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# PHYSICS DIVISION

## QUARTERLY PROGRESS REPORT

FOR PERIOD ENDING
DECEMBER 15, 1949

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# PHYSICS DIVISION

A. H. Snell, Director
E. O. Wollan, Associate Director

# QUARTERLY PROGRESS REPORT
## for Period Ending December 15, 1949

DATE ISSUED FEB 7 - 1950


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## TABLE OF CONTENTS


INTRODUCTION AND SUMMARY 4

PHYSICS OF SOLID STATE 5

- Effect of Radiation on Metals 5
- Uranium-Aluminum Fuel Elements for MTR 5
- Bonded-Wire Strain Gages 5
- X-Ray Diffraction 6
  - The crystal structure of "$UAl_5$" 6
  - High-temperature study of $Fe_2O_3$ 8
- Irradiation Creep Experiment 8
  - Fabrication of fission heaters 9
  - Assembly and performance 9
- Thermal Conductivity of Uranium-Bearing Materials 12
  - Low temperature graphite samples 12
  - High temperature graphite samples and BeU alloy 14
- Radiation Damage in Germanium 15
  - Elastic energy loss of germanium ions 16
  - Comparison with experiment 18
- Recalculation of Fast Neutron Flux Distribution in X-10 Pile 19
- Saturation Effect as a Function of Irradiation 19

## INTRODUCTION AND SUMMARY

The classified section of the Physics Division Quarterly Progress Report is devoted in this instance entirely to the work of the Radiation Damage Section. (For the unclassified sections, see ORNL 577.)

*Radiation of Cu-Zn and Cu-Al Alloys.* Pile radiation causes a slight decrease in the resistivity of some of these alloys; this change does not anneal out below 200°C.

*Bonded-Wire Strain Gages.* A report has been issued covering a study of the best way to use bonded-wire strain gages for measurement of thermal coefficients of expansion. Applied to uranium, the gages indicate coefficients which vary from specimen to specimen, and even from place to place on single specimens, within the limits 5 to 30 x $10^{-6}$. Improvements on the technique of using these gages continue to be made.

*X-ray Diffraction.* The structures of the U-Al compounds are being investigated. Results on "$UAl_5$" have revealed the positions of the uranium atoms. Density considerations suggest that "$UAl_5$" is really $UAl_4$.

*Creep Experiments.* Fission heaters have been fabricated and tried in the pile, but they do not look very good. Construction proceeds on other apparatus for creep tests on wires and rods.

*Thermal Conductivity of Uranium-Bearing Materials.* Preliminary results show a decrease by a factor of 75 in the thermal conductivity of the outer part of a U-graphite slug as the result of pile exposure.

*Radiation Damage in Germanium.* Rough agreement has been obtained between the rate of change of conductivity observed in a Ge plate exposed to pile radiation, and the rate to be predicted on a simplified theory according to which the number of displacements resulting from elastic collisions and the resulting ionization by germanium knock-ons is estimated on stopping-power theory.

# PHYSICS OF SOLID STATE

## EFFECT OF RADIATION ON METALS

*D. S. Billington, R. H. Kernohan*

It has been shown that pile irradiation causes a slight decrease (ca 2%) in the resistivity of certain Cu-Zn and Cu-Al alloys (Cf. last Quarterly Report). Efforts to anneal out this effect have been made by heating the alloys up to 200°C. Thus far no change in the induced effect has been noted. Experiments are underway for studying the resistance-temperature behavior above 200°C.

## URANIUM-ALUMINUM FUEL ELEMENTS FOR MTR

*L. C. Templeton*

During the past quarter, because of the remodeling of parts of the pile building, this section was deprived of most of its experimental facilities, such as the hot laboratory. It is for this reason that measurements on the 45 days irradiation samples have not been completed. Results will be reported in the next report together with those for the 95 days samples, which have been received from Hanford in the meantime.

## BONDED-WIRE STRAIN GAGES

*M. R. Goodman*

ORNL 518 entitled "Thermal Coefficient of Expansion of Uranium by Means of Bonded-Wire Resistance Strain Gages" was issued recently, and the abstract is quoted below:

"With a view toward a better understanding of the uranium slug blistering problem and the causes of the dimensional instability of uranium, the thermal coefficient of expansion of various slugs and special samples of uranium was investigated. Bonded-wire resistance strain gages were used for this purpose. The coefficient of expansion of uranium at 32.5° to 60.0°C is unpredictable and may lie within the range 5.0 to 30.2 × $10^{-6}$. This wide range is in agree-

ment with values reported in the literature. Original structural inhomogeneities manifested by differences in coefficient of expansion found on one and the same sample are believed to exist along the uranium specimens.

"The strain gages used were found to have peculiar properties such as gage creep and gage zero shift which have to be differentiated from the effects due to the uranium. Methods are suggested to overcome these gage troubles so as to obtain greater strain gage stability and accuracy."

During the past quarter, experiments were performed with a different type of strain gage, embodying the principles previously learned. Results definitely indicate that, if bonded-wire resistance strain gages are properly used, coefficient of expansion can be measured to better than $\pm 0.2 \times 10^{-6}$. Better gage stability was also indicated in that the maximum gage zero shift thus far observed during cyclic temperature change between 32.5 and 60.0°C was within $+10$ and $-3 \times 10^{-6}$ in/in. A different type of gage creep was noted. For unstressed specimens, instead of the gage readings either constantly increasing or decreasing with time; a very slow fluctuation about the zero axis is observed. The maximum variation, during 10 days, has been about $\pm 15 \times 10^{-6}$ in/in.

A program is under way to observe and measure the effects of irradiation on strain gages and their components.

## X-RAY DIFFRACTION

*M. A. Bredig, B. S. Borie,* F. A. Sherrill*

*The Crystal Structure of "$UAl_5$" (B. S. Borie*).* The crystal structures of two of the three uranium-aluminum intermetallic compounds have been investigated by X-ray methods.[1] $UAl_2$ was reported to be diamond cubic ($a_0 = 7.72$ Å) and $UAl_3$ simple cubic ($a_0 = 4.26$ Å). The $UAl_2$ cell contains 8U and 16 Al atoms which are probably arranged in the crystobalite ($SiO_2$) structure. $UAl_3$ has one molecule per unit cell and is an isomorph of $AuCu_3$.

The third compound was reported to be $UAl_5$. It exhibits a *Debye-Scherrer* pattern too complicated to permit indexing and cell size determination.

The crystal structure of "$UAl_5$" is now being investigated using a *Weissenberg* goniometer. A series of photographs for rotation about two of the crystallographic axes reveals a body-centered orthorhombic cell of dimensions $a = 4.41$

* Metallurgy Division.

[1] A. R. Kaufman, P. Gordon, and R. N. Palmer, CT-953, 1943.

± .03 Å, $b$ = 6.25 ± .05 Å and $c$ = 13.60 ± .10 Å. In addition to the suppressed reflections characteristic of the body-centered cell, absences indicating a (001) glide plane were observed.

Space groups $C_{2v}^{22}$ - $I2ma$ and $D_{2h}^{28}$ - $Imma$ are the only ones which are consistent with the observed extinctions.[2] The only difference between these space groups is a mirror plane normal to the $a$ axis in the second one. Since the translation distance in this direction is 4.4 Å, and the atomic diameters of both uranium and aluminum are in excess of 2.5 Å, all of the atoms would be forced to lie in the planes $x = 0$ and $x = ½$ for this space group. Since the symmetry of such an atomic array may be described by space group $I2ma$, it is chosen as the space group of the crystal.

Because of the relative intensities of reflections of the type 0k0 and 001, the uranium atoms must lie in special positions 4($b$). (For the orientation chosen, the positions are $x$, ¼, $z$; $x$, ¾, $z$; ½ + $x$, ¾, ½ + $z$; ½ + $x$, ¼, ½ - $z$.) To satisfy the oberved intensities, $2\pi\ (x/a) = 0$ and $2\pi\ (z/c) = 40°$.

Since this space group has a center of symmetry in the $yz$ plane, a two dimensional *Fourier* synthesis of the electron density as projected onto this plane is possible. With moderately accurate values for the structure amplitudes one should be able to find coordinates for the aluminum atoms. A preliminary effort to accomplish this has yielded little more than confirmation of the uranium coordinates. In spite of the fact that the crystal used for the photographs is quite small, its absorption coefficient is large enough to require an absorption correction in the intensities. Since the crystal has a fairly irregular shape, such a correction will be difficult if possible at all. Further efforts to account for the absorption in the crystal and, failing this, to prepare a crystal of more regular shape are planned.

The data gathered thus far seem to indicate that the formula $UAl_5$ is incorrect. This formula was originally chosen by assigning to the compound the nearest simple formula lying within the proper composition range on the equilibrium diagram. However, the formula $UAl_4$ provides a better check with the crystallographic data. A sample containing the compound and free aluminum was found to have a density of 3.359 g/cc. This sample contained 24.0% uranium by weight. If it were assumed that each uranium atom is bound to five aluminums, the density of the compound would be 5.62 g/cc,[3] while its density, based on its molecular weight and the cell size, is found to be 6.44 g/cc. If it is assumed that the compound is $UAl_4$, the density based on these same physical

[2] Internatl. Tab. z. Bestimmung v. Kristallstruk., Gebr. Borntrager, 1935.

[3] M. A. Bredig and L. C. Templeton, Physics Division Quarterly Report, ORNL 365.

measurements is 6.13 g/cc as compared to 6.12 g/cc for its X-ray density.

Both X-ray densities mentioned were calculated assuming four molecules per unit cell. If a smaller or larger number is assumed, the agreement is worse in both cases.

Another argument against $UAl_5$ is that there is apparently not enough room in the unit cell for 20 aluminum atoms and four uranium atoms. In the face-centered cubic structure of aluminum there is one atom per 16.5 cubic angstroms. If it is assumed that a uranium atom occupies about the same volume as an aluminum atom, since uranium has approximately the same atomic volume as aluminum, for $UAl_5$ there is one atom per 15.5 cubic angstroms. It is unreasonable for the atoms to be more densely packed in the orthorhombic cell than in the face-centered cubic cell of aluminum. If the formula is assumed to be $UAl_4$, the volume per atom is 18.65 cubic angstroms. This compares favorably with 19.16 for $UAl_2$ and 19.32 for $UAl_3$.

A comparison of the volume per mole of $UAl_4$ to that of ($UAl_3$ + Al) shows that no significant volume change is involved in this reaction.

*High-Temperature Study of $Fe_2O_3$ (F. A. Sherrill).* The heating device of the X-ray diffraction counter spectrometer, referred to previously (Chemistry Division quarterly reports), was employed in the investigation of an iron oxide preparation submitted by C. G. Shull in connection with his neutron diffraction study of anti-ferromagnetism. Modifications in the apparatus, such as employing a lavite sample holder and an oxidation-resisting heating coil, permitted heating the oxide in air, thus avoiding decomposition into a lower oxide. No structural transition was observed in the temperature range up to 925°C.

## IRRADIATION CREEP EXPERIMENT[4]

*W. E. Brundage, W. Primak*[5]

An irradiation creep apparatus[6][7] was assembled with a hollow 2S-aluminum specimen heated by a fission heater[8] and operated in a fuel channel in the X-10 pile.

[4] Sponsored by the Argonne National Laboratory.

[5] Consultant, Argonne National Laboratory.

[6] ORNL 365, p. 15.

[7] ORNL 480, p. 22.

[8] ORNL 66, p. 44.

*Fabrication of Fission Heaters.* A creep unit similar to the pile unit but with a 3 section electrical heater was assembled and was placed into a wind tunnel operated to simulate pile conditions. The electrical heater was adusted until the three thermocouples placed at the ends and at the center of the specimen, respectively, were within 2°C of the desired temperature. The heat losses through the head end of the apparatus proved to be too large for the heat output of the fission heater as originally designed. Accordingly, the heater unit was lengthened and permitted to extend into the head end. This apparatus was calibrated electrically. From the calculations of L. P. Hunter[8] the uranium loadings required to reproduce the three sections of the electrical heater were computed. The $U_{235}$, in the form of $U_3O_8$ 93% enriched in $U_{235}$, was mixed in proper proportion with a mixture of petroleum coke and pitch ("K" mix). The final mixtures were pressed in a cylindrical mold to form the heater sections. The sections were cured for 24 hours at 200°C and then carbonized at 1000°C.[9]

*Assembly and Performance.* The fission heater cylinders (slugs) were hermetically sealed (heliarc-welded) into a stainless steel cylinder and assembled into the creep unit as shown in Fig. 1. The unit was inserted into a fuel channel of the X-10 pile by means of the auxiliary equipment (pile charging apparatus) shown in Fig. 2. With the pile operating at its normal power output it was found that the temperature maintained at the foot and center ends of the specimen were 2/3 of what was expected, and, at the head end, 1/2 of what was expected. It is believed that the neutron absorption of the construction materials were not adequately considered by Hunter in his calculations. Also, during the electrical calibration, the charging equipment was not attached to the creep unit. In the pile, heat must have been conducted from the head end by this charging equipment. It has become clear that the use of fission heaters is proving too clumsy for the present application. It is intended to replace them with suitable electrical heating.

The creep unit to perform creep tests on wires and rods[10] has been redesigned and partially fabricated[11] and is shown elsewhere.[12] Many of the assembly difficulties encountered in previous models have been eliminated. A specimen has been designed which does not slip and which creeps only in its gauge length. The specimen can be fabricated from a variety of materials.

(9) Data on the shrinkage of "K" mix - $U_3O_8$ mixtures on carbonization and on graphitization, and the density and mechanical properties of the resultant products had been previously obtained by C. Segaser in this laboratory (unreported).

(10) ORNL 480, p. 22; ORNL 365, p. 15. Also called high stress model ANL 4300, p. 58.

(11) Design work and supervision of fabrication by F. Beyer (ANL).

(12) See current quarterly report - Naval Reactor Division (ANL).

[redacted] DWG. No. 8194

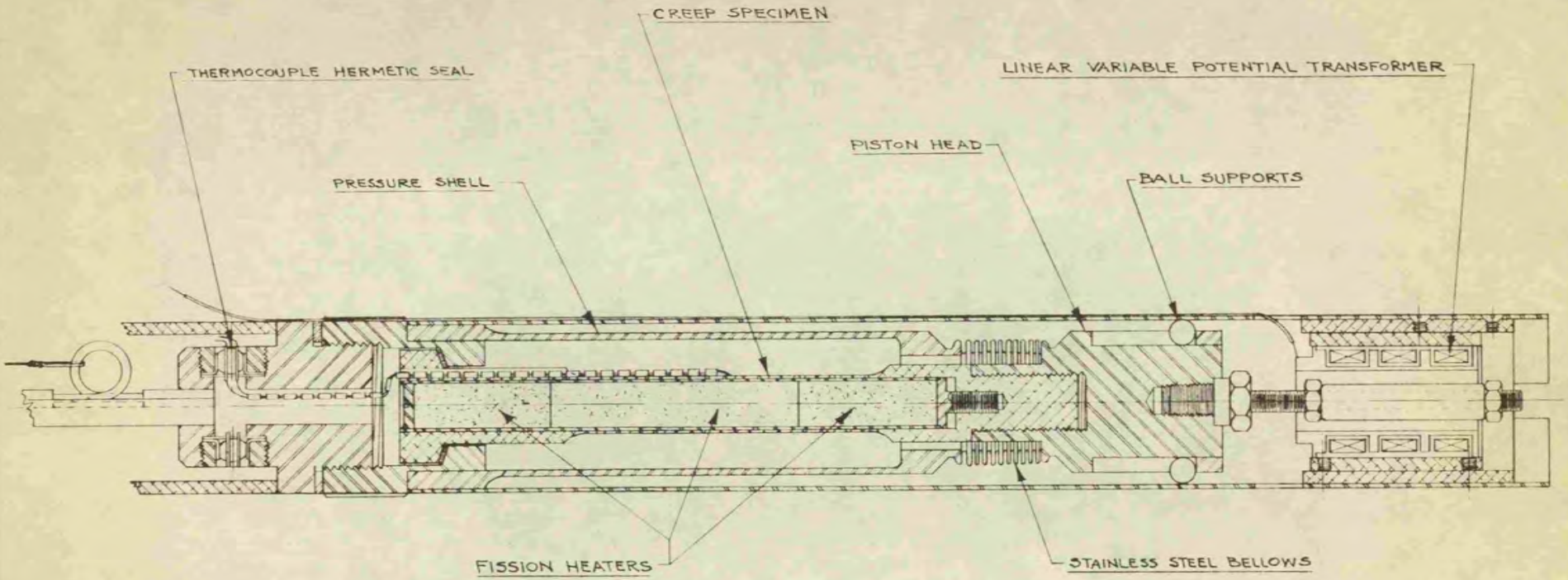


FIG. 1

PILE CREEP TEST APPARATUS

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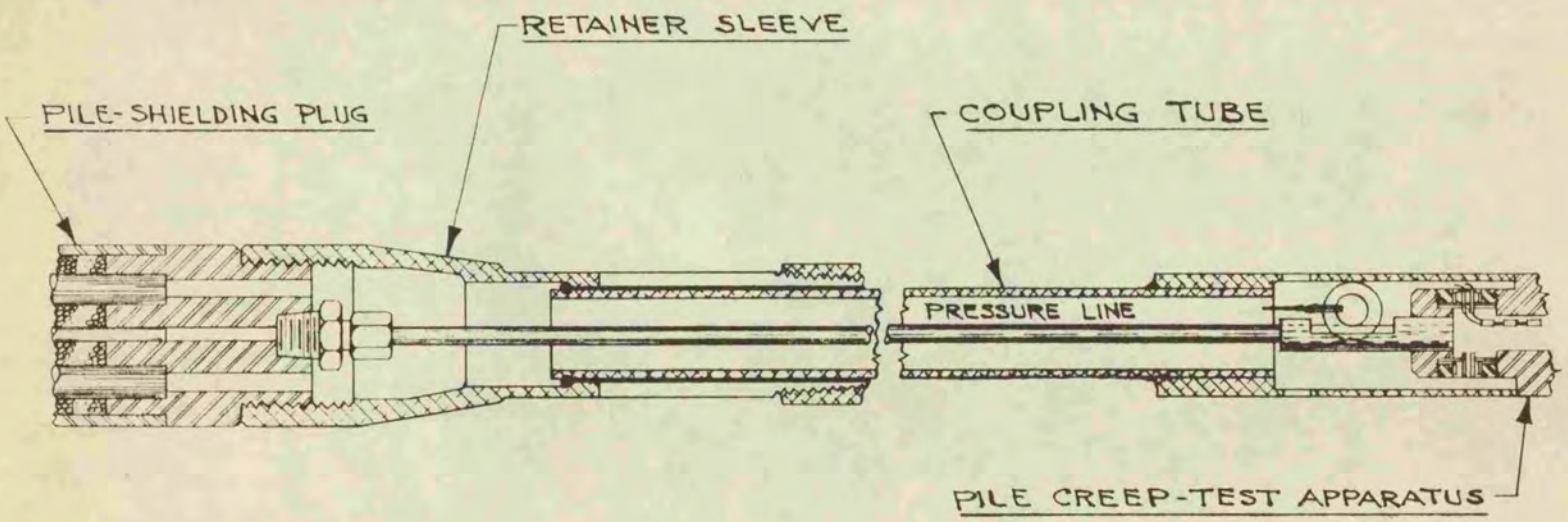


FIG. 2

PILE CHARGING TUBE

E. ANDREWS 12-30-49.

Several zirconium specimens have been fabricated and tested and found satisfactory.[13]

Instrumentation for recording extension has been completed.[14]

## THERMAL CONDUCTIVITY OF URANIUM-BEARING MATERIALS[15]

*R. G. Berggren, J. M. Kincaid, W. Primak*[16]

It was previously reported[17] that a low temperature thermal conductivity apparatus containing a UNH impregnated and fired graphite sample had been inserted into the X-10 pile. This irradiation is continuing. The results obtained are given below. In addition, the following thermal conductivity samples have been placed into the X-10 pile and are currently being irradiated:

(a) A BeU sample in the low temperature thermal conductivity apparatus. This alloy was discussed previously.[18]

(b) A UNH impregnated graphite sample which was then pitch impregnated and graphitized at 2500°C (graphite density approximately 1.6 gm/cc, 4.219 g uranium oxide per 24.268 g graphite). The sample was assembled in a modification of Hunter's high temperature thermal conductivity apparatus[19] developed by R. E. Githens (NEPA).[20][21]

*Low Temperature Graphite Samples.* Two temperatures were recorded for this sample, the temperature at a point at about .5 $r$ ($r$ is the radius of the sample) and the temperature difference between the points .75 $r$ and .5 $r$, and are referred to as $T$ and $\Delta T$ respectively. These are plotted as a function of the bombardment (The latter is estimated rather than measured and its scale may be in error by as much as 30%.) in Fig. 3. The peculiar shape of the $T$ curve is interpreted as an annealing of the thermal conductivity damage produced at lower temperatures caused by the rising temperature of the region between .75 $r$ and .5 $r$. The outer rim of the sample is at a fairly constant temperature—that of the wall of the torpedo. If it is assumed that the heat transfer coefficient from the sample to the walls has remained constant, it is possible to compute the temperature drops across the zones defined by the thermocouple positions, and hence the average thermal conductivities for these

(13) Fabrication and testing were performed by S. H. Paine (ANL) and will be reported separately.

(14) This work has been performed by C. E. Stilson (NEPA) and will be reported in detail shortly.

(15) Sponsored by the Argonne National Laboratory.

(16) Consultant, Argonne National Laboratory.

(17) ORNL 480, p. 20.

(18) ORNL 480, p. 21.

(19) TID 66.

(20) To be reported.

(21) We are indebted to Hugh Robertson (NEPA) for assembling this apparatus.

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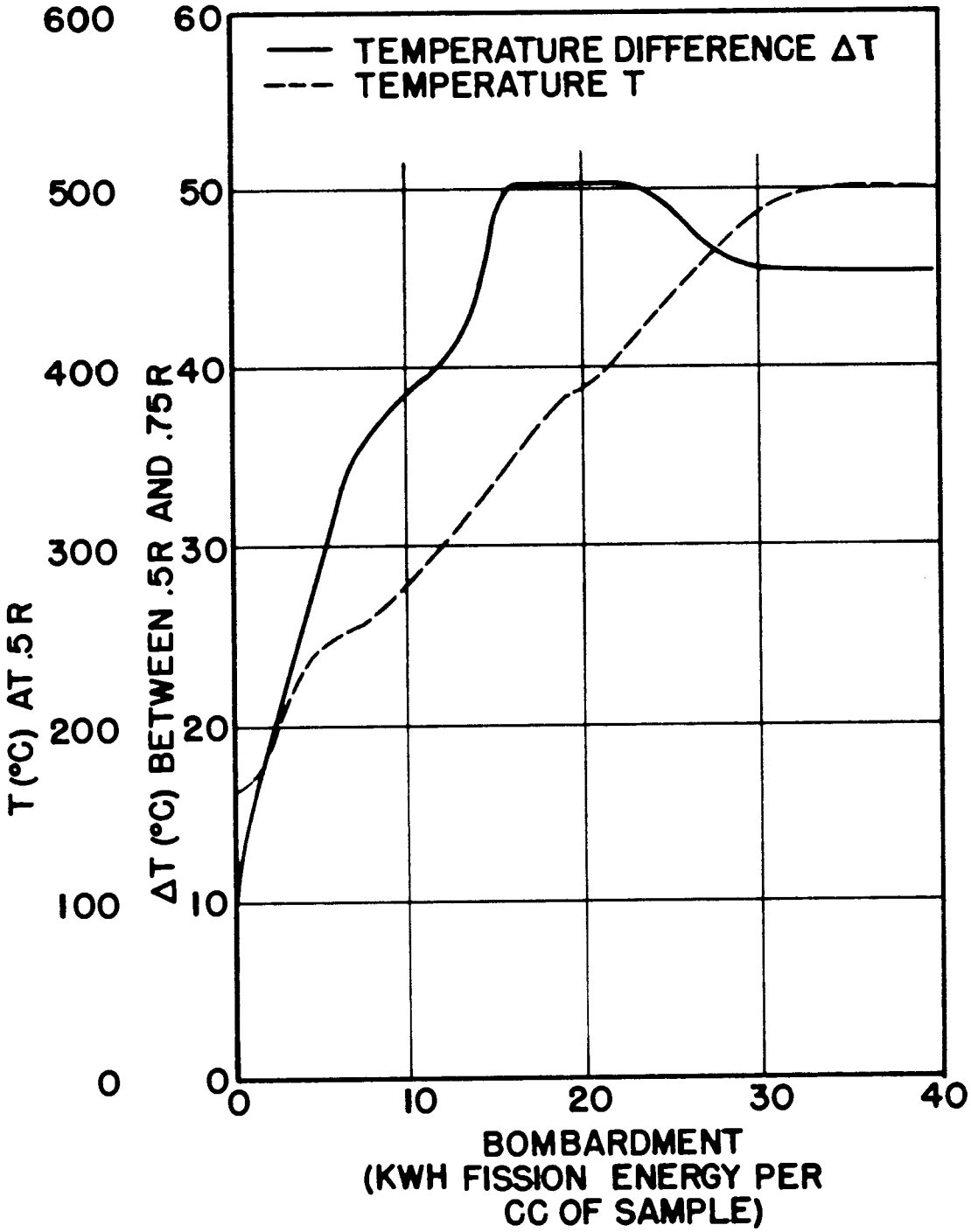


FIG. 3
BEHAVIOUR OF GRAPHITE SAMPLE IN LOW TEMPERATURE THERMAL CONDUCTIVITY APPARATUS

zones. The average thermal conductivity of the outer zone was estimated to have decreased by a factor of about 75. If this estimate is correct, the change is greater than that previously reported,[22][19] but it is what might be expected from the effect of the temperature coefficient on the results obtained by Hunter.[19][23] Accordingly, the flattening of the $T$ curve may be saturation. Since Hunter[19] found that even at higher temperatures a fifty-fold decrease in thermal conductivity is attained, it is expected that the $\Delta T$ curve will again start to increase and rise until such a value is reached. The irradiation is being continued to see whether this effect will be observed. The data obtained by Hunter, some of which have been reported[19] are being re-examined in the hopes that annealing effects might explain the sigmoid shape of his $\Delta T$ curves for graphite and the fall of his $\Delta T$ curves for BeO.

*High Temperature Graphite Samples and BeU Alloy.* These two samples were loaded into the same fuel channel at X-10 separated about 2½ feet from each other. (They were linked by two dummy torpedoes in a manner that permitted the parts to be disconnected for individual discharge from the channel.) The temperatures at which the samples operated were much lower than expected. The temperature at which the low temperature thermal conductivity apparatus operated indicated a power output of the BeU sample of about 1/3 that expected from the electrical calibration of the apparatus. The temperature at which the high temperature apparatus operated indicated a power output of about 1/2 that expected from the behavior of similar equipment placed in the pile previously. It was concluded that the neutron flux had been reduced by placing two samples into the channel simultaneously. Three possible causes are: (a) The samples were in a reduced flux region in the pile; (b) the samples shadowed each other; (c) the additional metal placed into the hole had a sufficient cross section to reduce the flux to the extent found. It was estimated[24] that the effect of (a) could not be more than 10% and that the effect of (b) was perhaps another 10%. Much greater local effects seemed likely from the third possibility (c). The equipment has now been redesigned to reduce its neutron cross section to a fraction of its former value, and this new equipment will be used in future experiments.

The irradiations have not progressed far enough to warrant an analysis of the data. The indications are that the thermal conductivity of the BeU alloy

(22) HW 13117.

(23) We are indebted to O. C. Simpson (ANL) for this suggestion.

(24) We are indebted to F. Thalgott (Argonne National Laboratory) for assistance in making these estimates.

is remaining sensibly constant and that the thermal conductivity of the graphite sample is decreasing slowly—more rapidly than previous high density impregnated samples,[25] but much more slowly than low density samples.[19]

## RADIATION DAMAGE IN GERMANIUM

*G. E. Evans*

A theoretical calculation has been made of the damage to be expected in germanium crystals from pile radiation. These calculations were based on several postulates: (1) That the lattice damage is due solely to the presence of displaced germanium atoms; (2) That these displacements are produced by the elastic collisions of fast neutrons or fast germanium knock-ons; (3) That other types of radiation present in the pile are of negligible effect; (4) That the effects of healing can be ignored; (5) That the interaction of a fast knock-on and a germanium atom can be treated as a two-body problem. Several of these postulates, and especially the last two, are of doubtful validity. Despite this fact, the results are in good agreement with experiment.

A preliminary calculation was carried out to determine the effect of inelastic collisions of germanium knock-ons with atoms of the lattice. It was assumed in these calculations that the effective charge of the germanium ions could be determined by the Knipp-Teller relationship, and that the classical equations for inelastic energy loss apply. According to the classical calculation of Bohr, the rate of inelastic energy loss ($-dE/dx$) depends only on the charge and velocity of the incident particle and the structure of the stopping material. This relation can be written

$$-(dE/dx)_I = (Nz_1)^{4/3}\ g\ [v/(z_1)^{1/3}], \qquad (1)$$

where $N$ is the density of the stopping material in atoms per cc, $z_1$ is the effective charge of the incident particle, and $v$ its velocity. $g[v/(z_1)^{1/3}]$ is a function of the parameter $v/(z_1)^{1/3}$ which is tabulated by F. W. Brown (NAA SR-4) from data for the ionization losses of alpha particles in air. By inserting values of $v$ and $(z_1)^{1/3}$ in the equation (1) above, we may thus calculate $-(dE/dx)_I$ for germanium ions in air at NTP. We may estimate the value of $-(dE/dx)_I$ for germanium ions in a germanium lattice by multiplying the rate of energy loss in air by the ratio of density of air to solid germanium and

[25] ORNL 365, p. 17.

the ratio of stopping powers of "air atoms" to germanium atoms. The stopping power of germanium relative to air is not known, but it was assumed that the stopping power should be approximately the same as that of copper. Even for copper the stopping power relative to air is not known in the energy range of interest, so an extreme extrapolation was necessary (involving considerable guess-work, since a straight-forward extrapolation of the existing data yields highly improbable results). A few of the results of these calculations are listed in Table I.

TABLE I

| $Hi$(ev/layer) | $E$(Ge) (Mev) | $E$ neutron (Mev) | $H'e$(ev/layer) |
|---|---|---|---|
| 6.41 | .242 | 8.8 | 7755 |
| 14.6 | .379 | 13.8 | 5587 |
| 698.4 | 4.64 | 168 | 746 |

In Table I, $Hi$ is the inelastic energy loss in electron volts per lattice layer; $E$(Ge) is the energy of the incident Ge ion in Mev. $E$ neutron is the energy of a neutron whose average knock-on would have the energy $E$(Ge), and $H'e$ is the elastic energy loss in electron volts per lattice layer. It is obvious from a comparison of these values that the inelastic energy loss is negligible compared to the elastic energy loss within the energy range of interest; even at 30 Mev neutron energy, the inelastic losses of Ge knock-ons amount to only 1% of the elastic losses, and at lower energies this percentage rapidly decreases. Thus despite the highly approximate nature of several of the steps in this calculation, it is felt that we may safely ignore inelastic energy losses of Ge ions as compared to elastic losses.

*Elastic Energy Loss of Germanium Ions.* Elastic energy losses, $(-dE/dx)e$, have been computed for Ge ions as a function of the energy of the Ge ion, using the equations developed by H. M. James (ORNL 307). Essentially the calculation is of the "family tree" type. For a given neutron energy $E_0$ we assume a uniforn distribution of knock-on energies ranging from zero to $4AE_0/(1 + A)^2$ where $A$ is the mass of the Ge atom. For each possible value of the knock-on energy, we compute the number and energy of the secondary knock-ons as the energy of the primary knock-on is reduced from its original value to 25 ev through elastic

collisions. In computing the number of secondary knock-ons, we consider only those elastic collisions transferring 25 ev or more energy to the struck atom, thus assuming that 25 ev is the energy required to displace a Ge atom from its lattice position. The secondary knock-ons may in turn produce tertiary knock-ons, whose number and energy can be estimated from the number and energy of the secondary knock-ons. The sum of primary, secondary, and tertiary knock-ons gives the number of knock-ons produced, on the average, for a single impact of a neutron of energy $E_0$ with a Ge atom in the lattice. This type of calculation is then repeated for a series of neutron energies covering the range of fast neutrons in pile radiation, giving the number of displacements $N(E)$ as a function of neutron energy. If we multiply this value by the fast neutron scattering cross section of germanium and the flux expressed as a function of neutron energy, and then integrate over the energy, we obtain the number of displacements to be produced in Ge per second when irradiated in the given neutron flux spectrum.

The fast neutron scattering cross section for germanium is not known, but can be replaced approximately by the cross section for zinc, expressed as a function of neutron energy. The neutron flux as a function of energy has been given by Weinberg et al. (CP-G 2439).

There are several major sources of error in the calculation of the number of displacements. We have assumed that the problem can be treated as a series of interactions of a fast Ge ion and individual atoms of the lattice, i.e., as a two-body problem. It is very doubtful whether this approximation is valid, considering the low knock-on energies involved. We have ignored the effects of healing; in fact we have ignored all structure sensitive features of the problem. The theory does not include any dependence on temperature, although changes in temperature are known to alter the net damage. We have incorporated data concerning the fast flux spectrum in the pile whose absolute accuracy is uncertain.

In view of these uncertainties, it is perhaps fortuitous that the theoretical results are in good agreement with presently available experimental data.

The number of knock-ons per initial knock-on from a neutron of energy $E_0$ can be given approximately by

$$Ns \text{ (total)} \doteq 1.19 \times 10^{-4} \; E_0 .$$

The number of displacements per neutron collision has been computed for three locations in the pile: (1) For the surface of a slug, 436; (2) For the center of the lattice, 135; (3) For the center of a slug, 682. If the damage is

proportional to the number of displacements, the ratio of damage at these positions should be 3.23 : 1.00 : 5.05. For graphite, the corresponding ratio computed for the same flux gives 2.4 : 1.0 : ?, showing that as the peak neutron energy increases, the damage increases more rapidly for germanium than for carbon. This result might be generalized to say that as the per cent ionization energy loss decreases, the sensitivity to the peak neutron energy value increases. The fact that, for different locations in the same pile, the ratios of damage produced are different for carbon and for germanium implies that it may not be possible in any simple way to predict the damage produced in one substance from a knowledge of the damage produced in any other substance. The damage produced depends not only upon the number and *average* energy of the neutrons, but also upon the distribution of neutron energies. A study of this problem using monochromatic neutrons appears profitable.

*Comparison with Experiment.* For a particular Ge plate, the Hall constant was measured as 135, so the number of carriers is given by $7.37 \times 10^{18}/135$ or $5.46 \times 10^{16}$ carriers. During the first two hours of irradiation, the measured value of $1/R$ fell from 0.259 to 0.097, a decrease of 0.00135 per minute. The relative decrease is

$$0.00135/.259 \times 60 = 8.71 \times 10^{-5}/\text{sec}.$$

Assuming a fast flux for this sample ("C" hole) of $7 \times 10^{11}$/sec, the number of carriers predicted per second from radiation damage is

$$(7 \times 10^{11})\ (135)\ (4.44 \times 10^{22})\ (10^{-24}) = 4.20 \times 10^{12}.$$

(The "135" above is the number of displacements per neutron collision at the center of the lattice; we assume one carrier per displacement.) The change in $1/R$ per second is thus

$$4.20 \times 10^{12}/5.46 \times 10^{16} = 7.69 \times 10^{-5}/\text{sec}.$$

or Theory: $7.69 \times 10^{-5}$/sec.
Experiment: $8.71 \times 10^{-5}$/sec.

Introduction of the effects of healing would tend to lower the theoretical damage rate.

Experiments are being planned to reduce the theoretical error inherent in the calculation above, by enabling empirical evaluation of rates of energy loss, etc, which are very difficult to evaluate theoretically. An examination

of the sources of error in this calculation indicates the need for further experiments in several fields: (1) Determining the effective charge of fast ions; (2) Determining the cross sections for inelastic collisions for a greater variety of ions, and especially in the lower energy and velocity range ($v < 10^9$ cm/sec); (3) Extending tables of fast neutron scattering cross sections to include more substances and lower energy neutrons; (4) Studying the structure-sensitivity of materials with respect to stopping power, especially for slow positive ions; (5) Studying the relation of damage to neutron energy using monochromatic neutron sources; (6) Determining the range-velocity relationships for different positive ions in various lattices to provide a critical test of certain portions of the above theory.

## RECALCULATION OF FAST NEUTRON FLUX DISTRIBUTION IN X-10 PILE

*D. K. Holmes*

For a more accurate understanding of the effects of neutron bombardment in solids a better knowledge of both the slow and fast neutron fluxes present during various tests is greatly desired.

It is a possibility that the values currently in use for the fast flux at various points in the pile may differ from the true flux by as much as a factor of two or three. The present values are taken from diffusion theory calculations which involve rather severe approximations. An attempt has been made to obtain the flux using a Monte Carlo type calculation, based on data taken directly from the X-10 pile. However, it was immediately found that the sampling must be quite large in order to effect any improvement over present values for the flux. The calculation will have to be made on the IBM, and awaits availability of manpower for this work.

## SATURATION EFFECT AS A FUNCTION OF IRRADIATION

*J. C. Pigg, K. Lark-Horovitz*

The question of how far neutron effects will saturate is of great importance in future reactor development. Since the electrical conductivity of a germanium semi-conductor is a sensitive indicator of neutron-produced changes, sample 42-V-3 (N type, resistivity 7 ohm cms) has been placed in a central hole and its conductivity has been followed as a function of irradiation. Due to

some temperature fluctuations there is a scattering of points, but the measurements do definitely indicate that the conductivity is still increasing after a total integrated flux of $6.8 \times 10^{18}$.