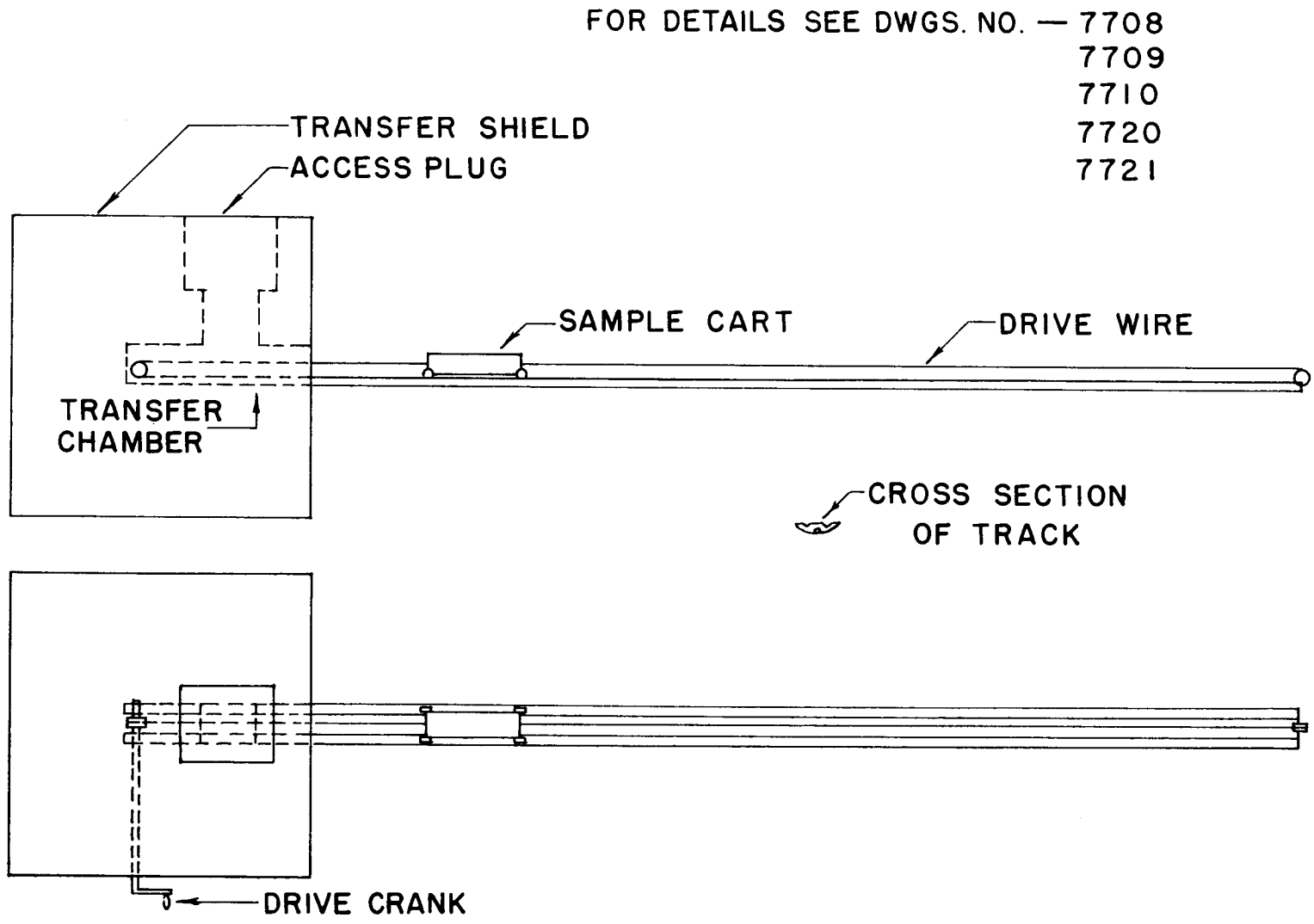

SAMPLE LOADER
FIG. 1

quarterly reports[1,2] have been extended. In one of those reports[1] data were presented which seem to indicate that the Cu_2O changed conduction type on bombardment, i.e., from P type (hole conduction) to N type (electron conduction). The conductivity of the samples apparently decreased, passed through a minimum, and then increased. More recent studies[3] of the behavior of lead wire insulation resistance under pile bombardment caused a reinvestigation of these data. Because of the large decrease in insulation resistance of the type of wire used in these earlier experiments, the possibility was indicated that after a short period of exposure the measurements reflected this change instead of that of the sample being bombarded. Subsequent exposures using the most durable lead insulation available (polyethylene) confirmed this as fact. These later experiments indicate that for pile exposures up to 15 days the resistance of Cu_2O increases monotonically and approaches a high saturation value.

The initial behavior of the conductivity as a function of bombardment time has been investigated more carefully. A number of Cu_2O plates have been exposed in a high fast-flux region for periods up to about 4 hr and readings were taken at frequent intervals. The behavior of one such sample is shown in Fig. 2. As was noted previously[2] the form of the curve appears to be hyperbolic. This has been checked and found not to be the case. The initial slope of the conductivity vs. bombardment curve has been determined for several samples, and, although the initial portion is not nearly so linear as in the case of germanium,[4] the initial rate of conductivity decrease is smaller than that of germanium by a factor of 10 to 100. Also, in contrast with that of germanium, the initial slope seems to vary from sample to sample.

Bombardment of Cu_2O Rectifiers (J. H. Crawford, J. C. Cleland, J. C. Pigg, F. W. Young, and K. Lark-Horovitz*). Cu_2O rectifier bombardment experiments previously described[1,2] have been continued. Attention has been

*Purdue University.

(1) Cleland, J. W., Crawford, J. H., Jr., Lark-Horovitz, K., and Pigg, J. C., "Semiconductor Bombardment Research," *Physics Division Quarterly Progress Report for Period Ending June 15, 1950*, ORNL-782, p. 71 (Oct. 4, 1950).

(2) Cleland, J. W., Crawford, J. H., Jr., Lark-Horovitz, K., Pigg, J. C., and Young, F. W., "Semiconductor Bombardment Research," *Physics Division Quarterly Progress Report for Period Ending September 20, 1950*, ORNL-865, p. 87 (Jan. 8, 1951).

(3) Pigg, J. C., "Effect of Pile Radiation on Performance of Electrical Leads," *Ibid.*, p. 106.

(4) Crawford, J. H., Jr., and Lark-Horovitz, K., "Fast Neutron Bombardment Effects in Germanium," *Phys. Rev.* 78, 815 (1950).

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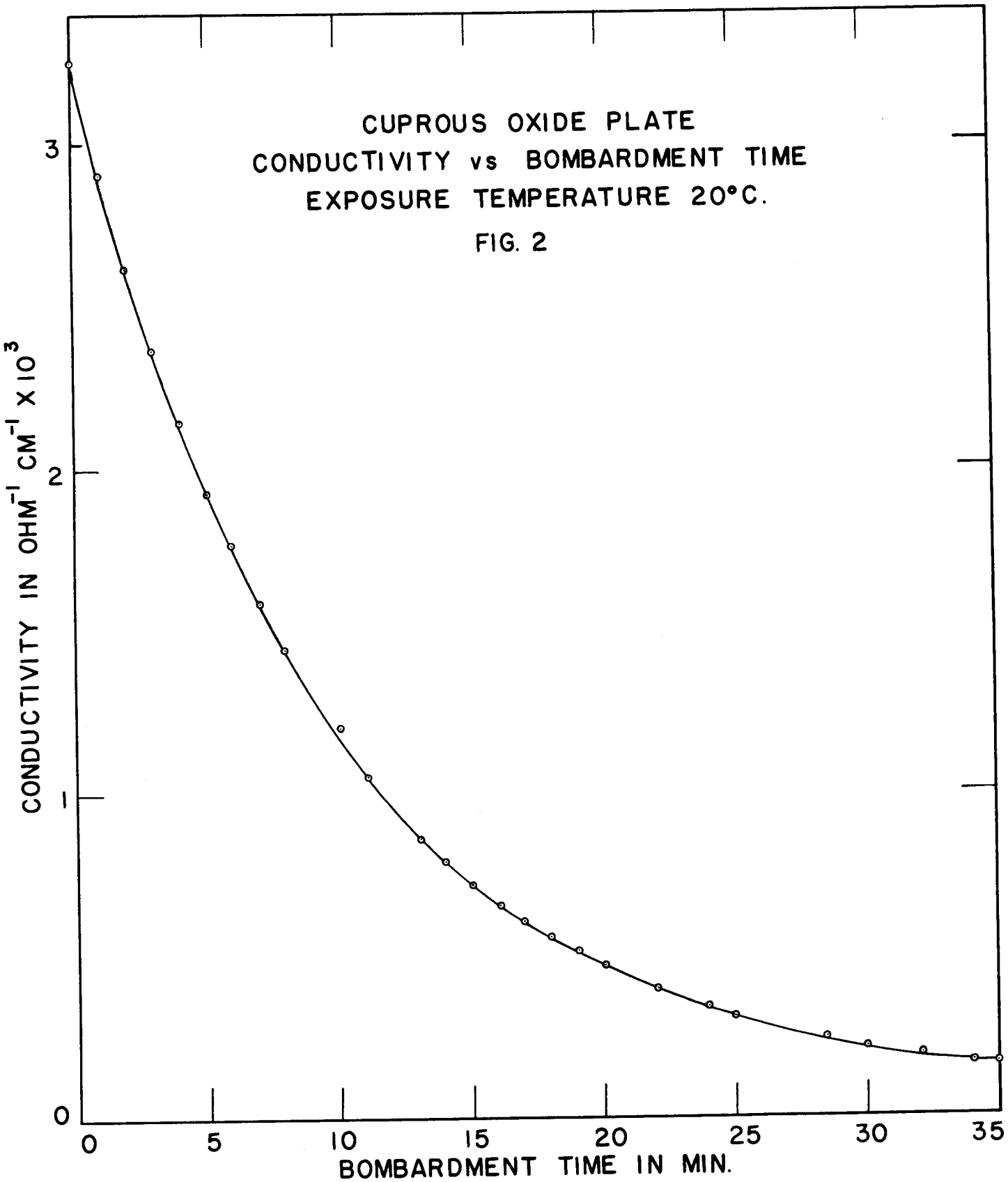


concentrated on the specially prepared rectifier disks furnished by S. J. Angello of Westinghouse Research Laboratory. The complete forward and back current-voltage characteristics of several disks have been measured during bombardment. An analysis of their behavior will be reported at a later date.

Studies of the Rectification of Oriented Single-Crystal Copper—Cuprous Oxide Rectifiers (F. W. Young). A program is in progress to prepare single-crystal Cu-Cu_2O rectifiers and to study the effect of crystallographic orientation on the properties of these rectifiers. It is hoped that these studies will give some information on the anisotropy of the chemical potential of copper and, through bombardment experiments, will throw light on the problem of the conductivity change observed in Cu_2O on neutron bombardment.

These rectifiers are being prepared by oxidizing single crystals of copper which have been cut into plates 1 by 1/2 by 1/8 in. with a desired crystal face parallel to the surface. These copper crystals are polished mechanically with fine emery paper and electrolytically with a phosphoric acid solution. The crystals are heated in a hydrogen atmosphere to the temperature of oxidation (about 1000°C), the hydrogen is evacuated, and oxygen at approximately 2 mm Hg pressure is introduced. After 30 min of oxidation at this temperature the sample is cooled rapidly to room temperature.

The Cu_2O film which is formed by this oxidation process is a single crystal, as determined by X-ray diffraction. To date, (100) and (111) crystal plates of copper have been oxidized, and the orientation relations are: (111) of Cu_2O parallel to (111) of copper and (111) of Cu_2O parallel to (100) of copper. The X-ray data show that the Cu_2O is in a slightly strained condition, which is to be expected.

Some qualitative information has been obtained on the rectification characteristics of these samples. These data seem to indicate that the (111) copper—(111) Cu_2O is a better rectifier than the (100) copper—(111) Cu_2O. These results are not conclusive, however.

Low-Temperature Bombardment of P Type Germanium (J. H. Crawford, J. C. Cleland, J. C. Pigg, F. W. Young, and K. Lark-Horovitz*). It has been shown[4] that the initial rate of decrease of the conductivity of N type germanium on

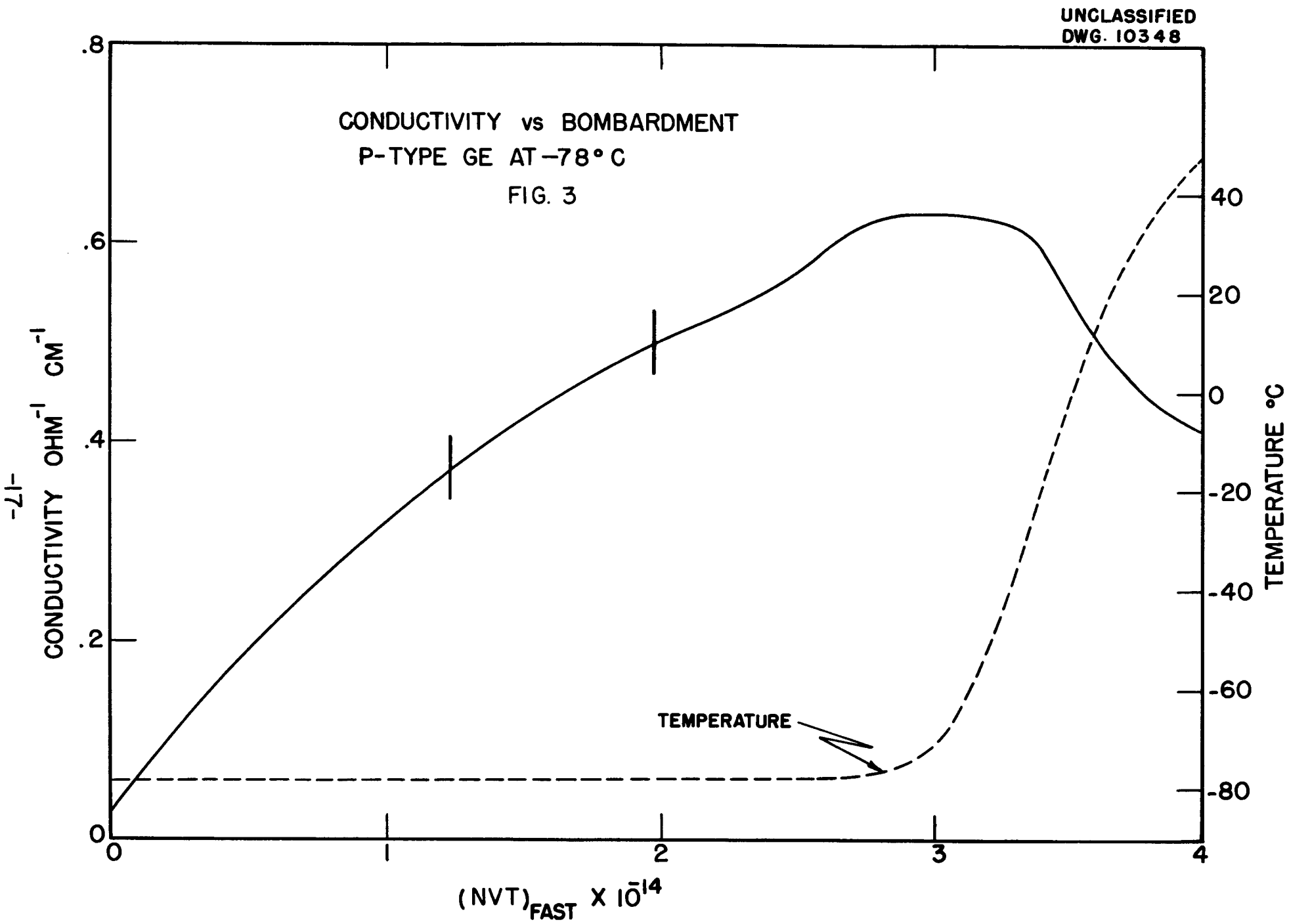
*Purdue University.

bombardment is essentially temperature independent, which is expected from the theory of semiconductors. On the other hand, the rate of conductivity change from P type germanium is expected to be temperature dependent since only those acceptors introduced by bombardment which are thermally ionized are capable of increasing the carrier concentration. An experimental indication of this temperature dependence has been reported.[5]

In order to investigate this point further two P type germanium plates have been bombarded in the pile at dry ice temperature. It was found that not only was the initial slope much lower, indicating temperature dependence, but also that apparently the initial slope was dependent on the original carrier concentration. The behavior of one of these samples, the one with the lower conductivity, is shown in Fig. 3. In addition it was found that, if the bombardment axis of the sample of higher conductivity was translated so that its initial conductivity fell on the curve for the lower conductivity sample, the two curves then coincided. This is indicated in Fig. 3; the two curves coincide between the vertical marks. A dependence of the rate of bombardment-produced change in conductivity may be explainable on the basis of equilibrium between ionized acceptors and free holes. This point is being given further consideration and an attempt to explain this dependence quantitatively will be made.

Fast-Neutron-Flux Determination in an Experimental Hole (J. W. Crawford, J. C. Cleland, J. C. Pigg, F. W. Young, and K. Lark-Horovitz*). Most of the more recent work on semiconductor irradiation is now being carried out in hole 51, a water-cooled hole containing a neutron converter (an enriched uranium doughnut to convert thermal to fast neutrons). Since originally most of the measurements were taken at the center of the pile, it was felt necessary to find some means of comparison of the fluxes in these two positions. A relative determination was made using N type germanium plates. The conductivity was measured during bombardment and the linear portion of the initial slope of the conductivity-vs.-bombardment curve was compared with data taken at the center of the pile. The initial rate of change observed in hole 51, is, within 20%, twice that observed in the center of the pile. The amount of damage produced in germanium is sensitive to the energy of the fast particles. Consequently, this observation does not necessarily mean that the flux is twice as great, since the fast-neutron-energy spectrum may be somewhat different. On the basis of these results, however, more careful planning of

(5) Crawford, J. H., Jr., and Lark-Horovitz, K., "Thermal Equilibrium in Neutron-Irradiated Semiconductors," *Phys. Rev.* 79, 889 (1950).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CONDUCTIVITY vs BOMBARDMENT
P-TYPE GE AT -78° C
FIG. 3
CONDUCTIVITY OHM^{-1} CM^{-1}
.8
.6
.4
.2
0
TEMPERATURE °C
40
20
0
-20
-40
-60
-80
TEMPERATURE
0
1
2
3
4
(NVT)$_{FAST}$ X 10^{-14}

future experiments can be made and the data obtained in this position in the pile can be better evaluated.

Efficiency of Bombardment-Introduced Acceptors for Carrier Production (J. H. Crawford, J. C. Cleland, J. C. Pigg, F. W. Young, and K. Lark-Horovitz*). It is well known that the initial rate of decrease of the conductivity of N type germanium is much greater than the rate of increase of conductivity after the sample has been converted to P type (after the minimum is passed). As was pointed out above, this is the expected behavior, since only those vacant states introduced into the forbidden energy region (electron traps or acceptors) which are capable of being thermally ionized are effective in increasing the carrier concentration in P type germanium. In order to obtain a better quantitative idea of the efficiency of the bombardment-introduced acceptors, the relation between the initial linear slope and that after conversion was studied for a number of N type conductivity vs. bombardment curves. The ratios of the initial linear slope to that after conversion at room temperature for various original electron concentrations n_e^0, as determined from the Hall coefficient for a number of samples, are listed in Table 1. It is interesting to note that the slope ratios of those samples irradiated at room temperature are unmistakably dependent on the initial electron concentration, and, since at room temperature the donor states are essentially exhausted in the unirradiated material, this is approximately equal to the original donor concentration. It has been shown that the initial linear slope is essentially constant from sample to sample, the only variation being due to small differences in the mobility. Consequently, this result indicates that the slope after conversion is dependent on the initial donor concentration being larger for smaller n_e^0.

This dependence may be explained qualitatively in two ways. Since the original donor concentration is indicative of the amount of damage required to reduce the conductivity to its minimum value and since the rate of annealing is directly dependent on the concentration of damage, the rate of annealing immediately after the minimum is passed would be expected to be greater the greater n_e^0. This would tend to decrease the slope after conversion. Also, an effect analogous to the common ion effect of solution chemistry may exist. Thus n_e^0 of the acceptors are already ionized at the conductivity minimum, and the fraction of introduced acceptors which ionize to produce carriers will be repressed in proportion to n_e^0. Both of these effects, however, should cause

*Purdue University.

an inverse dependence on n_e^0 while examination of Table 1 indicates that the dependence should be more nearly exponential. This problem will be studied further.

TABLE 1

Ratio of Initial Slope to That After Conversion at Room Temperature for Various Electron Concentrations

SAMPLE	SLOPE RATIO	n_e^0
1	7.2	4.2×10^{14}
2	8.0	5.1×10^{14}
3	10.0	1.3×10^{15}
4	12.9	2.5×10^{15}
5	21.0	1.0×10^{16}
6	21.4	2.8×10^{16}
7	24.3	5.5×10^{16}
P type	6.5	10^{13}

Magnetic Properties Research (J. H. Crawford, Jr.). It has become evident that a knowledge of the effect of reactor radiations on magnetic properties of material is not only desirable but necessary in the design of instrumentation for in-pile use. In addition, information of this nature would be valuable in obtaining a better understanding of the behavior under extended exposures of certain structural materials such as stainless steels and iron base alloys, not to mention its value in obtaining a better understanding of the solid state.

Little extensive research of this sort has been done at ORNL. Siegel and Billington[6] carried out some simple experiments on the effect of pile exposures on the field strength of certain permanent magnets. Similar experiments are now being carried out in connection with work on the design of a

(6) Siegel, S., and Billington, D. S., private communication.

densitometer for the HRE.[7] A simplified before-and-after experiment on the effect of pile exposure on the magnetic susceptibility of stainless steel was performed by Dismuke, Carroll, and Glick in connection with an ANL experiment.[8] The only extensive use of magnetic measurements has been in the field of semiconductor bombardment research where the use of the Hall effect is almost indispensable in characterizing these materials as to current carrier concentration. Plans are now being considered to extend Hall coefficient measurements to metals. Because of the very small magnitude of the Hall effect in metals the use of large magnetic fields is necessary.

In order to make the measurements discussed above possible, more magnetic equipment is necessary than is available at present. For this reason a large electromagnet capable of producing fields up to 37 kilogauss at a power of 125 kw over a gap of 2 in. has been ordered from Arthur D. Little, Inc. This magnet will be installed in one of the Physics of Solids hot cells and will be readily adaptable to most of the measurements contemplated. In addition a small magnet of similar design is being constructed at the Laboratory. The smaller type magnet was designed by J. G. Daunt of Ohio State University and has been in extensive use there.

Cryostat for Pile Irradiations (R. P. Metcalf). The cryostat is intended for in-pile radiation damage studies at temperatures between 100 and 300°K. Its development has been underway for some time and has been reported in the quarterly reports of the Physics Division.

The cryostat is a 1-1/8-in.-O.D. aluminum tube long enough to reach nearly to the center of the reactor. It is insulated by a vacuum jacket and cooled by a coil through which helium gas is circulated. The apparatus for circulating the helium and cooling it with liquid nitrogen was purchased from Arthur D. Little, Inc. The development and construction of the cryostat itself have been carried out at ORNL with the participation of the Engineering Department and Research Shops. The present cryostat, whose design incorporates several improvements, was completed in October.

During the past quarter extensive bench tests of the cryostat have been carried out. Its performance compares favorably with design expectations. Several minor alterations and adjustments to the helium refrigerator have been made, the most important involving the automatic temperature controller. The cryostat now appears to be ready for installation in the pile.

(7) Davenport, W. H., Jr., and Powell, R. H., ORNL-864, p. 71 (Dec. 28, 1950).

(8) To be published at a later date.

Lithium-Iron Cyclotron Bombardment (N.A.A., W. W. Parkinson*). To study the combined effects of radiation damage and corrosion, an experiment is being conducted jointly by ORNL and North American Aviation, Inc. in which an iron specimen in contact with lithium at temperatures up to 950°C will be bombarded with alpha particles from the Berkeley 60-in. cyclotron. Annealing and pre-irradiation metallurgical testing have been completed on a number of specimen plates of Globe iron. Two of these specimens have been sent to Berkeley for irradiation as control samples not in contact with lithium. Three of the specimen plates were welded onto capsule bodies to form containers for lithium. These capsules were filled with lithium in an argon atmosphere provided by a glove box for which a purification system was designed and constructed.

The target box, containing a heater to maintain the capsule at operating temperature and a gas jet to distribute the heat generated by the cyclotron beam (and which mounts the specimen on the cyclotron and encloses it in an inert atmosphere), was bench-tested.

The filled capsules and the target box were moved to Berkeley where two attempts were made to irradiate with alpha particles. In both attempts the heaters failed owing to the inability of the ceramic coil-form to withstand the force applied to the heater winding by interaction of the cyclotron magnetic field and the heater current.

After heating, it appeared that the closure plug of one of the capsules had leaked, so a different type plug has been made up and tested to avoid this trouble in future capsules. New heaters have been made up using a coil-form of stainless steel with alumina tubing for electrical insulation. These forms show no breakage but have led to melting of the wire winding after several hours of operation. Tantalum and platinum are being substituted for the Kanthal wire in an effort to make a satisfactory heater.

In addition to the work on iron, plates of type 316 stainless steel have been welded onto flanged cylinders of the same material to test arc-welding techniques. Leaky welds showed that changes are necessary in capsule design or in welding procedures.

*This work is being done under the supervision of Dr. H. Pearlman, NAA.

3. CRYSTAL PHYSICS

Study of the Effect of Radiation on Metal Crystals (T. H. Blewitt, R. R. Coltman, and F. A. Sherrill). According to the theory developed primarily by Seitz, Mills, Bohr, and Brown[1] neutron irradiation will change the physical properties of solids as the result of neutron collisions displacing atoms from their lattice sites. It is proposed then that the observed changes in the physical properties result from the interstitial atoms and atomic vacancies created by the neutron knock-ons and from a localized region of high thermal oscillations resulting from the Coulomb interaction of the displaced atom and the neighboring atoms in their lattice sites. The primary purpose of the studies being undertaken by this group is to seek critical experiments by which this theory can be evaluated. Experiments have been conducted or are being carried out to evaluate the effects of these two mechanisms on the physical and mechanical properties.

The effect of irradiation on the properties of single crystals of copper has received the most attention, although it is intended to widen the study to include single crystals of aluminum, magnesium, zinc, bismuth, and copper-gold alloys. Copper is a particularly useful metal to study, since it can be obtained in high purity, it has a short half-life for neutron capture, and it shows pronounced radiation effects.

Two single crystals of the same orientation were grown from the same melt in high vacuum utilizing the Bridgman technique. These samples were cast in the shape of standard half-inch ASTM tensile specimens. They were then vacuum annealed at 700°C for 1 hr and sealed in evacuated quartz tubes. One sample was then placed in the Oak Ridge reactor in a water-cooled hole for a period of one month. The fast-neutron flux for this irradiation was equivalent to about 2×10^{18} nvt. The stress-strain curve of both samples was then determined by an interrupted test. The tensile load was applied with a Baldwin-Southwark tensile machine using a Tate-Emory load cell of full scale range of either 1200 or 6000 lb, according to the load required. The elongation was determined from fiducial marks and use of a toolmaker's microscope. The results are shown in Fig. 4. A discontinuity appears in both curves at a shear

(1) See, for example, F. Seitz, "The Influence of Pile Radiations on Solid Materials," *J. Metallurgy and Ceramics*, No. 1, p. 142, July, 1948 (TID-65).

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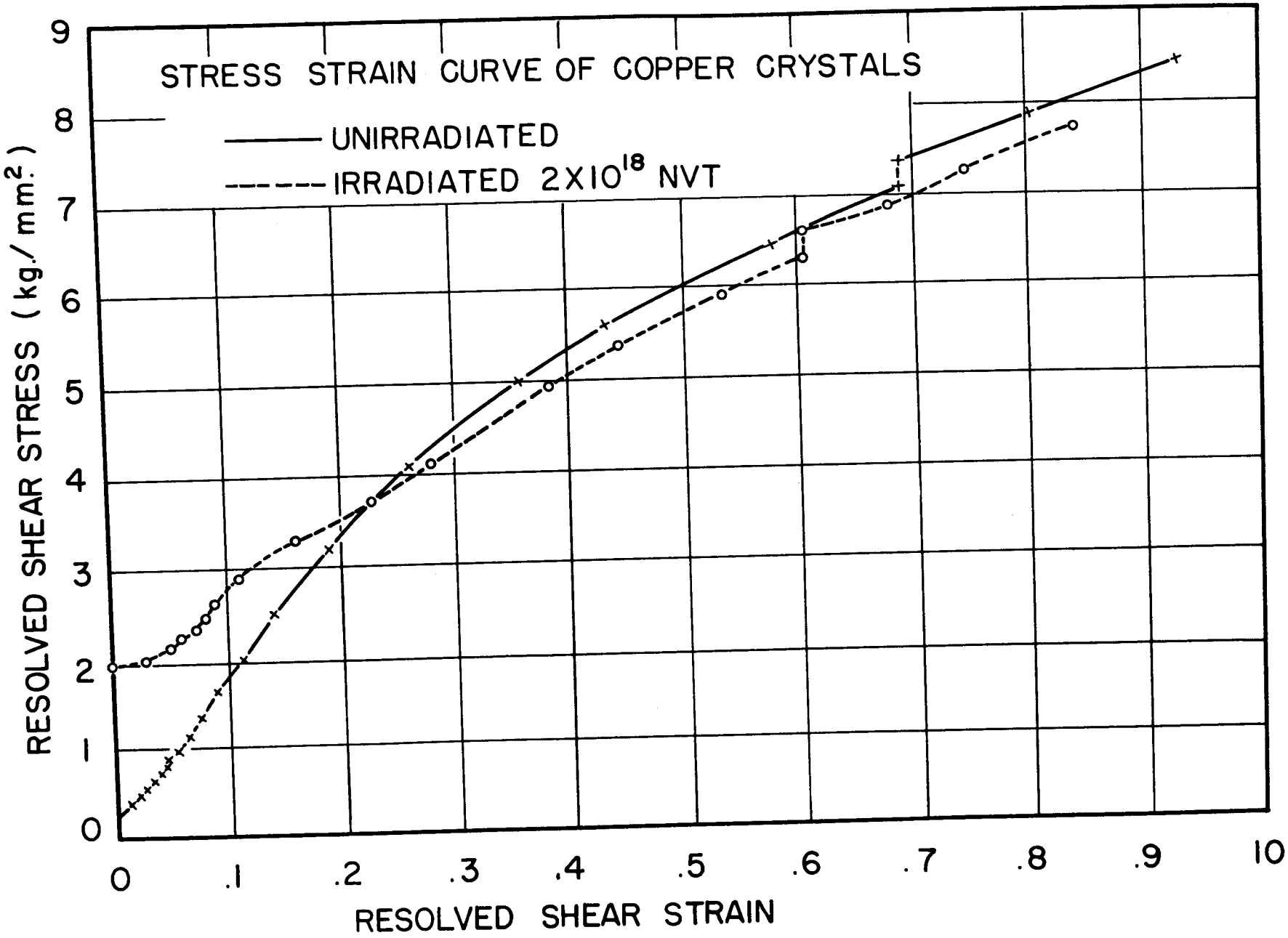


FIG. 4

strain of about 0.60. This discontinuity arises as a result of an additional pile irradiation of 2×10^{18} nvt.

Several interesting facts are apparent from the data. The critical shear stress shows a pronounced dependence on irradiation, a relatively short exposure showing an increase from 0.241 to 2.00 kg/mm^2. The critical shear stress is not affected nearly so much in the case of a cold-worked crystal as in an annealed one. It may be observed in Fig. 4, for example, that after a shear strain of 0.70 the radiation appears to be only about 20% as effective as in the annealed specimen. The reason for this behavior is not clear. It could be argued that thermal spikes have an annealing effect, tending to recover some of the crystal imperfections induced from cold working, and that this is counterbalanced by radiation hardening. Or, it could be argued that the crystal imperfections introduced by neutron bombardment have a relatively small influence since the disorder produced by the cold working is the dominating factor. A study of the change in the resistivity of cold-worked specimens after irradiation would yield some valuable information in regard to this latter point since the change in resistivity induced by cold working is a different order of magnitude from that induced by radiation effects.

Earlier survey experiments by Billington and Siegel(2) on the effects of radiation on the hardness of various metals and alloys suggested that there might be an analogy between cold working and radiation hardening. It is clear from the results in Fig. 4 that there is not a 1-to-1 correspondence between radiation hardening and cold working. There is, however, a suggestion from the shape of the stress-strain curve that radiation hardening may be similar to solid-solution hardening. For example the effect of adding silver to gold,(3) zinc to copper,(4) and gold to copper(5) appears to affect the stress-strain curve in a manner somewhat analogous to that of radiation. If the vacant lattice sites and interstitial atoms which are induced by the irradiation are regarded as impurity atoms, the shape of the stress-strain curve would then be logical. In other respects, however, this analogy is not borne out so well; solid-solution hardening results in the latent slip systems

(2) Siegel, S., and Billington, D., "Effect of Reactor Radiation on Metals," *J. Metallurgy and Ceramics*, No. 2, p. 54, January, 1949 (TID-66).

(3) Sachs, G., and Weerts, J., "Zugversuche an Gold-Silberkristallen," *Z. Physik*, 62, 473 (1930).

(4) Goler, V., and Sachs, G., "Zugversuche an Kristallen aus Kupfer und α-Messing," *Z. physik* 55, 581 (1929).

(5) Blewitt, T. H., and Koehler, J. S., *Symposium on Plastic Deformation of Crystalline Solids*, Mellon Institute, Pittsburgh, May, 1950.

hardening at a faster rate than the active systems,[2-4] resulting in the absence of asterism in Laue X-ray pictures for strains in which slip has occurred on only one slip system.[4,5] Laue back-reflections were made, and, insofar as could be determined, irradiation had no effect on either the orientation or the asterism of X-ray shots. The asterism had become so intense after strains of 0.25 that it was impossible to determine the orientation of the sample; consequently it could not be determined if the latent slip system had hardened faster than the active system.

Further consideration of the changes in electrical resistivity and density also raises serious objections to the concept that simple interstitial atoms and atomic vacancies can account for the observed changes in the stress-strain curve. This will be considered in detail after the effects of radiation on the density and the electrical resistivity have been indicated.

Four single crystals were grown in vacuum in the shape of standard 3/16-in. tensile specimens. Two of these, 3A and 3B, had identical orientations. One of these identical samples was not irradiated; the others, T-1 and T-2, were irradiated in the Oak Ridge reactor for an integrated fast-neutron flux of 2×10^{18} nvt. The electrical resistivity was measured on all four samples before and after the irradiation at room temperatures and at liquid-nitrogen temperatures. The measurements were made by causing a known current (usually a few amperes) to flow through the sample, and then measuring the drop in potential between two voltage probes. The value of the current was determined by measuring the drop across a standard 0.01-ohm resistor (rated at 100 amp) with a type B Rubicon potentiometer, and the drop in potential across the sample was determined by a type C Rubicon thermo-free microvolt potentiometer. In order to ensure that contact and thermal emf's did not reduce the accuracy of the results, the reported values are the averages of readings taken with the direction of the current reversed. The direction of the potential drop across the sample was reversed by means of a Wenner key to reduce thermal emf's. The contact and thermal emf's observed were surprisingly low: reversing the current introduced a difference of only about 0.01 μv in most cases.

The temperature was determined by a copper-constantan thermocouple. It should be noted that the values reported are only relative since the thermocouple was not calibrated. The potential probes consisted of razor blades

held in position by strips of nylon. These had to be removed prior to radiation as the neutrons would have destroyed the nylon. It was found that the resistance could be determined to an accuracy of better than 0.01% at room temperature; the geometry of the samples and the temperature could not be determined to this accuracy. By assuming that the temperature dependence of the resistivity was not changed by irradiation, it was found that the results could be repeated with an average deviation of 0.05% at room temperature (as can be seen from the results in Table 2). This assumption appears to be reasonable, as only changes in the number of carriers and the Debye characteristic temperature will affect the thermal coefficient of resistance. It does not appear that the number of carriers could be changed, as copper has a half-filled band of electrons; changes in the Debye characteristic temperature will have a second-order effect on resistivity. Also, the results of the thermal coefficient of resistivity observed in Table 2 are not in disagreement with the average observed results, namely, that the electrical resistivity changes by 0.23% at 20°C for a flux of 2×10^{18} nvt. It is hoped that the apparatus can be modified so that the accuracy can be increased by a factor of 10.

The changes in density were measured on the same sample by hydrostatic weighing in carbon tetrachloride. Only relative measurements were made, the density being compared to that of a gold control sample. In order to remove systematic errors the values of density were reduced to those of the unirradiated sample. The results are given in Table 3. It may be observed that the results on sample T-1 did not appear to be reproducible; consequently this sample was discarded. The results can be summarized by stating that if there is a change in density for a fast-neutron flux of 2×10^{18} nvt, it is extremely small, probably decreasing the density by less than 0.005%. Since it was desired to measure the density, resistivity, and stress-strain curves on the same samples it was necessary to use fairly small samples (about 17 g). The accuracy of the experiment can be increased somewhat by using heavier samples, and experiments with heavier samples are being contemplated in which the stress-strain curves of these samples will be measured. However, the experiment is being delayed pending the delivery of a low-load tensile machine.

If it is assumed that the increase in resistivity and the apparent decrease in density arise from the presence of simple interstitial and vacancy atoms, which seems to be a rather questionable assumption since it has been

TABLE 2

Change in Resistivity of Copper Single Crystal from Irradiation

SAMPLE	ρ_{RT}	ρ_{LN}	ΔT	$M \times 10^{-3}$	ρ'_{RT}	ρ'_{LN}	ρ'_{20}	$\Delta\rho'_{20}$	$\Delta\rho'_{20}$ (avg)
BEFORE IRRADIATION									
3-B	1.6621	0.19208	221.22	6.6497			1.6639		
3-B	1.6802	0.19358	223.825	6.6419	1.6822	0.19381	1.6658	0.0019	
T-2	1.68375	0.19593	221.08	6.7298	1.6637	0.19360	1.6671	0.0032	
T-2	1.70825	0.19720	224.06	6.7440	1.6844	0.19444	1.6663	0.0024	
T-1	1.59080	0.18407	221.92	6.3389*	1.6688	0.19309	1.6664	0.0025	
T-1	1.70585	0.196045	223.69	6.7495	1.6806	0.19314	1.6651	0.0012	
3-A	1.6929	0.19884	223.03	6.6989	1.6805	0.19738	1.6772	0.0133	
3-A	1.7042	0.19894	223.77	6.7268	1.6847	0.19666	1.6689	0.0050	
AFTER IRRADIATION OF 3-B, T-2, AND T-1 WITH 2×10^{18} nvt; 3-A UNIRRADIATED									
3-B	1.65215	0.19810	218.94	6.6413	1.6542	0.19835	1.6696	0.0057	
3-B	1.6497	0.19800	218.37	6.6479	1.6501	0.19805	1.6686	0.0047	+0.0042
T-2	1.6768	0.19954	219.44	6.7321	1.6563	0.19710	1.6689	0.0050	
T-2	1.6734	0.19999	219.17	6.7226	1.6553	0.19782	1.6692	0.0053	+0.00235
T-1	1.6754	0.20029	219.01	6.7353	1.6541	0.19774	1.6701	0.0062	
T-1	1.6907	0.20051	221.25	6.7354	1.6692	0.19796	1.6700	0.0061	+0.0048
3-A	1.6695	0.19708	220.18	6.6873	1.6601	0.19597	1.6688	0.0049	-0.0008
3-A	1.6757	0.19835	219.43	6.7324	1.6551	0.19591	1.6674	0.0035	

ρ_{RT} = resistivity at room temperature in micro-ohm-centimeters

ρ_{LN} = resistivity at liquid nitrogen temperature in micro-ohm-centimeters

ΔT = difference in temperature between ρ_{RT} and ρ_{LN}

$M \times 10^{-3}$ = average temperature coefficient of resistivity between 90 and 300°A

ρ'_{RT} = resistivity at room temperature, adjusted for error in geometry, in micro-ohm-centimeters

ρ'_{LN} = resistivity at liquid nitrogen temperature, adjusted for error in geometry, in micro-ohm-centimeters

ρ'_{20} = resistivity reduced to 20°C in micro-ohm-centimeters

$\Delta\rho'_{20}$ = difference in resistivity at 20°C from that of the first measurement of sample 3-B

$\Delta\rho'_{20}$ (avg) = average change in resistivity

*Knife edge mark doubtful.

TABLE 3

Relative Density* of Copper Before and After Irradiation

SAMPLE	TRIAL I	TRIAL II	TRIAL III	AVERAGE
BEFORE				
T-1	1.000183	1.000288	1.000382	1.000284 ± 0.000068
T-2	1.000261	1.000292	1.000263	1.000272 ± 0.000013
3-B	1.000042	1.000121	1.000047	1.000070 ± 0.000034
AFTER 2×10^{18} nvt				
T-1	1.000138	1.000454	1.000269	1.000287 ± 0.000111
T-2	1.000219	1.000237	1.000136	1.000197 ± 0.000041
3-B	1.000163	1.000029	1.000089	1.000094 ± 0.000046

*The density is in reference to a single copper crystal of the same shape as the samples which were irradiated.

shown[6] that these imperfections have considerable mobility at 20°C, the effect of these imperfections on the critical shear stress can be calculated in a crude way by utilizing the analogy of radiation hardening and solid-solution hardening. The number of imperfections can be computed from the resistivity change and their effect on the critical shear stress from the lattice distortion. If it is assumed that the vacancies and interstitials induce a lattice distortion corresponding to an impurity atom of one-half the size of the solvent atoms and that the valence of the vacancy or interstitial is either 0 or 2, then the critical shear would be expected to rise by about 50% from the published data pertaining to solid-solution alloys.[3-5] It will be recalled that the radiation increased the critical shear stress by approximately 40 times this crudely calculated value. It thus appears difficult to explain the change in the stress-strain curve by the presence of simple interstitial and vacancy atoms although more elegant calculations are certainly needed.

It is believed that a critical experiment can be performed to decide the role played by interstitials and vacancies in the radiation hardening of metals. There are three distinct possibilities: (1) these imperfections play no role in radiation hardening; (2) at room temperature some type of coagulation of these imperfections occurs either with themselves or the many other imperfections present in the crystal (dislocations, etc.); and (3) these imperfections do not act similarly to the impurity in the case considered above. Since the interstitials or vacancies do not appear to be mobile at liquid-nitrogen temperatures, a neutron bombardment and a determination of the critical shear stress at this temperature with and without a room temperature annealing should yield some very informative data. For example, if the critical shear stress were raised by the room temperature annealing, the coagulation of the vacancies and interstitials would be expected to be important; if the critical shear stress were unaffected by the annealing, the influence of interstitials and vacancies would appear to be of only secondary importance; and if the critical shear stress were lowered, apparently simple interstitials and vacancies would play an important role in the hardening. Furthermore, the interstitials and vacancies have different mobilities, so by studying the effect of different annealing temperatures it may be possible to determine the role each of these imperfections plays. A cryostat to be placed

(6) Blewitt, T. H., Taylor, W. E. and Coltman, R. R., "The Change in Resistivity of Copper by Low Temperature Annealing," *Bull. Am. Phys. Soc.* 26, No. 2, p. 13 (Mar. 8. 1951).

in the pile is nearing completion and it is hoped that this experiment can be performed during the next quarter.

In order to attempt to learn something of the nature of the imperfections causing radiation hardening, other experiments have been made. Single crystals were irradiated at 2×10^{18} nvt and annealed at 250, 425, and 950°C, respectively, for 1 hr. Vickers hardness impressions were subsequently made and it was found that the complete recovery occurred for the 425 and 950°C annealing without the appearance of recrystallization. There was no apparent change resulting from the annealing at 250°C.

Experiments are also being undertaken to investigate how the degree of crystal imperfections changeswith irradiation. This is being done by X-ray and electron diffraction. To date a copper crystal has been prepared, and transmission electron diffraction shots have been made on the (100) plane. Kikuchi lines, which are indicative of a high degree of perfection, have been observed. The X-ray-diffraction shots were made by R.L.Sherman at K-25. The crystal is now being irradiated in the Oak Ridge reactor, and the electron-diffraction pattern will again be studied for the appearance of Kikuchi lines. An experiment to reveal similar information is also being made by measuring the X-ray reflection coefficients of copper crystals. Preliminary work has been done with the help of B. S. Borie and it has been found that crystals can be prepared which have a half-width of about 15 min. The crystal is slowly rocked 1° per hour through the Bragg angle with the Geiger tube remaining fixed.

Straightforward experiments of the effect of exposure time on the stress-strain curve are also being made. To date two annealed single crystals have been irradiated at each of the following fast-neutron fluxes: 4×10^{18}, 2×10^{18}, 1×10^{18}, 5×10^{17}, and 2×10^{17}. It is hoped that the range of exposures may be extended by exposures in higher flux reactors. The taking of the stress-strain data is awaiting the arrival of a tensile machine with an accurate weighing system for light loads.

86-in. Cyclotron Studies (R. J. Jones and J. S. Luce, Electromagnetic Division at Y-12, and M. J. Feldman). A number of copper samples have been irradiated near room temperature using an internal beam of protons in the 86-in. cyclotron, and measurements have been made to determine the effect upon

hardness. The irradiations made thus far have been primarily to determine the proper technique and the power density required to obtain satisfactory data on physical property changes. The bombarding proton energy has been varied for one sample and was selected by positioning the sample holder with respect to the center of the cyclotron. This was accomplished during irradiation by moving the target holder stem through a Wilson type vacuum seal. The proton beam pattern is approximately 0.6 by 6 cm.

The arrangement for irradiation of the copper samples consisted of an aluminum water-cooled sample holder in which a 0.015-in. aluminum window had been milled. The copper samples were inserted in the water passage of the holder, directly back of the aluminum window. The water stream was thus in contact with the entire back surface of the copper sample. The water flowed at 4 gpm with a velocity of 5.2 ft/sec and had a temperature of 15°C.

Three copper samples have been irradiated. The samples were commercial sheet copper ¼ by 0.020 in. and approximately 4 in. long. They were vacuum annealed at approximately 900°C for 1 hr. The first sample was irradiated with an average of 1.4 μa-hr/cm^2 at a constant energy of 20 Mev over an area of 0.6 by 6 cm. The second sample, in order to obtain more uniform damage through the sample, was irradiated at several proton energies, from 3 to 18 Mev varied by 3-Mev steps, with a total of 1.4 μa-hr/cm^2 (average of the irradiated area). The irradiation of the third sample was a repeat of the first irradiation. The change in hardness in all three samples was within the error expected from measurements made on a Tukon hardness machine.

The experimental arrangement to be used in the 86-in. cyclotron for determining the effect of irradiation on the creep of metals at elevated temperatures has been worked out in principle, and the components are in the process of construction.

The internal beam of the 86-in. cyclotron will be used to irradiate a thin-walled cylindrical sample. The cylindrical sample will be cooled by liquid metal pumped through the cylinder at the rate of approximately 10 gpm by an electromagnetic pump. The cylindrical sample will be rotated at 500 rpm to facilitate liquid-metal pumping and to obtain uniform irradiation in the direction of rotation.

In making creep measurements it is necessary that the temperature of the target not fluctuate more than a few degrees. In view of the rapid temperature changes due to fluctuations of the cyclotron beam, it will be extremely difficult to compensate for them by alternately heating and cooling the sample. Consequently, it is believed that better results can be obtained by increasing the thermal capacity of the system by using a circulating liquid metal. The liquid metal flowing through the thin-walled cylindrical sample results in efficient heat transfer with a temperature gradient of only a few degrees depending on the material under test. The fluctuations of the sample temperature from cyclotron beam off to beam on will be of the same order.

Purdue Cyclotron Irradiation (B. Gossick* and K. Lark-Horovitz*). The Purdue Program emphasis has been placed on molybdenum and stainless steels which are of interest in high-temperature reactor designs. The chief work has been with molybdenum. After techniques have been developed with molybdenum, the same set of apparatus will be applied to the investigation of stainless steel.

In order to obtain reproducible results, a study of grain size, degree of preferred orientation, strain, and hardness of commercially available rolled molybdenum was made. Three standard thicknesses, 5, 10, and 20 mils, were selected. With the 5- and 20-mil samples powder and back-reflection X-ray patterns show sharp lines, indicating that grain size is in the range 10^{-2} to 2×10^{-4} mm. X-ray patterns from the 10-mil sample exhibit spottiness in the rings, indicating that the grain size is somewhat larger than 10^{-2} mm. Preferred orientation is marked in each thickness, but particularly so in the case of the 5-mil sample. Density was calculated from the lattice parameter determined from back-reflection patterns, and the value obtained(7) was 10.22. Agreement in density between 5- and 10-mil samples was within the experimental error. These results were supplemented by photomicrographs of the polished and etched surfaces of the different samples. Using equipment with a magnification of only 100 diameters, it was possible to resolve grain boundaries in only the 10-mil sample, which is consistent with the X-ray determination of grain size. With the 10-mil sample the grain size was estimated at 7×10^{-2} mm. This value is greater than that indicated by the X-ray patterns, but, according to Dr. Billington of ORNL, this discrepancy is typical of the two methods, has the usual order of magnitude, and is in the same direction. The same X-ray and photomicrograph techniques are now being employed to determine the structure of the rolled sheets after different annealing treatments. Microhardness

*Purdue University.

(7) The Metals Handbook gives 10.2. Since we have no explanation for the appearance of two very weak extra lines in the back-reflection patterns, a measurement of the bulk density using a pyknometer was made, and the value obtained was 10.21 g/cc.

tests taken with a Tukon tester yield an average Knoop number of 245 for the 5-mil sample, 207 for the 10-mil sample, and 233 for the 20-mil sample.

Resistivity measurements using the equipment immediately available have been troublesome. Three different sample holders have been designed and tested. It is felt that further modifications are still required in order to arrive at a suitable design. The justification for seeking an extremely accurate and sensitive means of measuring resistivity is that bombardment-induced changes in resistivity are small in the case of metals.

Resistivity of the 5-mil sample in as-received condition has been measured within an error of 8.4×10^{-9} ohm-cm, this error being averaged by applying the method of least squares. The resistivity ρ as a function of temperature T is linear within experimental error, and can be expressed as $\rho = 5.022 - 0.02265T$ over the range 77 to 300°K. It should be added that refinements of the techniques are not yet such that this accuracy can always be maintained with successive measurements. With less accurate and earlier measurements of the 5- and 10-mil sheets, the resistivity agreed with the equation just given within the experimental error. It is surprising that the difference in cold working between the 5- and 10-mil sheets, which is quite evident in X-ray measurements and hardness tests, does not produce an easily discernible difference in resistivity.

One of the 5-mil samples of molybdenum was bombarded in the Purdue cyclotron for 4 hr with a 3-μa beam of 10-Mev deuterons. The sample was cooled by heat conduction through a brass bar immersed in dry ice. The temperature of the sample was measured during the bombardment with a thermocouple. Whenever the temperature rose to 40°C, the bombardment was temporarily interrupted while the dry ice supply around the brass bar was replenished. Cross-sections for deuteron-induced transmutations in some of the naturally abundant isotopes of molybdenum are high, and after the bombardment the sample read over the tolerance of a health monitor at a distance of approximately a meter. After three days the tolerance value was obtained at a distance of about 10 cm. A radioautograph of the sample, made with a 5- min exposure, indicated a relatively uniform bombardment across the sample. After more decay a more accurate measurement will be made with a Geiger-Mueller tube, masking different parts of the surface with lead. It was felt that as the recrystallization temperature of molybdenum is around 1280°C, the effects of

radiation might be "frozen in" by keeping the sample below 40°C during bombardment. Not having hot-laboratory facilities for measuring resistivity, one day elapsed after bombardment before a measurement could be safely made. By that time any variations in resistivity which may have been produced were not detectable by the apparatus. Hardness and X-ray measurements await further decay in the sample. Resistivity measurements in situ would be desirable and will be attempted. Smaller samples might also be used, as they could be bombarded longer, and give the same total activation as a large sample irradiated for less time.

Development of very sensitive instruments for determining creep under bombardment is essential because of the short range of particle penetration and fluctuations in specimen heating produced by the beam. A large assembly of instruments is required, and this part of the program is in the development stage. Control circuits have been completed. These include tuning coil assemblies, tuned amplifiers, and recording indicators of creep and creep rate. Tests of the circuits have been satisfactory as to sensitivity and stability, but supplementary shielding and filtering are required to reduce stray pick-up. A microformer type of mutual inductance bridge has been developed for use as the sensing device in the extensometer. About 80% of the parts for the creep machine have been turned out by the Machine Shop. The mechanical design of the creep machine is complete except for the furnace. Requirements for controlling the temperature profile across the wire are stringent, and the development of a suitable furnace may take several months. Future plans are primarily concerned with a satisfactory completion of the work now underway. However, if possible, it would be advantageous to incorporate measurements of other physical properties and enlarge the scope of metals under investigation. A repetition of Andrade's[8] experiment, using polonium alpha particles incident on a single-crystal cadmium wire creep specimen, will be carried out.

Thermal Conductivity of Structural Alloys at High Temperatures (A. F. Cohen). Designs have been prepared for the measurement of the change in thermal conductivity as a function of temperature under pile irradiation. Construction of the experimental parts for the measurements on 316 stainless steel are nearing completion and preliminary bench experiments are anticipated this month. The other materials to be considered for thermal conductivity measurements are 347 stainless steel, inconel, inconel X, and molybdenum.

(8) E. N. Andrade, "Effect of Alpha Ray Bombardment on Glide in Metal Single Crystals," *Nature* 156, 113 (1945).

Out-of-pile experiments are being planned to determine absolute values of thermal conductivity of alloys at high temperatures. The accuracy in these out-of-pile experiments is expected to be within a few percent.

Thermal Conductivity (R. H. Kernohan and C. C. Webster). In addition to plans for measuring in-pile thermal conductivity, apparatus is being designed and built to measure thermal conductivity remotely in the hot cells by so-called "before" and "after" methods.

The apparatus being designed will necessarily be simple in operation and will measure only relative changes in conductivity. Essentially the method is one of longitudinal heat flow. One end of the specimen will be heated to a temperature in the range 100 to 200°C. Heat losses from the specimen to the surroundings will be kept nearly constant, and the temperature drop at the cooler end of the specimen will be recorded. High accuracy is not to be expected.

A literature search is being carried forward on thermal conductivity standards, techniques of conductivity measurement, and heat-transfer problems.

Coloration Studies on High-Density Glass (R. H. Kernohan; G. M. McCammon of ORNL Physics Division). A study has been made of the effect of gamma radiation on the optical transmission characteristics of a high-density glass which could be useful as window material for hot cells or aircraft reactor shields.

Several cylindrical specimens of glass were made for use in this investigation by the Penberthy Instrument Company, 666 Adams Street, Seattle 8, Wash. The Penberthy Instrument Company furnished the following information on this glass:

Name	Hi-D glass
Chemical composition by synthesis	
PbO	81%
SiO_2	17.3%
TiO_2	1.35%
As_2O_3	0.35%
Density	6.4 g/cc (0.23 lb/cu in.)
Index of refraction	1.96
Color	Light yellow tint, nearly colorless in thin sections
Gamma shielding characteristics	Equivalent of steel and about 55% as effective as lead

Each glass specimen was a cylinder about 7/8 in. in diameter and 2 in. long. The optical transmission was measured through the 2-in. thickness by a Beckman spectrophotometer, model B, from the violet (400 mμ) end of the spectrum through the red (800 mμ). The original transmission characteristics are indicated by the graphs labeled *OT* in Figs. 5 and 6.

The specimens were placed in the center of a 300-curie Co^{60} gamma source available in the Chemistry Division. By varying the time of exposure different doses were obtained. Specimen D was given a dose of 43,000 r, and specimen F a dose of 1,000,000 r. Both specimens were very dark brown when removed from the gamma source. This phenomenon is the well-known one of color center production by highly ionizing radiation.

The transmission characteristics of these specimens were measured at specified times after removal from the gamma source. Specimen D was kept in the dark when not being measured and specimen F was exposed continuously to light. The source of light was a 150-watt light bulb held exactly a foot from the specimen.

The results can be best indicated by the graphs shown in Figs. 5 and 6. The times on each graph indicate the total elapsed time after removal from the gamma source to the time of transmission measurement. After 11 days specimen D seemed to reach saturation in its recovery from (or fading of) coloration and it was then exposed to light in the same way as specimen F. Curve "13 Days-X" of Fig. 5 gives the transmission 13 days after gamma exposure plus 21 hr of light exposure while curve "24 Days-Y" gives the transmission 24 days after gamma exposure plus 160 hr of light exposure.

The rate of recovery during the early stages for one wavelength (600 mμ) is shown in Fig. 7 for four specimens. Specimens B and C were exposed to a dose of 24,000 and 150,000 r, respectively, and kept in the dark in the same manner as specimen D. The rate of recovery appears to be roughly a logarithmic function of time.

It is well known that high-lead-content glasses will fade and that the application of heat will remove the color centers induced in crystals and optical materials by high-energy radiation. However, the acceleration of fading of color centers by the mere application of light indicates that the

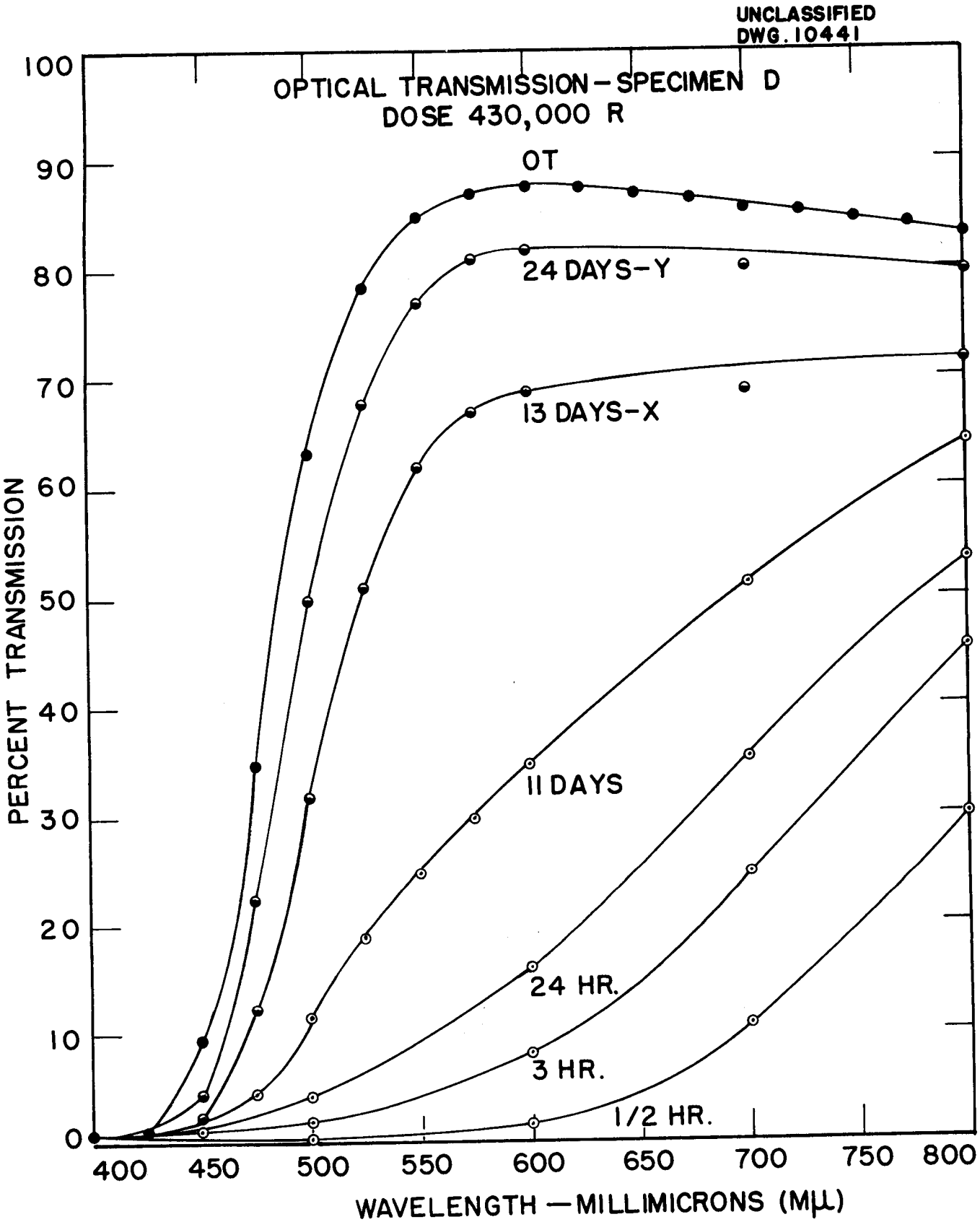

UNCLASSIFIED
DWG. 10441
OPTICAL TRANSMISSION - SPECIMEN D
DOSE 430,000 R
OT
24 DAYS-Y
13 DAYS-X
11 DAYS
24 HR.
3 HR.
1/2 HR.
PERCENT TRANSMISSION
0
10
20
30
40
50
60
70
80
90
100
400
450
500
550
600
650
700
750
800
WAVELENGTH — MILLIMICRONS (Mμ)

FIG. 5

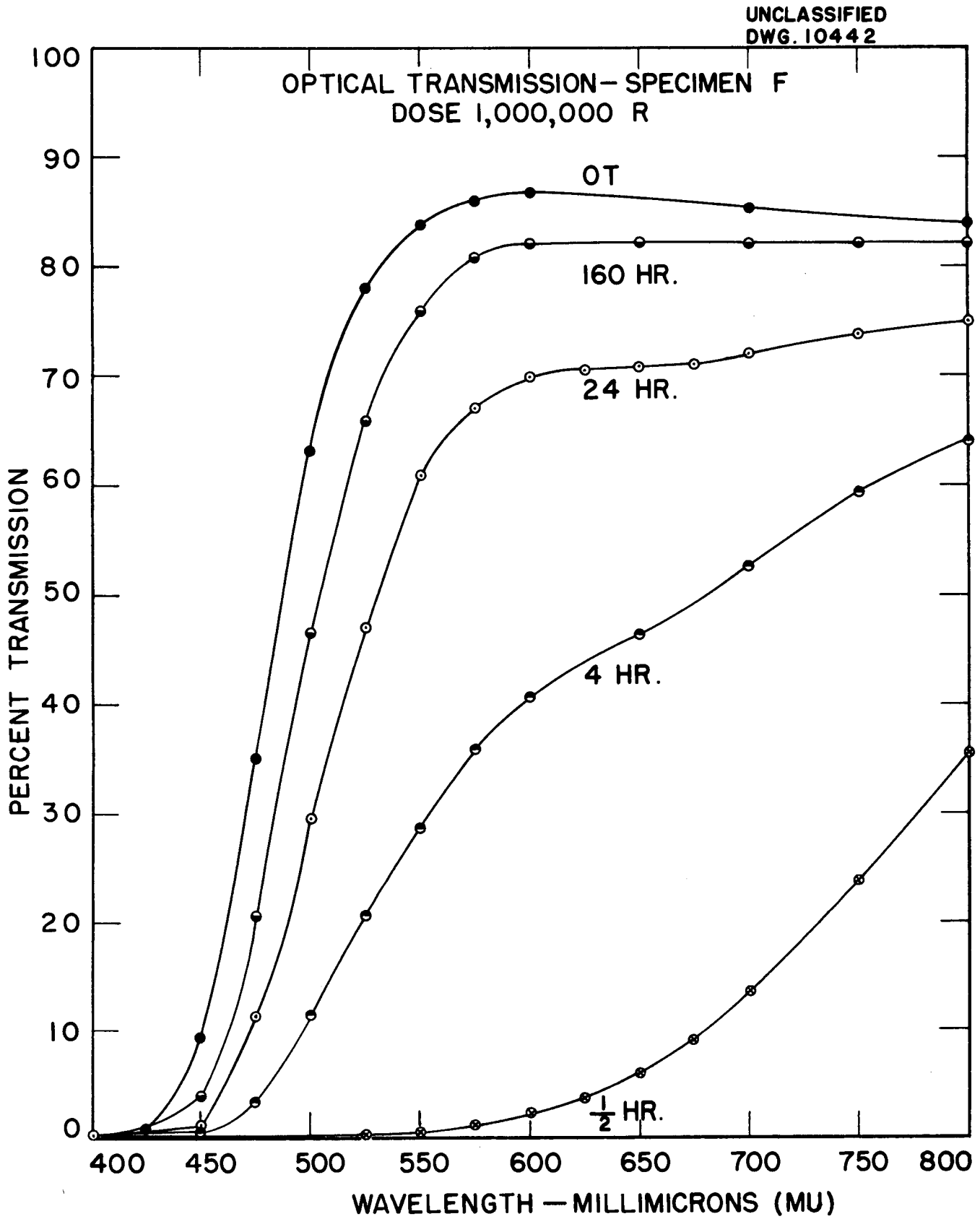

UNCLASSIFIED
DWG. 10442
OPTICAL TRANSMISSION—SPECIMEN F
DOSE 1,000,000 R
OT
160 HR.
24 HR.
4 HR.
½ HR.
PERCENT TRANSMISSION
100
90
80
70
60
50
40
30
20
10
0
400
450
500
550
600
650
700
750
800
WAVELENGTH — MILLIMICRONS (MU)

FIG. 6

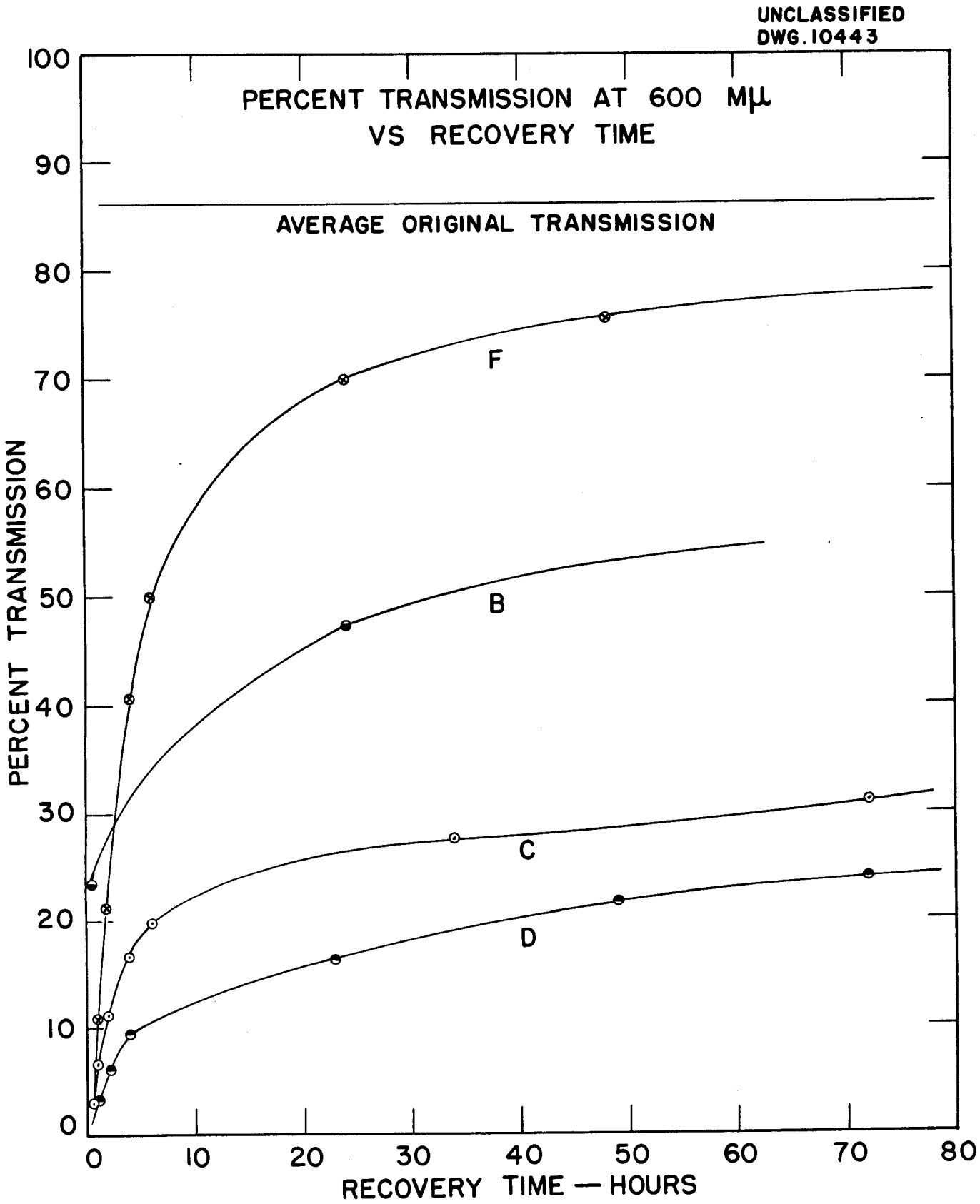

UNCLASSIFIED
DWG. 10443
PERCENT TRANSMISSION AT 600 Mμ
VS RECOVERY TIME
AVERAGE ORIGINAL TRANSMISSION
F
B
C
D
PERCENT TRANSMISSION
RECOVERY TIME — HOURS
0
10
20
30
40
50
60
70
80
90
100

FIG. 7

glass tested may be a very suitable shielding window material. This is particularly true since the transmission curves after gamma exposure very nearly returned to the original transmission curve.

A separate detailed report on this investigation will be published soon.

Development of Hot Cell Apparatus (R. H. Kernohan). The equipment designed to measure the electrical resistance of irradiated materials was completed and moved to the Solid States Building. The equipment operates satisfactorily, but additional cables and tubing were necessary to link the apparatus in the cell with the mobile control panels. Two 17-ft cables are being made by the Instrument Division, and several lengths of Tygon tubing have been made to link up compressed air and water.

An aluminum instrument panel was designed and built for each of the three cell faces. These will facilitate the making of plug-in connections to remotely controlled apparatus.

Designs for a vacuum furnace to be used in one of the hot cells were completed by the Engineering Division and sent to the shops. This vacuum furnace contains a fused silica tube with an effective heating space about 18 in. long and 2¾ in. in diameter. Temperatures up to 1000°C can be maintained.

A small general-purpose vise to be operated remotely was completed by the NEPA shops. Certain mechanical revisions, wiring, and an instrument panel for the vise have yet to be made.

4. RADIATION METALLURGY

Effect of Radiation on Pure Metals and Simple Solid-Solution Alloys (W. E. Taylor, G. T. Murray, and F. M. Blacksher). Hardness and resistance samples of several metals and alloys have been exposed in the Oak Ridge reactor. The effects of the exposure are given in Table 4. The error in hardness readings is estimated to be ±5 DPH numbers. The estimated error in resistance measurements is ±0.2%.

There does not appear to be a marked effect on radiation hardening as a result of alloying of copper. However, the general trend is that harder alloys undergo less radiation hardening. Preliminary experiments have shown that radiation hardening anneals out within 17 hr at 300°C. The rate of annealing is considerably higher at higher temperatures. Further investigations of the effect of annealing on radiation hardening in copper alloys are planned.

The resistance changes resulting from irradiation are small but appear to be real. The changes are not consistent as in some cases the resistance increases and in others it decreases. In at least one case (Cu-Al) where there was a relatively large decrease the samples were found to change in resistance as a result of heat-treatment (quenching and annealing). Detailed analysis[1] indicated behavior similar to that found for precipitation-hardening alloys. A new alloy has been prepared which does not change as a result of heat-treatment, and is now being irradiated. In-pile measurements of the resistance of Cu, Cu-Zn, Cu-Ge, and Cu-As have also been made. No changes greater than the experimental accuracy (±1%) were noted during a two-week exposure.

X-ray line studies were made on copper and alloys with zinc, gallium, germanium, and arsenic in cooperation with the X-ray Group of the Metallurgy Division. No change in the shape of the (311) line was observed as a result of four weeks of irradiation in the Oak Ridge reactor. These results cannot be considered conclusive, however, since it was observed that the line broadening due to cold working was largely annealed out within two weeks. The experiment is being repeated with pure copper and an alloy of 12.5 atom % zinc in copper using pressed compacts and longer exposure times.

Radiation Damage in Unstable Alloys (W. E. Taylor, G. T. Murray, and F. M. Blacksher). Earlier work has indicated a resistivity decrease due to

(1) *Metallurgy Division Quarterly Progress Report for Period Ending July 31, 1950*, ORNL-827, (Dec. 4, 1950).

TABLE 4

ALLOY (atom %)	HARDNESS (DPH)			RESISTANCE (μohms)			FLUX FOR HARDNESS SAMPLES (nvt)	FLUX FOR RESISTANCE SAMPLES (nvt)	REF.
	BEFORE	AFTER	INCREASE	BEFORE	AFTER	% INCREASE			
Cu	40.8	56.5	15.7	116.8	116.8	+0.17	1.5×10^{18}	1.5×10^{18}	
Zr	227.5	226.2	-1.3	2555	2569	+0.55	1.5×10^{18}	1.5×10^{18}	
Cu—1.5 Zn	25.6*	59.8*	34.2*	98.7	99.0	+0.3	1.5×10^{18}	1.5×10^{18}	
Cu—6.3 Zn	40.4*	64.0*	23.6*	154.5	153.5	-0.65	1.5×10^{18}	1.5×10^{18}	(2)
~~Cu—12.6~~ Zn	53.1*	66.9*	~~13.8*~~	208.2	204.5	-1.8	1.5×10^{18}	1.5×10^{18}	(2)
Cu—2 Zn	48.9	73.4	24.5	112.3	112.1	-0.18	2.5×10^{18}	1.5×10^{18}	
Cu—4 Zn	47.9	72.2	24.3	131.3	131.0	-0.23	2.5×10^{18}	1.5×10^{18}	
Cu—2 Ga	47.2	69.9	22.7	202.9	203.4	+0.25	2.5×10^{18}	1.5×10^{18}	
Cu—4 Ga	56.8	78.6	21.8	313.6	313.2	-0.13	2.5×10^{18}	1.5×10^{18}	
Cu—2 Ga	52.1	72.9	20.8	509.5	510.2	+0.14	2.5×10^{18}	1.5×10^{18}	
Cu—4 Ge	64.6	80.2	15.6	737.2	737.9	+0.10	2.5×10^{18}	1.5×10^{18}	
Cu—2 As	66.5	86.2	19.7	733.1	733.6	+0.06	2.5×10^{18}	1.5×10^{18}	
Cu—4 As	77.4	95.5	18.1	1354	1356	+0.15	2.5×10^{18}	1.5×10^{18}	
Cu—0.61 Al	27.3*	61.9*	34.6*	148.7	148.6	-0.1	1.5×10^{18}	1.5×10^{18}	(2)
Cu—6.18 Al	58.6*	72.7*	14.1*	353.8	350.3	-1.0	1.5×10^{18}	1.5×10^{18}	(2)
Cu—9.5 Al	65.3*	75.3*	10.0*	436.7	427.0	-2.2	1.5×10^{18}	1.5×10^{18}	(2)
Cu—3.5 Si	60.4*	72.0*	11.6*	665.2	665.0	-0.1	1.5×10^{18}	1.5×10^{18}	(2)
Cu—5.6 Si	77.0*	83.6*	6.6*	939.8	939.4	0.0	1.5×10^{18}	1.5×10^{18}	(2)
Cu—1 Sn	56.2	80.4	24.2	213.9	214.8	+0.39	1.7×10^{18}	1.7×10^{18}	(1)
Cu—2.7 Sn	68.3	86.2	17.0	361.8	362.8	+0.27	1.7×10^{18}	1.7×10^{18}	(1)
Cu—5.4 Sn	86.4	96.4	10.0	681.7	681.8	+0.01	1.4×10^{18}	1.4×10^{18}	
Cu—1 Mn	43.7	57.4	13.7	233.3	233.1	-0.17	1.4×10^{18}	1.4×10^{18}	
Cu—5.8 Mn	58.2	75.0	16.8	923.8	921.9	-0.19	1.4×10^{18}	1.4×10^{18}	
Cu—11.6 Mn	69.2	81.4	12.2	1355	1350	-0.37	1.4×10^{18}	1.4×10^{18}	
Cu—17.4 Mn	81.5	93.1	11.6	2415	2408	-0.29	1.4×10^{18}	1.4×10^{18}	
Cu—23.2 Mn	91.2	103.2	12.0	3118	3115	-0.10	1.4×10^{18}	1.4×10^{18}	

*Rockwell F hardness.

neutron irradiation in certain alloys of copper containing 12.6 atom % zinc and 9.5 atom % aluminum. Subsequent investigation of the effects of thermal treatment on these samples showed aging behavior similar to that of precipitation alloys.[1] New alloys of these compositions have been prepared using high-purity materials and vacuum-fusion techniques. These alloys, which do not show any thermal aging phenomena, are now being irradiated.

The investigation of radiation damage in Cu-Be age-hardening alloy has continued. Consideration of previously reported data[2] suggested the hypothesis that radiation induced a nucleated condition of the alloy. During the present period measurements of X-ray line broadening have been made to check this theory. The results obtained have not been entirely consistent. Single crystals are being irradiated to see whether Gunier-Preston streaks are induced. Single-crystal metallographic samples have been prepared and will be irradiated in order to make sure that the effect is not associated with grain boundaries. Measurements of internal friction at 1.5 cycles per sec have shown that this increases from about 0.00020 to about 0.00040 during an exposure to 1.8×10^{18} neutrons/cm^2.

The investigation of age-hardening alloys is being extended to other alloy systems, including Al-Si, Al-Mg, Al-Cu, and Fe-Cr.

Apparatus for Fundamental Investigations (W. E. Taylor, G. T. Murray, and F. M. Blacksher). The following pieces of apparatus have been designed and constructed or are in the process of construction:

1. Homogeneous shear apparatus. This equipment is intended to accomplish the same ends as the machine described by Rohm and Kochendorfer.[3] The ends of a single crystal rod are held rigidly, and a dead weight load is applied in such a way that the applied stress is a shear stress in one of the slip systems with no bending or rotational forces on the lattice. A stress-strain curve is obtained which is entirely different from that obtained in the axial tension test. The deformation is not accompanied by asterism of the Laue spots. The simple deformation caused by this apparatus will be used to study radiation hardening.

   Preliminary test of the apparatus with a copper crystal indicated satisfactory behavior in the central portion of the crystal. Modifications are being made to facilitate mounting the sample and to reduce bending at the ends of the crystal.

(2) *Physics Division Quarterly Progress Report for Period Ending September 25, 1949*, ORNL-480 (Nov. 8, 1949).

(3) Rohm, V. F., and Kichendorfer, A., "Neue Ergebnisse über die Verfestigung bei der plastischen Verformung von Kristallen. I. Schubverformung von langen Kristallen," *Z. Metallkunde*, 41,265 (1950).

2. Vacuum-furnace system. This system is designed for annealing, aging, and diffusion experiments covering the temperature range up to 900°C. There will be four independent furnace chambers with facilities for quenching with cold inert gases.

3. A new salt bath has been set up to provide facilities for aging samples in the temperature range above 150°C.

4. The Tukon hardness-testing machine designed for use in the hot cells is in routine use so that any defects may be discovered before it is installed in the cells.

Creep Under Irradiation (J. C. Wilson, M. J. Feldman, J. C. Zukas, and W. W. Davis). The creep work in the Physics of Solids Institute is directed toward determining the effect of radiation on creep of metals. The program at present is concerned with the problem of creep testing materials for the ANP program at temperatures of 1500°F (815°C). Tests are now being run in the ORNL reactor, but these are preliminary in nature since the ultimate tests will be run in the MTR with possible tests at Hanford in the interim. The earlier work in this section is reported in ANP Division quarterly reports numbered ORNL-768, 858, and 919.

No further data from creep tests under irradiation have been obtained. The main work during the quarter consisted in improving methods of construction of the apparatus and checking of the components. All future experiments will be run on the bench to determine creep rate and then placed in the pile. In view of the complex and indeterminate stress conditions in the cantilever specimens, which make it difficult to compare the data from different specimens of slightly different geometry, it is felt that this will, initially at least, offer the best means of comparison between irradiated and unirradiated creep specimens.

Operation of a creep test in the intense gamma field supplied by the Co^{60} source located in the canal at the ORNL reactor is contemplated. The geometry of the source is such that the present cantilever apparatus must be modified to place the long axis of the specimen vertical. This project is in the shop.

The source of a number of burnouts of furnace leads has been traced to corrosion of the nichrome wire by silver solder where the copper lead wires are soldered to the nichrome. Placing these junctures at a cooler spot has

alleviated this difficulty. A condenser-discharge spot welder has been received for welding of joints occurring in construction of the creep apparatus. In situ welding of the various lead wires in the apparatus is being developed.

A preliminary test of effect of radiation on thermocouple characteristics under irradiation shows a possible change of emf of chromel-alumel and iron-constantan couples at 1220°F after a period of two weeks. These couples were used to run cooling (melting point) curves on pure aluminum in an alumina crucible in the reactor.

Effects of masses of metal in the field of microformers on the linearity were studied. Also, temperature coefficients of microformers and variations in cores were checked to eliminate possible errors of interpretation of creep results. Little if any effect on the microformer was observed when it was mounted on a slotted aluminum base. Individual cores do show some variations, and in some cases abrupt changes in voltage output per unit of travel were observed. All future microformers and cores used will be individually calibrated while mounted in the creep apparatus. The in-pile microformer primary is now connected in series with the primary of the out-of-pile microformer which reads extension on a micrometer and dial gauge. This eliminates temperature effects which change the resistance and thus the impedance of the units. Without such a connection a temperature coefficient of about 1.0001 in. error per degree centigrade change in temperature is observed. Preliminary data from a sliding-wire contact potentiometer to be used as a possible extensometer in fluxes where microformer heating may be excessive has indicated that the present resolvability of readings (0.0003 in.) may be improved.

A pilot model of a tensile creep apparatus containing its own loading weight on a lever arm is in the shop. The specimen will be tubular so that materials such as sodium may be introduced into the tube to study stress corrosion during creep tests.

During February at least two complete tests at 1500°F on 347 or 316 stainless steel will be run in the ORNL reactor with stresses of the order of 1000 psi.

Examination of Irradiated Strain Gauges (M. R. Goodman). Sufficient time had elapsed to enable the radioactivity to decrease from the specimens of

copper, 2S aluminum, and Nilvar discussed in the quarterly report ORNL-782, p. 84, so that with proper precautions the irradiated strain gauges cemented on the specimens could be inspected and tested. The specimens and their housing unit were found to be slightly corroded. It was therefore necessary to saw and pry open the assembly in order to get at the specimens, during which rough treatment was unavoidable. The appearance of the specimens and strain gauges viewed from several angles is shown by the photographs, Fig. 8. The protective strain-gauge coatings of bakelite cement were found to have become quite brittle, and they easily chipped off in many places, exposing bare and corroded wire.*

It must be admitted that the appearance of the specimens, strain gauges, and wires left much to be desired and gave thought for speculation as to the possible causes of in-pile erratic strain-gauge readings.[4] However, most, if not all, of the chipping-off damage of the insulations is believed to have occurred during the rough handling received in opening the assembly. All wires fed through a center hole in the upper collar of the housing. After irradiation the wires were pulled apart for strain-gauge identification and appeared as photographed.

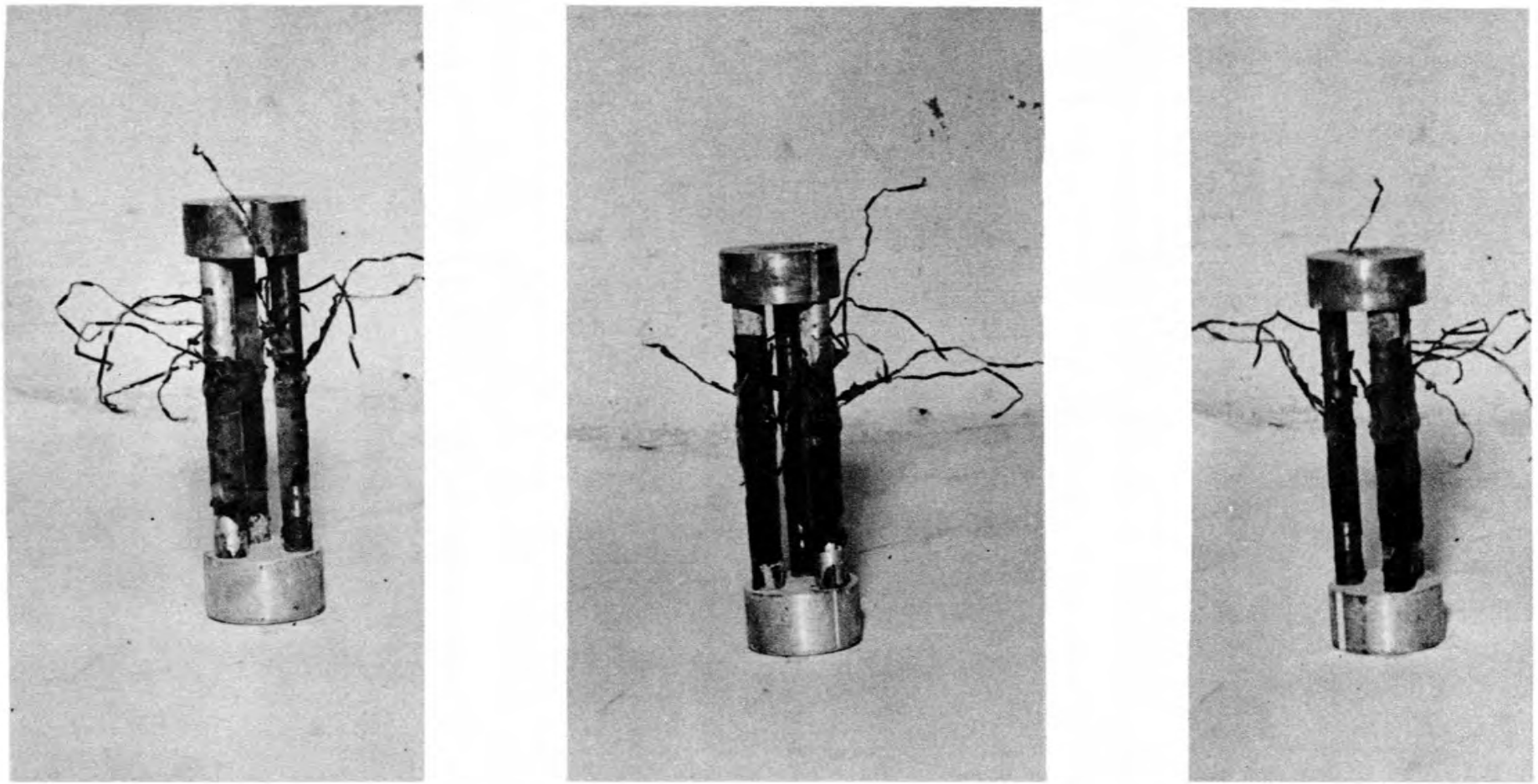
At the completion of the experimental in-pile strain-gauge readings the insulation resistance had decreased from greater than 10^9 ohms to a range varying from 1.5×10^5 to 2.0×10^4 ohms. A recheck of the insulation resistance after the assembly was pulled apart (four months later) indicated that the insulation resistance of all strain gauges had increased to greater than 10^7 ohms (limit of the Simpson meter used).

To check whether the strain gauges were still properly bonded to their specimens, tensile testing was resorted to. Owing to unavoidable difficulties encountered in handling hot specimens, two of the gauge wires snapped off before tensile testing, and during testing one more gauge was made inoperative. The specimens were stressed as follows several times each, both in the same and in different positions in the jaws of the tensile machine: Nilvar to 7000 psi, 2S aluminum to 3000 psi, and copper to 2500 psi.

The resulting graphs of stress vs. strain were examined by the staff of the Metallurgy Division. Some of the curves were not quite normal, but it was felt that allowances had to be made owing to the conditions of testing, e.g.,

*Ruge-De Forest, Inc. had cemented the strain gauges to the specimens and had included about 1 ft of rubber-insulated lead wire. This was satisfactory as it was not initially planned to expose these particular samples to pile radiation. Since this wire could not be removed without disrupting the strain gauges, wire with polyethlene and glass insulation was soldered to this wire for in-pile experimentation. This latter wire insulation remained intact, although slightly burned.

(4) *Physics Division Quarterly Progress Report for Period Ending September 30, 1950,* ORNL-865 (Jan. 8, 1951).



STRAIN GAUGE SPECIMENS AFTER IRRADIATION

FIG. 8

UNCLASSIFIED
PHOTO 7375

slipping and nonlinear alignment. The conclusion reached was that three of the strain gauges (one on each specimen) were still properly bonded to their specimens and that one strain gauge was no longer adequately bonded to its specimen. As previously mentioned, no data were obtained for two other strain gauges.

The fact that at least half the strain gauges used appear to be still good after being subjected to irradiation of 3.0×10^{18} fast neutrons/cm^2 indicates that if sufficient strain gauges are applied they can probably be used for an investigation of dimensional changes as low as 1×10^{-6} in./in. during and after pile irradiation. Whether the strain-gauge characteristics have changed, and, if so, in what particular variable and by what magnitude, still remains to be determined.

The value for the strain gauge[5] can be redetermined by temperature cycling between 32.5 and 60°C and compared with the data before irradiation. Creep curves before and after irradiation should also be compared at 32.5 and 60°C. Such work has not yet been performed.

As mentioned in the quarterly report ORNL-865, work has been performed on the program in making many precision dimensional measurements for before and after pile irradiation on specimens of copper, 2S aluminum, and sheet gauge bakelite material. Measurements to 1×10^{-5} in. are made by means of an electrolimit gauge.

The carrying out of the above-mentioned experiments should reveal and segregate any change in strain-gauge characteristics and variables and enable a proper evaluation and breakdown of experimental in-pile dimensional changes as indicated by means of bonded-wire resistance strain gauges. These gauges would be more useful in many types of experiments if their characteristics were better understood.

(5) Goodman, M. R., *Characteristics and Behavior of Bonded Wire Resistance Strain Gages in Thermal Coefficient of Expansion Measurements*, Parts I and II, ORNL-706 (May 31, 1950) and 707 (June 13, 1950).

5. NAVAL REACTOR

Thermal Conductivity of Uranium-Bearing Materials* (W. Primak,** R. G. Berggren, R. M. Carroll, J. Redman, and C. Ellis). Irradiation of BeU and ZrU reported previously[1] was continued through this period. No significant changes in thermal conductivity were observed.

A uranyl nitrate hexahydrate—impregnated carbon sample placed in a modified intermediate-temperature torpedo has been installed. While operating at about 550°C its thermal conductivity changed much less rapidly than did that of impregnated graphite samples.

The rewiring of thermocouple leads performed in the previous quarter failed to remove the irregularities from the data; therefore the study of these irregularities was continued.

*Sponsored by Argonne National Laboratory.

** Consultant, Argonne National Laboratory.

(1) Previous reports of this work are to be found in the progress reports of the ORNL Physics Division, e.g., ORNL-864, p. 8; ORNL-781, p. 7.

6. ENGINEERING PROPERTIES

Irradiation Effects on Beryllium Metal (L. C. Templeton). Specimens of forged, extruded cast, and extruded flake metal (turnings) and of QT metal, four types of beryllium metal, have been exposed in the Hanford Pile for approximate periods of 30 days (2.13×10^{19} nvt), 150 days (9.77×10^{19} nvt), and 267 days (1.73×10^{20} to 1.86×10^{20} nvt). The specimens, 3/16 in. in diameter by 2.5 in. long, were prepared by Dr. A. R. Kaufman at MIT from the same melt, in the case of the first three types, which was supplied by the Brush Beryllium Company. The QT metal, whose composition varies and which may have approximately 0.5% magnesium, was also supplied by Brush.

Measurements of electrical resistance, length, and density have been made at ORNL. Other properties are being measured at Battelle, M.I.T., and the National Bureau of Standards. The specimens supplied to ORNL had been annealed in vacuum for 1 hr at 800°C.

The results are shown in Table 5 as percent change, based on the pre-irradiation values. A minus sign indicates a decrease (real or apparent) in the value of the property measured. The precision of measurement is estimated at 0.1% for density, 0.4% or less for electrical resistance, and 0.02% for length. The changes in the properties measured are for the most part less than the precision of measurement, and are uniformly of the same order of magnitude as the precision of measurement. The values for changes in electrical resistance have been corrected so as to account for any changes in the controls and the calibration of the apparatus used for measurements.

Summaries of parts of this work have appeared in Physics Division progress reports ORNL-480, September, 1949, and ORNL-864, September, 1950.

Measurement of internal friction (damping) has not been made as yet on the irradiated specimens.

Irradiation Effects on Kovar (L. C. Templeton). Six specimens were cut from each of two pieces of kovar stock and heat-treated as explained in Table 6. Information about the composition of the two pieces of stock is not available at present, but will likely be presented in a final report. Length, density, hardness, and electrical resistance measurements were made. The specimens were then divided into two groups of four specimens each (four being

TABLE 5

Irradiation Effects on Beryllium Metal

SPECIMEN NO.	EXPOSURE (days)	TYPE OF METAL	DENSITY CHANGE (%)	ELECTRICAL RESISTANCE CHANGE (%)	LENGTH CHANGE (%)
6	Control	QT			-0.01
7	Control	QT			-0.02
1	30	QT	-0.02	0.6	-0.01
2	30	QT	0.00	-0.2	0.03
8	30	QT	-0.03	0.6	-0.01
4	150	QT	0.00	0.4	0.00
5	150	QT	-0.01	0.0	-0.01
9	150	QT	-0.12	-0.7	-0.01
0	267	QT	0.04	0.2	-0.01
3	267	QT	0.01	0.2	0.00
15	Control	Forged			-0.01
16	30	Forged	0.00	0.0	0.00
13	150	Forged	0.00	-0.5	-0.01
10	267	Forged	-0.01	0.3	-0.03
12	267	Forged	-0.02	0.2	-0.01
14	267	Forged	-0.01	0.4	0.00
25	Control	Extruded cast			
26	30	Extruded cast	0.01	-0.4	-0.02
27	30	Extruded cast	0.01	0.5	0.00
28	30	Extruded cast	0.00	0.3	-0.02
20	150	Extruded cast	-0.02	0.3	-0.02
24	150	Extruded cast	0.01	-0.2	-0.02
29	150	Extruded cast	0.01	-0.4	-0.02
21	267	Extruded cast	0.03	0.3	-0.02
22	267	Extruded cast	-0.01	-0.1	-0.02
23	267	Extruded cast	-0.01	0.1	-0.02
35	Control	Extruded flake			-0.01
36	Control	Extruded flake			-0.01
33	30	Extruded flake	-0.01	0.6	-0.02
34	30	Extruded flake	0.01	0.2	-0.03
37	30	Extruded flake	0.01	0.1	-0.04
30	150	Extruded flake	0.01	-0.2	-0.03
39	150	Extruded flake	0.00	-0.6	-0.02
40	150	Extruded flake	-0.01	0.4	-0.02
31	267	Extruded flake	0.01	0.0	-0.02
32	267	Extruded flake	-0.02	0.0	-0.02
38	267	Extruded flake	-0.03	0.4	-0.02

TABLE 6

Irradiation Effects on Kovar

SPECIMEN NO.	HEAT TREATMENT*	EXPOSURE (days)	LENGTH CHANGE (%)	ELECTRICAL RESISTANCE DECREASE (%)		DENSITY DECREASE MEASURED (%)
				MEASURED	CORRECTED**	
6-1	A	Control	0.01	0.0	0.0	
6-2	A	20	0.02	3.7	3.7	0.06
6-3	A	100	0.01	7.6	7.6	0.46
6-4	AQ	Control	0.01	1.3	0.0	0.03
6-5	AQ	20	0.06	10.1	8.8	0.06
6-6	AQ	100	0.03	9.6	8.3	0.26
7-1	A	Control	0.01	3.7	0.0	0.04
7-2	A	20	0.01	8.4	4.7	0.25
7-3	A	100	0.04	8.9	5.2	0.44
7-4	AQ	Control	0.01	2.1	0.0	0.00
7-5	AQ	20	0.02	12.4	10.3	0.11
7-6	AQ	100	0.01	9.0	6.9	0.37

* "A" means that the specimen was twice annealed in a vacuum for 1 hr and slow cooled, first at 800°C and later at 900°C. All preirradiation measurements were made after the first annealing but prior to the second annealing. "AQ" indicates that the specimen was annealed at about 800°C and then quenched in liquid nitrogen for 10 minutes.

** The values in this column were obtained from the preceding column by subtracting the percentage changes of the control specimens.

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retained for controls) and irradiated in the Chalk River Reactor for periods of 20 and 100 days.

The precision of the measurements is estimated to be 0.02% for length, 0.4% for electrical resistance and 0.1% for density. The results given in Table 6, percent changes due to the effects of irradiation, are calculated on the basis of preirradiation values. Length showed no significant change. Electrical resistance changed as much as 10% (decrease), the effect being slightly greater in the case of the quenched specimens. There appears to be little correlation between exposure time and change in electrical resistance. The quenched specimens experienced less density change than those only annealed. Also, the longer exposure period produced the greater density change (decrease in density) in both the quenched and unquenched specimens.

Postirradiation hardness measurements will be made.

Personnel Addition to the Engineering Properties Section (O. Sisman, C. D. Bopp, R. L. Towns, and W. K. Kirkland). Beginning approximately March 1 the Engineering Properties of Irradiated Materials Group of the Reactor Technology Division will be combined with the Engineering Properties Section of the Physics of Solids Institute. This group is currently working on the physical properties of irradiated plastics, elastomers, and ceramics; pile-induced activity in engineering materials; induced activity and radiation damage with liquid metals in a flowing system; radiation stability of the MTR fuel assembly. This work is now being reported in the "General Reactor Engineering Research" quarterly report, but beginning next quarter it will be included in the Physics of Solids Institute quarterly report.

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