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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

APRIL 1964

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ORNL-3628

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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

APRIL 1964

DATE ISSUED

May 6, 1964

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Oak Ridge, Tennessee
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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

APRIL 1964

This Status and Progress Report summarizes the unclassified portion of the Laboratory's work. Some of the topics are included every month, but the majority are reported on a bimonthly schedule.

REACTOR DEVELOPMENT

GAS-COOLED REACTOR PROGRAM

Steam-Graphite Reaction Experiment. — A graphite fuel element sleeve of the type to be used in the EGCR was examined following exposure to superheated steam. The sleeve, which originally weighed 10,270 g, lost 1390 g during 1076 hr of exposure at a constant pressure of 155 psig and temperatures varying from 1200 to 1580°F. The depth of graphite removal from the wall of the sleeve varied from an average of 0.183 in. at the steam inlet end to an average of 0.0123 in. near the outlet end. We think the nonuniform removal of graphite is associated with a blanketing effect of the reaction products, hydrogen and carbon monoxide. The rate of reaction determined from the gas analysis is substantially less than the estimated value used in the EGCR design calculations.

GCR-ORR Loop No. 1 Operation. — Irradiation continued in the loop 1 experiment to investigate the behavior of radioactive fission products released to a circulating helium stream from a small hole in a stainless-steel-clad UO_2 fuel element. The cladding and central temperatures were maintained at approximately 1400 and 2400°F respectively. The fission-gas release rate continued to be low in comparison with that of a previous similar experiment. Pressure and temperature cycling did not affect the measured release rate.

LITR Capsule Irradiations. — Two capsules containing pyrolytic-carbon-coated particles in each of four compartments continued operation at indicated fuel central temperatures between 1400 and 2100°F. Both uranium carbide and uranium-thorium carbide mixtures are included in the capsules. Estimated burnups have now reached 7.6 to 15.3 at. % of the heavy metal (U + Th).

ORR Poolside Capsule Irradiations. — Irradiation of two capsules containing 6-cm-diam fueled-graphite spheres was completed, and we removed them for postirradiation examination. One of these (capsule 08A-7) was terminated prematurely after an estimated burnup of 2.3 at. % of total heavy metal when ^{133}Xe was detected in the control gas line. It was concluded that the leakage was from the static portion of the capsule. The

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other capsule (05B-7) had previously developed a leak in the primary container that allowed argon control gas to enter the sweep gas, and it had been retracted from the region of high neutron flux.

Two new capsules were installed, one containing EGCR-type fuel and the other containing 6-cm-diam fueled-graphite spheres. Irradiation of two other capsules continued. One contains EGCR fuel, and the other contains 6-cm-diam spheres.

Eight-Ball Experiment. — The fourth eight-ball experiment was completed. In this experiment the test specimens consisted of 1-1/2-in.-diam spheres fueled with pyrolytic-carbon-coated UC_2 fuel particles. A fifth similar experimental assembly was installed.

Phase Relationships in the Th-U-C System. — Differential thermal analysis of several of the ThC_2-UC_2 alloys not previously examined by this technique indicated that at UC_2 contents of 33 wt % or less the transformation takes place over a narrow temperature range with very little hysteresis evident (based on comparison of transformation temperatures obtained on heating and cooling). However, the alloys containing 50 and 67 wt % UC_2 showed a much broader main transformation peak with greater thermal hysteresis. A second peak also appeared after we heated the alloy to approximately 1300°C. This peak was smaller and sharper than the main peak, but in the case of the 50 wt % UC_2 alloy it was approximately 160°C lower in temperature than the main peak; for the 67 wt % UC_2 alloy the small peak was approximately 80°C higher in temperature than the main peak.

Examination of the x-ray diffraction traces of these specimens showed that the broadening of the main peak could be correlated with an increase in the range of temperatures at which both high- and low-temperature structures coexisted. However, because of the temperature gradient across the x-ray diffraction sample, we could not check the temperatures accurately. The x-ray diffraction traces did not show any structure change which would correlate with the secondary peaks noted above. However, if they were due to a small amount of a second phase appearing and disappearing, we would not expect this to show on the x-ray diffraction pattern. The lattice parameters from diffraction patterns of the high-temperature cubic phase at 1500°C are in close agreement with those calculated on the assumption that the alloys obey Venard's law.

Thermal Conductivity and Electrical Resistivity Measurements on Graphite. — Measurements of the thermal conductivity of CGB graphite normal to the extrusion direction were extended to 910°C in a radial heat flow apparatus. The results at 704 and 604°C after exposure at 910°C were about 1% higher than those of the first heating cycle. This increase was caused by slight contamination of the Pt–10% Rh vs Pt thermocouples at 910°C.

The results obtained to date may be described to within ±2% by the relation

$$1/k = R = 0.001265\ T(°K) + 0.5454\ ,$$

where R is the thermal resistance in w^{-1} cm °C. It should be noted that these results are tentative pending remeasurement of the thermocouple positions. Prior to this remeasurement, which calls for the destruction of

the measuring disks, we will reinstrument the specimen with new Pt–10% Rh vs Pt thermocouples, install the cold-wall muffle, and obtain data from 50 to 200°C. These data are needed to supplement the previously obtained low-temperature results, which were in doubt because of very small temperature differences.

Isothermal, steady-state, electrical resistivity measurements were made both perpendicular and parallel to the extrusion direction on specimens machined from the same CGB bar stock. Measurements were by the four-probe potentiometric method under a vacuum of 10^{-5} to 10^{-6} torr, between 23 and 1000°C, and were reproducible to ±0.1% and accurate to within ±0.25%. The results indicate that the resistivities in the perpendicular and parallel directions are in the ratio of about 2:1 over this temperature range. The electronic portion of the thermal conductivity, calculated by using the Wiedemann-Franz-Lorenz relation,

$$k_e = LT/\rho \ ,$$

where

k_e = electronic portion of k [w cm^{-1} $(°C)^{-1}$],

L = Lorenz number, 2.447×10^{-8},

T = temperature (°K),

ρ = electrical resistivity (ohm-cm),

is less than 1% of the measured k at room temperature and is approximately 6% at 1000°C in the perpendicular direction. The validity of the W-F-L relation is questionable, particularly for graphite, but the analysis is included for completeness.

Measurements of the thermal conductivity of CGB graphite both parallel and perpendicular to the extrusion direction will also be made in a longitudinal heat flow apparatus. Evaluation of the apparatus has yielded encouraging results. The low-temperature results from this apparatus and those from the radial heat flow apparatus, along with the previously noted electrical resistivity data, will permit a more complete analysis to be made of thermal conduction in graphite.

EGCR Startup Studies. — The IBM 7090 program TRAN is a code for calculating the transient behavior of the neutron flux as a function of position in a reflected reactor following injection of a pulse of neutrons. Improvements in the method for obtaining converged eigenvalues for the matrix which yields the time-dependent magnitudes of the various components of the flux have resulted in nearly fivefold reductions in running time relative to the time required by earlier versions of the program. The speed and accuracy of the program are now satisfactory for the performance of numerous survey calculations, as well as for the detailed analysis of experiments in pulsed subcritical assemblies.

Fast Gas-Cooled Reactor Studies. — Parametric studies, similar to those previously reported for helium and SO_2 coolants, were performed for a CO_2-cooled fast reactor with stainless-steel-clad UO_2-PuO_2 fuel. Results for CO_2 cooling are very similar to those for helium cooling for equal volume fractions of the various constituents. Heat transfer calculations indicate that a somewhat smaller volume fraction of CO_2 than

of helium would be required, and, as a result, there would be a correspondingly smaller volume of metal in fuel-element spacers. An optimized CO_2-cooled reactor may therefore be expected to have a slightly higher breeding ratio than an optimized helium-cooled reactor.

ARMY PACKAGE POWER REACTOR PROGRAM

A PM fuel specimen assembly was inserted into the A-2 position of the ORR pressurized-water loop on December 20, 1963, as a companion to the PM fuel specimen assembly which had been initially placed in the A-1 position of the loop August 29, 1963. Soon after the insertion of the second assembly, the concentration of soluble ^{60}Co in the water began to increase. Within two months the concentration rose tenfold to about 25,000 dis sec^{-1} $liter^{-1}$. The increase appeared to be due to an increase in the rate of release to the water rather than to a decrease in removal from the water, because tests showed that the purification system was operating at its normal efficiency.

A likely source of ^{60}Co in large quantities was the cobalt alloy (NIVCO, 73.50% Co) used as a neutron flux suppressor in the fuel assemblies. Both fuel assemblies were removed from the loop February 22, 1964, in order to determine if the flux suppressors on the assemblies had undergone significant corrosion.

The hot-cell examination of the assemblies showed that the nickel plate and the underlying cobalt alloy of the flux suppressors of the A-2 position assembly were corroding.

When the fuel assemblies were removed from the loop, the ^{60}Co concentration immediately dropped by about 30%. During the month to follow, while the fuel assemblies were being examined, the ^{60}Co concentration decreased by another 20%.

On March 9, 1964, the A-1 position assembly was reinserted into the loop and was operated to the end of ORR cycle No. 52 with no apparent effect on the concentration of soluble ^{60}Co. The data indicate that ^{60}Co deposited in the loop is being slowly dissolved in the coolant and that the A-2 position assembly was the source of the high ^{60}Co level.

In the meantime, the defective flux suppressors were removed from the A-2 position specimen holder in a hot cell and were replaced with cobalt alloy flux suppressors which have a nickel plate applied by a different technique. As a backup measure, an order was placed for hafnium, to fabricate flux suppressors to replace the cobalt alloy should these corrosion problems persist. The defective flux suppressors were examined destructively, and the corrosion effects noted were found to be quite extensive.

The A-2 position fuel assembly was reinserted into the loop on April 10, 1964, and both assemblies are operating satisfactorily with no increase in the coolant ^{60}Co activity.

REACTOR FUELS AND MATERIALS

Behavior of High-Temperature Materials Under Irradiation. — Dimensional measurements of the BeO specimens irradiated in experiment 41-8

(maximum dose, 8.2×10^{21} neutrons/cm^2) have been completed and compared with those of specimens of experiment 41-9, which was irradiated over the same flux profile as 41-8 but to a lower maximum neutron dose (4.0×10^{21} neutrons/cm^2). No differences in volume expansion were found among the four types of BeO irradiated at 650°C, but low-density, small-grain BeO expanded the least and high-density, large-grain BeO expanded the most at 1100°C in both experiments. This result correlates with gross damage data. For corresponding doses at 1100°C, BeO irradiated at low fluxes expanded more than specimens of the same types irradiated at high fluxes. This unexpected effect is still under investigation.

Conceptual designs for a series of irradiation experiments with unfueled pure carbides have been developed for irradiation in the ETR facility. The first specimens will be irradiated at low temperature (200 to 400°C) in water-cooled stainless steel capsule assemblies. Very high temperature (1200 to 1500°C) irradiations will follow, utilizing uncompacted carbide powder beds to isolate the specimens from dissimilar containment materials and to provide a thermal-gradient annulus for dissipation of heat to the secondary containment. Details and preliminary calculations for these experiments have been submitted for preparation of construction drawings and fabrication. The experiments will contain 1/2-in. right cylinders, single crystals, and powders of high-purity Cb, Ta, Ti, W, and Zr carbides.

FUNDAMENTAL HEAT TRANSFER AND FLUID DYNAMICS

Boundary-Layer Transient Phenomenon. — Analysis of the fluctuating component of the local rate of heat transfer to turbulently flowing water (measured by the hot-film surface probe previously described) was performed by using an analog filter circuit. The resulting power spectral density (relative power per unit bandwidth) vs frequency correlations are qualitatively similar to spectra of the longitudinal component of velocity fluctuations measured in boundary layers as reported in the literature. This similarity suggests that the observed fluctuations at the fluid-solid interface may be "induced" by longitudinal velocity fluctuations near the pipe wall. An experiment is in preparation to test this hypothesis by correlation analyses of the fluctuations in local heat transfer rate and fluid velocity.

Boiling-Potassium Studies. — Additional information concerning the effect of cavity radius on the amount of liquid superheat required to sustain nucleate boiling of potassium from a heated surface was obtained with the 20-in. natural-circulation loop. A new boiling surface was constructed of 1/2-in. sched-40 type 347 stainless steel pipe with nine 0.006-in.-diam holes drilled through the wall and subsequently welded closed from the outside to produce pores with a length-to-diameter ratio of approximately 10 on the inside surface of the pipe. The holes were spaced 3/4 in. axially and 180° circumferentially. The boiler and condenser were instrumented with 0.010-in.-diam Chromel vs Alumel thermocouples spot welded to the outside surface. Stable boiling was achieved in the temperature range 900 to 1550°F with superheats ranging from 81 to 15°F respectively. At the low saturation temperature levels (900 to

1250°F) where superheat values varied from 81 to 19°F, respectively, the preliminary data are in good agreement with predictions based on the thermodynamics of bubble formation and cavity size; the superheat values at the higher saturation temperatures are somewhat higher (3 to 12°F) than predicted.

An intermediate-flux boiler (100,000 Btu hr^{-1} ft^{-2} maximum heat flux) was installed in the forced-convection boiling-potassium loop in lieu of the high-flux boiler, which has been delayed by fabrication difficulties. Stable boiling was readily achieved and maintained by the use of two boiling cavities at the boiler entrance. Two series of runs were made that terminated in critical heat flux values of 60,000 Btu hr^{-1} ft^{-2}, with a mass flow of 0.697×10^{-5} lb hr^{-1} ft^{-2} and an exit quality of 99 to 100%, and 85,000 Btu hr^{-1} ft^{-2}, with a mass flow of 0.992×10^{-5} lb hr^{-1} ft^{-2} and an exit quality of 98%.

Reynolds Stress Measurements. — Some experimental error in the values of the Reynolds stresses observed in the water-flow test facility is believed to have been caused by the use of a hot wire whose length was too great relative to the pipe diameter, and the experiment was accordingly transferred to a larger-diameter flow facility. In this new facility the pipe diameter is 8 in. (compared with 3 in. in the water loop) and the fluid is air. The hot-wire probes were redesigned for the new medium by lightening the needle supports and selecting a 0.00012-in.-diam tungsten wire to replace the 0.00023-in.-diam nickel wire used for the water-flow studies. A satisfactory tungsten-to-steel electrical connection by a modified soft-soldering procedure was developed, and tungsten has proved to be greatly superior to nickel as a hot-wire material.

The measured pressure drop in the air test facility compared accurately with that predicted from the standard friction-factor plot by use of the flow rate obtained by integration of the measured mean velocity profile. In the law-of-the-wall region, the velocity profile compared satisfactorily with the well-known smooth-pipe law.

Reynolds stress measurements have been made in the air-flow system with the following results:

1. The $\overline{u_x^2}$ component of the turbulent stress, referred to the friction velocity, compares favorably with that observed by Laufer.
2. The shear components, $\overline{u_x u_\theta}$ and $\overline{u_r u_\theta}$, are measured to be zero, as expected.
3. The $\overline{u_x u_r}$ shear component is approximately 70% of the value predicted by the measured pressure drop.
4. Uncertain results have been obtained for the $\overline{u_r^2}$ and $\overline{u_\theta^2}$ normal stresses.

POWER REACTOR FUEL PROCESSING

Chemical Analysis of Advanced Reactor Fuels. — The use of electrometric methods of analysis for elements contained in fuels either by choice or through contamination is a continuing study. Chronopotentio-

metric techniques are being studied in an effort to determine the effect of strong oxidants on electrode surfaces and as an aid in the elucidation of electrode reactions. The information obtained from chronopotentiometric studies does not lead directly to more sensitive or precise analyses, but is expected to clarify voltammetric processes that do yield precise quantitative data at low concentrations.

An examination of a new form of carbon known as "glassy" carbon is being carried out to evaluate its use as an indicator electrode material. Glassy carbon is a pure form of carbon and has much the same structure as a glass. It is highly impervious to gases and liquids. In contrast to pyrolytic graphite, glassy carbon is isotropic. Although some of the data are contradictory, the indications are that electrodes made of this material will be most suitable for conductimetric and potentiometric titrations of redox systems. The apparently very high capacitance of an electrode of glassy carbon will result in a charging current of such magnitude as to make voltammetric usage difficult.

Hot-Cell Dissolution Studies on PuO_2-UO_2 Fuel. — Sectioned specimens of irradiated stainless-steel-clad pellet and swaged PuO_2-UO_2 fuel samples were obtained from the Vallecitos Atomic Laboratory of the General Electric Company in connection with their Fast Oxide Breeder program. The samples, which were irradiated in the General Electric Testing Reactor from 36,300 to 42,700 Mwd per metric ton of uranium plus plutonium and decayed about three years, were declad with sulfuric acid, and the exposed oxide fuel was dissolved in nitric acid to determine rates of dissolution of the mixed oxides. Parallel tests were made with mechanically declad samples.

The swaged oxides generally disintegrated to a fine powder when the stainless steel cladding was removed with 6 M H_2SO_4 (Sulfex process). About 1% of the uranium was lost to the decladding solution. The pellets, which had a density 95% of theoretical, were intact after decladding; however, the soluble uranium loss was about 2%. Plutonium losses are not available at this time.

Analyses indicate rapid dissolution of the irradiated pellets: complete dissolution in 3.5 or 7 M HNO_3 in the absence of fluoride in less than 1.5 hr to provide terminal concentrations higher than 200 g/liter of heavy metal. Unweighable dissolution residues contained principally iron, chromium, and nickel from the stainless steel, and molybdenum, rhodium, palladium, and zirconium from fission products.

One batch of swaged oxide was dissolved in 10 M HNO_3. About 82% of the uranium dissolved to a concentration of 287 g/liter in 2.5 hr; 96% was dissolved in 23.5 hr. The balance of the oxide was dissolved in less than 2 hr in a fresh batch of 10 M HNO_3–0.05 M NaF. The lower rate of dissolution of the swaged oxides may have been caused by a higher local density for these oxides.

The fuel specimens, containing 20% PuO_2–40% $^{235}UO_2$–40% $^{238}UO_2$, were prepared at the Vallecitos Atomic Laboratory of the General Electric Company. The mixed plutonium-uranium oxides were made by precipitation from nitrate solutions with ammonium hydroxide, drying, and reduction to oxide in a hydrogen-nitrogen atmosphere at 900°C. Finely ground oxide was either pressed into pellets and sintered to a density 95% of theoretical

and then loaded into stainless steel tubes, or swaged to 75% of theoretical density in stainless steel tubes. The specimens developed heat fluxes of 0.86×10^6 to 1.24×10^6 Btu hr^{-1} ft^{-2} and cladding surface temperatures of 930 to 1080°F during irradiation. All specimens contained a void in the fuel column due to center melting.

Dissolution of Sol-Gel-Derived ThO_2-UO_2. — Cyclic dissolution tests were made with 2-g charges of typical ThO_2-UO_2 (96-4%) produced by the sol-gel process. In these tests the oxide was digested for 20 hr in boiling 13 M HNO_3–0.04 M HF–0.04 M $Al(NO_3)_3$, the dissolved ThO_2-UO_2 was removed, and a fresh charge of oxide and acid was added to the undissolved ThO_2-UO_2 prior to the next digestion. This procedure was repeated for six cycles in two series of experiments. In one series, the thorium concentration in solution would have been 1 M if each charge of fresh oxide had totally dissolved; in the other, the goal was a thorium concentration of 0.5 M.

In the first series, steady state was achieved in about two cycles. The solutions from each of the first two cycles had thorium concentrations of about 0.8 M and H^+ concentrations of about 9.5 M. About 90% of the oxide present at the start of each cycle was dissolved; that is to say, the heel represented about 10% of the oxides. Over the six cycles, 97% of the oxide charged was dissolved. These results are in good agreement with those obtained in engineering-scale tests.

In the other series, steady state was also achieved in about two cycles. The solutions had thorium and H^+ concentrations of about 0.4 and 11.5 M respectively. About 96% of the oxide present at the start of each cycle was dissolved; the heel, therefore, represented about 4%. Over the six cycles, more than 99% of the oxide charged was dissolved.

Thorium-Uranium Feed Adjustment Studies. — Several methods for preparing stable acid-deficient thorium and uranium nitrate solutions are being examined as possible bases for head-end processes in fuel recovery systems. Preliminary results show that solutions containing only about 1 mole of nitrate per mole of thorium may be prepared by multiple contacts of thorium nitrate solutions with a tertiary amine. An aqueous solution containing 200 g of Th per liter, 0.010 g of U per liter, 0.1 M F, 0.2 M Al, and 0.06 N HNO_3 was contacted with equal volumes of 0.1 M Alamine 336 in n-dodecane that contained 3.5 vol % tridecyl alcohol. After the aqueous solution was contacted with 3.7 moles of amine per mole of thorium, only about 1 mole of nitrate per mole of thorium remained.

Chloride Volatility. — The behavior of uranium chloride during conversion to U_3O_8 at high temperature and the nature of the UO_2 obtained by subsequent reduction of the U_3O_8 with hydrogen were investigated. Uranium chloride was produced by chlorinating uranium metal turnings and collecting the volatilized uranium chloride at the cool exit of the quartz reactor. In one run, the uranium chloride was converted to U_3O_8 by oxidation with pure oxygen at 100 to 600°C in 30 min. In a similar run, oxygen containing 3% water vapor was used. The two U_3O_8 products contained 0.04 and 0.001 mole of chloride per mole of U_3O_8 respectively. After the U_3O_8 was reduced with pure hydrogen at 600°C for 30 min, the UO_2 products contained 7×10^{-4} and 6×10^{-4} mole of chloride per mole of UO_2 respectively. The surface areas were 0.7 and 0.08 m^2 per gram of

UO_2 respectively. The U_3O_8 samples lost 105 and 102%, respectively, of the theoretical weight change during the reduction. These experiments show that uranium chloride can be converted rapidly to UO_2 and that the surface area of the UO_2 product can be decreased by adding water vapor to the oxygen.

Corrosion. – In 90% H_2SO_4–10% HNO_3, which is being considered as a chemical "burning" reagent for graphite fuels, Duriron and tantalum corroded at maximum rates of 0.2 and 0.3 mil/month, respectively, for 24 hr of exposure at 150°C. Of the materials tested, only these two showed sufficiently low rates. Types 309SCb and Carpenter 20SCb stainless steels, Corronel 230, Ni-o-nel, and Nichrome V showed maximum rates which varied from 7.7 to 29.9 mils/month.

Exposure of welded Corronel 230 in two successive cycles of burning UO_2-ThO_2-graphite fuel in oxygen at 800°C for 5 hr, followed by leaching in boiling 13 M HNO_3–0.04 M HF for 3 hr, resulted in a very slight weight gain without any apparent local attack. Exposure of welded specimens of type 309SCb stainless steel, Haynes 25, Hastelloy F, and Corronel 230 for 504 hr in boiling 7 M HNO_3–0.05 M HF containing 0.24 M dissolved UO_2 plus 0.06 M dissolved rare-earth oxides (used to simulate PuO_2) resulted in overall corrosion rates of 0.4, 0.6, 0.5, and 0.3 mil/month respectively.

Superheated steam plus 1% oxygen, being studied as a possible agent for decomposition of carbide fuels by hydrolysis, reacted with "A" nickel to form an adherent film. Assuming the oxide to be NiO, the weight gain corresponded to a corrosion rate of 1.8 mils/month for the first 168-hr exposure and of 1.5 mils/month for the first 336 hr. Type 304L stainless steel in steam at 825°C went through a period of initial weight gain and subsequently suffered scaling. At an exposure time of 1344 hr, the apparent corrosion rate was 0.3 mil/month. If the specimens had been descaled, the rate would have been higher.

Nickel exposed in pure oxygen formed an adherent, protective film at temperatures up to 800°C. At higher temperatures, the oxide film spalled irregularly. Nominal corrosion rates (based on weight gains) increased from 1.2 to 3.9 mils/month for exposures of 168 and 1008 hr, respectively, at 900°C and were higher but very erratic above 900°C.

Shear-Leach Process. – Two 10-liter batch leaching runs indicated that unirradiated stainless-steel-clad ThO_2–3% UO_2 pellet fuel sheared to 1/2-in. lengths may be leached on a 20-hr cycle to yield a product solution, nominally 1 M in thorium, and an undissolved residue of ThO_2-UO_2 amounting to less than 0.1% of the initial fuel. A ThO_2-UO_2 recovery of 99.9% was achieved in about 18 hr when the final solution contained 250 g of Th per liter and was 8.2 M in H^+, and in 16 hr for a final loading of 215 g of Th per liter in 9 M H^+. The initial leaching agent in both runs was 13 M in HNO_3, 0.04 M in F^-, and 0.04 M in Al; air sparging suspended the fuel fines released from the slotted fuel basket.

Stainless-steel-clad ThO_2-UO_2, when sheared into 1/2-in. lengths by a single-pin shear, released only about 37% of the core material from the cut piece, as compared with a value of about 90% for shearing of a multiple-tube array. This indicates that the relatively inexpensive single-pin shear, such as would be employed for small-scale reprocessing, will generate fewer core fines, thereby lessening the leacher agitation requirements.

THORIUM UTILIZATION PROGRAM

Kilorod Program. — The final 65 fuel rods containing 3% ^{233}U and 97% thorium were fabricated in the facility, completing the order for 1100 rods for the Brookhaven National Laboratory. Before the facility was placed in standby, a final run was made to obtain data on radiation exposures to operators during the handling of more highly radioactive fuel materials than those used for the Kilorod Program. Aged ^{233}U containing a concentration of ^{228}Th comparable with that in 14-day-old feed containing 1000 ppm of ^{232}U was used for this run. Data obtained during the blending and drying operations indicate no appreciable increase in worker exposure over that obtained during the processing of Kilorod material containing only 38 ppm of ^{232}U.

Thorium-Uranium Fuel Cycle Development Facility. — Title II design of the TUFCDF by the architect-engineer was authorized April 3, 1964; completion of the project is scheduled for early 1967. In the associated process development program, tests made with an experimental dryer indicate that radiant heating is completely satisfactory for gel drying and that the drying time can be reduced very markedly if fired particles of very large size are not required.

Preparation of Sol-Gel Microspheres. — Preparation of about 2300 g of thoria—8 wt % urania (highly enriched) microspheres needed for several proposed test programs was completed. After calcining, 56 wt % of the microspheres were 149 to 297 μ in diameter, 26 wt % were 297 to 420 μ in diameter, and the remainder were either smaller than 149 μ or larger than 420 μ.

The design and fabrication of a column to demonstrate the ORNL procedure for making microspheres as part of a sol-gel process exhibit at the Geneva Conference were started. The cylindrical column wall and solid tapered core proposed for future columns will be tested for this exhibit. Calculations were completed for a core with a graduated taper such that a specified linear fluid velocity at any point can be obtained by moving the core axially in the column. The tapered core will be made of Lucite for the column at the exhibit.

Both microspheres of 8% $^{235}UO_2$—ThO_2 and "emitting particles" of 1 to 10 μ diameter prepared for irradiation tests at General Atomic, Battelle Memorial Institute, and ORNL are ready to be delivered, except for analytical evaluation of the product fired in 4% H_2—96% Ar. The physical and chemical evaluation of the above microspheres at the air-calcined stage is complete. Although the gas evolution was high (0.65 cc/g), oxygen comprised 90% of the gases.

A 20-g batch of extremely small microspheres (0.5 to 7.5 μ in diameter) was prepared. These microspheres did not sinter on air-firing at 1150°C for 1 hr.

Gel-Sizing Studies. — Several alternative methods to ball-milling are being studied for sizing oxide fuels. Evaluation of the sol-gel oxides prepared by dripping thoria sols into boiling 2-ethylhexanol indicates that they are not suitable for use as the fine fraction in vibratory compaction because of open porosity. Although the size distributions of the particles were appropriate for the fine fraction of a two-fraction

vibratory-compaction mixture, and the pycnometric densities were 98.0 to 98.6% of theoretical, when these particles were substituted for the regular sol-gel particles of about the same size distribution, the bulk density of the vibratorily packed material was decreased about 3%. Examination of cross sections of the particles disclosed open porosities of about 5 to 10 vol %, explaining the 3% decrease in packed density.

A 1200-g sample, intended to represent what would be produced by ball-milling as a means of sizing gel in the Thorium-Uranium Fuel Cycle Development Facility, was prepared for examination. The proposed dryer conditions were used, and the material was air-calcined only. The gel did not degrade as rapidly as expected from previous results. Only 11 wt % of −200-mesh particles was obtained in 20 min; a longer ball-milling time should be used to produce more fines.

Sol Encapsulation Studies. — The encapsulation of ThO_2—3% UO_2 sol drops in organic polymer coatings and drying to obtain gel particles is still being studied under subcontract at the Southwest Research Institute. With a cellulose acetate—butyrate polymer, good encapsulated sol drops were formed, but collapse or breakage of the capsule wall due to shrinkage of the sol during drying continued to be the principal problem. Ethoxycellulose polymer and a phenoxy resin were tested as the encapsulating material, but satisfactory conditions for the hardening bath were not determined.

Additional tests were made of the gelling of sol drops by introducing them into diethylenetriamine or ethanolamine. Smooth spheres of 270-μ average size were prepared by washing the drops gelled in diethylenetriamine repeatedly in acetone and then in toluene, and drying them in air. Other washing or drying conditions gave cracked, clustered, or misshaped particles.

Development of Equipment. — Studies were continued for obtaining data for drying sols to gels by using radiant heating panels, as proposed for the dryer in the Thorium-Uranium Fuel Cycle Development Facility (TUFCDF). From the results of these studies, it appears that the dryer should be operated as follows: (1) Use an initial fast drying rate to remove about 60% of the water from the sol in about 2 hr. For the test dryer, this rate was obtained with the aluminum radiant panel at about 440°C by passing about 1.3 scfm of air over the 0.42-ft^2 tray. (2) Complete the drying in about three more hours. For the test dryer, this rate was obtained with a radiant panel temperature of about 290°C and 1.3 scfm of air.

Samples prepared with several combinations of drying conditions were submitted for examination. Additional material will be prepared with the proposed TUFCDF dryer conditions to permit more detailed tests of this product.

Microsphere Fabrication Development. — Design is nearing completion on the services and modifications required to operate the equipment for forming microspheres and for coating them. The equipment will be installed in Building 4508. This facility will make possible an engineering evaluation of a combined sol-gel—graphite-coating approach to the preparation of coated microspheres at the rate of several kilograms a day. Conceptual designs have been completed for the equipment items, and purchase specifications are being developed.

A large-diameter coater was designed on the basis of an analysis of the fluidization process and from model tests. It is expected that the new coater will operate more efficiently and give a more uniform product than the present equipment.

Irradiation of Thorium Fuels. — Four capsules containing ThO_2 and $^{233}UO_2$ were fabricated in the Kilorod Facility for the irradiation program.

Pellets of ThO_2-UO_2 that attained a burnup of about 100,000 Mwd/metric ton in the Engineering Test Reactor are being examined. The material appears to have retained its crystalline structure. About 12.5% of the fission gas produced was released.

Vibratory Compaction. — Modifications to one of the pneumatic vibrators eliminated the transverse component of energy that has been a serious problem in keeping the equipment attached to its mounting base.

Permeability of Vibratorily Packed Fuels. — If a water-cooled fuel element develops a leak during reactor operation and then "imbibes" coolant water during reactor shutdown, the result is "waterlogged" fuel. If the fuel is porous enough for the water to permeate it during shutdown, then, during reactor startup, when the rate of fuel temperature rise is large, the water may not escape (as steam) fast enough to keep the pressure in the element from exceeding safe limits. The rate of water release is thus of importance. It is related to the permeability of the fuel, and to be safe, the fuel should be permeable enough to prevent disastrous pressures from forming.

Accordingly, equipment was designed and is being built in order to determine the minimum acceptable permeability of the fuel for a typical rod configuration and reactor startup procedure. The data will require extrapolation to particular fuel assemblies.

Extension of the Sol-Gel Process to Newer Types of Fuel. — Three thoria-urania samples containing 15 to 25 at. % U were prepared from mixed sols. Samples dried under argon were found to have higher O/U ratios and lower densities than one dried in air. The reason for this unexpected result is not known. Drying in air will be studied further and compared with drying under reducing or inert atmospheres.

Physical and Chemical Properties of Molten Chlorides. — Further work was done on the removal of ^{233}Pa by sublimation from irradiated mixtures of thorium chloride and aluminum chloride. When the aluminum chloride was distilled at 250°C from an irradiated mixture containing 0.5 mole % thorium chloride, 38% of the protactinium was transferred along with the aluminum chloride. However, when the aluminum chloride was distilled at 150 to 250°C from irradiated mixtures containing 10 and 50 mole % thorium chloride, the protactinium remained with the thorium chloride.

MOLTEN-SALT REACTOR PROGRAM

Molten-Salt Reactor Experiment. — The graphite moderator assembly was installed in the reactor vessel, and the top head was welded to the

vessel. Machining of the reactor-vessel access nozzle and the control rod thimbles was completed, and their assembly with the reactor vessel was started.

Air flow tests were conducted with the radiator, and results were satisfactory. Installation of heaters and insulation in the coolant cell continued.

Except for installation of heaters and some insulation, work was completed in the drain tank cell.

Installation of the charcoal beds and vent-house piping was started. Other contractor work is nearly completed.

The critical-path schedule showed the MSRE Project to be 92.4% complete on April 1.

Reactor Analysis. — Recent calculations produced new values for control-rod worth under the initial critical condition. Also computed was the effect on rod worth of fission products and additional uranium in the core. The new calculations used the multigroup, two-dimensional program, EXTERMINATOR, with R-θ geometry and four neutron energy groups: a fast group, a thermal group, and two groups covering the important gadolinium resonances. The regions representing the rods had volumes equal to the cylindrical rod, air gap, and thimble assemblies in the reactor, with the effective blackness adjusted to account for the larger surface area in the R-θ approximation.

Results of the calculations for fuel C are summarized in the table below. Included for comparison are previous results (ORNL-TM-730), calculated with the two-group, two-dimensional EQUIPOISE code and x-y geometry, for the initial clean condition.

Worth of Three Control Rods Completely Through the Core (% $\delta k/k$)

		EXTERMINATOR	EQUIPOISE
Initial	Thermal	4.87	5.74
	Epithermal	0.64	0
	Total	5.51	5.74
Operating[a]	Total	5.22	

[a]Xenon and other poisons, amounting to 1.9% $\delta k/k$, compensated by additional ^{235}U.

The rods were represented in the EQUIPOISE two-group calculations by square regions with no epithermal absorptions and with surface areas equal to those of the actual thimbles. The fuel in both calculations was of composition C (about 0.9 mole % total uranium, no thorium). The EQUIPOISE calculations used a ^{235}U concentration of 0.29 mole %, computed for the clean critical condition by multigroup calculations with GAM-I cross sections. Calculations using more recent cross-section data, from the GAM-II

library, gave a clean critical concentration of 0.26 mole % ^{235}U; this was used in the EXTERMINATOR calculations for the clean case. The poisoning of 1.9% $\delta k/k$ for the operating case is an approximate upper limit, used to observe the effect on rod worth. (In analysis of the reactor operation, the rod effect will be based on rod calibrations under initial conditions, with corrections for the amounts of poison and additional uranium actually present.)

The rod worths estimated by the EXTERMINATOR four-group calculations should be more reliable than those previously reported. Although the expected worths are slightly less than those estimated by the EQUIPOISE calculations, they are quite adequate from the standpoint of operational convenience and safety.

Development of Components and Systems. — The drain-tank heater test continued past 8300 hr of operation without difficulty with the heaters. The drain-tank cooler test passed 500 startup cycles with no indication of cracking in the tubes. Both tests are continuing.

The design of the fuel sampler-enricher was approved for construction. A proposal for the coolant-salt sampler, incorporating a dual-key sequence interlock system, was accepted, and the design was started.

Measurement of the pressure drop across the MSRE heat exchanger gave reasonable agreement with the estimated value of 27 psig across the tube side but disagreed by a factor of 2 with the predicted value across the shell side. This difference has been attributed to choking at the inlet and outlet regions by the tube bundle. Four tubes were removed from these regions, and tests are under way to measure the improvement.

The engineering test loop was shut down after 4400 hr of circulation with a uranium-bearing salt at 1200°F, and small samples of graphite were removed for examination. Preliminary visual inspection revealed no change in the samples. Operation of the loop was resumed, and it is planned that the uranium concentration will be increased from 0.2 to approximately 0.7 mole % to provide additional information on the proposed sampling technique. The previously reported difference between the uranium concentration from sample analysis and from calculations was attributed to the inaccuracy of the method of chemical analysis used. Reanalysis of the samples by a coulometric method reduced the discrepancy from 10% to less than 3%, which is about the limit of accuracy of the calculated value.

A control-rod maintenance mockup was built, and tools were developed for replacement of control rod components. Tools for handling the auxiliary piping spool pieces were completed and successfully demonstrated.

MSRE Pump Program. — Assembly of the rotary elements for the MSRE fuel and coolant pumps was continued. Indications of rubbing were observed during the startup of the hot proof test of the rotary element for the fuel pump. During preheating of the prototype pump test facility and prior to filling it with molten salt, it is our custom to use the test pump to even out the temperature distribution in the preheated piping by circulating the system helium. After the rotary element had been accelerated to 750–800 rpm in approximately 1 min, shaft rubbing was indicated both by noise and increase in pump power. Examination showed that the shaft had rubbed against the surfaces of the purge gas labyrinth, with which it has a nominal radial clearance of 0.00225 in. The specific cause for the rubbing was not deduced during examination. The rotary elements

for both the fuel and the coolant pumps were provided with a radial running clearance of 0.005 in. between shaft and purge gas labyrinth and are being reassembled. Two drive motors, one each for the fuel and coolant pumps, were delivered and are being tested with the rotary elements.

After modifications to the densitometer previously used on the prototype pump facility were completed, it was installed in the water mockup of the MK-II fuel pump tank to measure the concentration of undissolved gas in the circulating water.

NUCLEAR SAFETY

Melting Experiments in TREAT Facility. — Two additional meltdown experiments have been run in the TREAT reactor to investigate the effects of a moist air atmosphere on the release of fission products from fuel melted under transient reactor conditions. The fuel (30 g of stainless-steel-clad 10%-enriched UO_2) used in each of these experiments was preirradiated in the ORR to approximately 2×10^{16} neutrons/cm^2, or 40 times the irradiation received during the transient. The atmosphere in the first of these experiments consisted of 3% water in air, and in the second 50% water in air. The preirradiation was performed in order to assure fission product behavior predominantly of the species in the fission chain ends rather than the precursors, as would be the case if all the fissions occurred during the transient. A 355-Mwsec transient with a period of approximately 75 msec was performed on each experiment. These assemblies are being shipped back to ORNL from Idaho for inspection and radiochemical analysis. The design of additional experiments is under way to provide higher ratios of water and air in the fuel environment as well as higher fission product inventories.

Properties of Aerosols Produced from Molten Reactor Fuels. — An initial meltdown of highly irradiated (7000 Mwd/ton) UO_2 was performed in the Hot-Cell Confinement Mockup Facility. This experiment was of special interest since it provided the first opportunity to compare fission product release from fuel irradiated to a realistic level with the results of the previously reported tracer-level experiment. Total release values, as expected, were not markedly different except for tellurium, which increased from about 12% to 60%. The release data are summarized in the following table.

The release of plutonium was in good agreement with previous estimates that its volatility would correspond to that of UO_2. Under the conditions of melting (20 g of stainless-steel-clad UO_2 in a zirconia crucible with air flowing at 18 fpm) only 5×10^{-3}% of both Pu and UO_2 vaporized, and most of this deposited rapidly in the confinement tank.

Particular emphasis was given in this run to the behavior of the airborne activity. Determinations of the concentration of small particles, sometimes referred to as condensation nuclei, in the confinement tank showed a reduction in count of 10^3 or 10^4 in the first 30 min after melting, due to agglomeration. The change in concentration was much slower after this time.

Distribution of UO_2 Aerosol and Fission Products from UO_2[a] Melted in Air[b]

	Distribution (% of inventory)									
	Iodine			Tellurium			Cesium			Plutonium
	A	B	C	A	B	C	A	B	C	C
Total release	84	64	96	12	12	60	29	37	35	0.005
Hot-zone deposition	6.3	11	0.4	3.3	1.9	2.5	3.2	16	6.2	0.0005
Total in aerosol tank	47	24	27	5.1	3.4	46	20	9.3	14	0.004
Activity remaining airborne after 3 hr	31	30	62	3.3	6.5	6.2	5.7	13	16	0.0001
Amount of iodine in penetrating form	3.7	0.4	0.2							
Iodine loss through 1.5 in. of charcoal	1.3	0.1	0.01							

[a]Runs A and B were made with tracer-level-irradiated UO_2. Run C was made with 20 g of stainless-steel-clad UO_2 irradiated to 7000 Mwd/ton.

[b]The fuel specimens in all three experiments were melted in filtered air, but the air in the confinement tank was diluted by ~25% with unfiltered cell air.

Data obtained by sampling the confined aerosol at intervals showed a rapid reduction from the calculated initial concentration of fission products in the tank to that in the first sample (10 min after melting). Iodine dropped from 96 to 10%, cesium from 35 to 12%, and tellurium from 60 to 5%. Indications of probable deposition of all three fission products in the sampling tubes were observed. In addition, it was found that about 75% of the iodine deposited on the walls of the confinement tank was desorbed by passage of 1.5 tank volumes of argon (270 liters) through the tank.

Behavior of Fission Products Released During In-Pile Destruction of Reactor Fuels. — Radiochemical analyses of three additional experiments on in-pile melting of miniature UO_2 fuel elements have been completed, and the results are tabulated below.

Material Released from the Fuel in UO_2 Melting Experiments

Expt	Percent Melted	Atmosphere	Flow Rate (fpm)	Percent Released						
				^{131}I	^{132}Te	^{137}Cs	^{106}Ru	^{89}Sr-^{140}Ba	^{95}Zr-^{144}Ce	UO_2
7	0–20	He	60	96		96	11	9.6	1.7	0.72
6,8	80–90	He	60	99.0	96.5	99.0	58	55	52	42
4,5,9	100	He	60	99.6	99.2	98	88	71	57	49
10	97	He	125	97	96	96		70	58	56
11	70–80	He	350	98	99.4	96	48	22	10	5.1
12	0–20	H_2O-He	60	94	88	92	24.4	14	3.7	1.8
13	100	H_2O-He	50	97	96	96	44	32	32	33
14[a]	100	H_2O-air	60	66	63	73	64	45	21	20

[a]Heated for 100 min.

Material Released from High-Temperature Zone of the Furnace in UO_2 Melting Experiments

Expt	Percent Melted	Atmosphere	Flow Rate (fpm)	Percent Released from Hot Zone						
				^{131}I	^{132}Te	^{137}Cs	^{106}Ru	^{89}Sr-^{140}Ba	^{95}Zr-^{144}Ce	UO_2
7	0–20	He	60	50	12	74	2.0	0.72	0.19	0.015
6,8	80–90	He	60	94	67	85	1.4	0.90	0.11	0.16
4,5,9	100	He	60	86	85	70	5.0	1.5	0.25	0.11
10	97	He	125	89	72	81		2.4	1.9	0.29
11	70–80	He	350	89	80	88	0.15	5.4	0.88	1.6
12	0–20	H_2O-He	60	86	63	71	0.21	0.79	0.24	0.18
13	100	H_2O-air	50	95	95	92	22	1.4	0.75	1.1
14[a]	100	H_2O-air	60	49	42	49	45	2.1	3.8	5.0

[a]Heated for 100 min.

Results from other experiments are provided for comparison. The three new experiments (12, 13, and 14) were performed to study the effects of atmosphere and of long high-temperature irradiation on the behavior and release of fission products. Atmospheres of moist helium in the 12th experiment and moist air in the 13th and 14th experiments were used, the dew point being 23°C in each case. The 12th and 13th experiments were preirradiated for 48 hr and then were kept near the melting temperature for 5 min. Experiment 14 was not preirradiated but remained at a high temperature (above the melting point of the stainless steel cladding but below the melting point of UO_2) for 100 min.

Visual examination of these experiments in the hot cell showed that the fuel in experiment 12 did not melt and apparently was somewhat hotter than the fuel in experiment 7. The fuel in experiment 13 melted completely. The fuel in experiment 14 appears to have melted completely, contrary to all indications that the fuel temperature was below the melting point of UO_2.

Comparing the results of experiment 12 with those of experiment 7: (1) The presence of moisture in the atmosphere seems to have had no effect on the release of fission products from the fuel itself. The slight increase in release of nonvolatile fission products was probably due to a slightly higher temperature of the fuel in experiment 12. (2) The release of iodine and tellurium from the high-temperature zone was increased when moisture was present in the atmosphere. The release of ruthenium decreased. The release of nonvolatile fission products did not change.

The results of experiment 13 may be compared with the results of experiments 4, 5, and 9: (1) The air atmosphere had no effect on the concentration of strontium, barium, zirconium, and cerium remaining in the fuel itself. The amount of UO_2 transported from the fuel zone was reduced. (2) The release of iodine, tellurium, and cesium from the high-temperature zone was increased in moist air, probably because of the moisture. Ruthenium was also released to a greater extent. There was no change in the release of strontium, barium, zirconium, and cerium.

Comparing the results of experiment 14 with those of experiment 13, the effects of precursors may be seen: (1) The release of iodine and tellurium from the fuel was reduced. These elements have nonvolatile precursors (tin and antimony). (2) The release of cesium, strontium, and barium occurred as volatile precursors (xenon and krypton), and most of these were found in the filter section.

Samples of the gas penetrating the filters and adsorbers in experiment 14 were analyzed by gamma spectrometry and were found to contain small amounts of the 131, 132, 133, and 135 mass chains. Preliminary analysis of the mass 132 data indicates that some Sb or Te penetrated the gas cleaning system during the initial 20 min of operation but not later. On the other hand, the mass 133 data indicate that there was released not more than 0.36% of the Sb, 0.0034% of the Te, a vanishingly small fraction of the I, and 50% of the Xe formed 10 min after the start. Analysis of these data is being continued.

Characterization and Control of Accident-Released Fission Products. — Iodine samplers referred to as "May packs" are extensively employed by British and American workers in studying the behavior of volatile radioiodine. They are named after F. G. May of AERE. The components of the May pack are intended to distinguish elemental iodine, iodine on particulates, and two classes of volatile iodine compounds, including those readily adsorbed on charcoal and those not so readily adsorbed. In view of the widespread application of these samplers, it is desirable to investigate their ability to make such distinctions. Accordingly, a program toward this end has been initiated, and one experiment has been performed, using a May pack having ports for diffusion tubes before and after each component. This May pack consisted of the following (in the order of the direction of flow): four layers of copper gauze, a membrane filter, two carbon-loaded filter papers, and two 2-in. charcoal beds. For this first test, rather dry filtered air carrying iodine, 99.7% elemental, ~10 mg/m^3, was employed at a velocity of about 1 fpm. In general, the behavior of iodine in the May pack, as indicated by the diffusion tubes, appeared consistent with the designed functions of the components of the pack. However, about 1% of the elemental iodine was apparently not retained by the copper gauze; if this is a usual occurrence, then May pack measurements would falsely label part of the elemental iodine as nonelemental. Another test, similar to the preceding but with a higher relative humidity, is planned.

It has been noted in a related study that the presence of moisture inhibits the adsorption or retention of iodine compounds by charcoal and charcoal-lined diffusion tubes. This effect may be the result of water molecules either covering the charcoal surfaces and hindering the adsorption of the iodine compounds or reacting with the iodine vapor or iodine compounds to form new molecules which are less reactive to the charcoal surfaces.

Nuclear Safety Pilot Plant. — Two runs were completed in which UO_2 was melted and the behavior of the resulting aerosol in the model containment vessel was observed. The first run was made with no agitation of the vessel atmosphere; the second was made with a 3000-cfm fan operating during the furnace operation period. In the first case the condensation nuclei concentration in the model containment vessel increased from 9×10^3

to 1.8×10^4 particles/cc, and in the second case to greater than 10^7 particles/cc. Thus, agitation appears to be important if it is desired to produce a well-dispersed aerosol in the model containment vessel. Other data from the runs are still being evaluated.

The experimental capability of the facility is being extended by the provision of heaters on the exterior of the containment vessel, which will permit attainment of shell temperatures up to 300°F. In addition, the sampling capability of the facility is being increased by the addition of eight sampling stations which will permit characterization of sampled aerosols as a function of time.

Reactor Containment Handbook. — The Reactor Containment Handbook is being prepared by ORNL for the AEC, Division of Reactor Development, to provide detailed information that will be useful in the design, construction, testing, and operation of reactor containment systems. Work on the handbook was begun early in 1962, and by March 1964 first drafts of all chapters were completed and published as CF memos. All chapters have been, or are being, reviewed by selected ORNL staff members as well as external reviewers. Rewriting to update and incorporate pertinent comments into the handbook is presently in progress. It is expected that all chapters will be in the hands of the editing staff (Reactor Division) late in May and that the work will be published in finished form in early August.

Nuclear Safety Information Center. — The Nuclear Safety Information Center will supply and operate a miniature information center on the subject of nuclear facility containment at the Third International Conference on the Peaceful Uses of Atomic Energy at Geneva, Switzerland, August 31—September 9, 1964. Preparation of material for the exhibit has been receiving top priority at the Center. So far, over 900 sources of information have been selected for use at Geneva.

NSIC is investigating the possible future use of electronic computers for the preparation of routine bulletins of the Center's accessions and for making retrospective searches of the Center's files. If NSIC adds these capabilities to its present functions, the IBM 7090 services at ORGDP will be utilized.

Information continues to be collected, evaluated, and filed into NSIC's manual storage system. To date, over 2100 sources of information have been processed.

Since the first of the calendar year, NSIC has received and answered 21 specific requests for information. In the same period 12 persons have visited the Center to utilize its services.

WASTE DISPOSAL

Clinch River Study. — Releases of water from Melton Hill Reservoir, typical for the generation of electric power during winter months, were simulated by flow through the gates of the dam in April 1964 to determine the effects of the releases on the dispersion of radioactive wastes released from White Oak Creek. Rhodamine-B dye was injected continuously for five days to simulate the release of radioactive wastes during the

weekday and the weekend. The rise and fall of water levels in the Clinch River, due to power releases, act as a gate, controlling flow from White Oak Creek. As a result the release of radioactive wastes from the creek is pulsed. The rate of movement and the dispersion of each pulse were observed at sampling sites 6.4 and 16.3 miles downstream from the mouth of the creek. The pulse released on the weekend produced the highest concentrations at these sampling sites. This result was similar to the results of tests made during summer conditions.

Mineral Exchange Studies. — In the absence of EDTA (Versene) the selectivity coefficient is near unity for ion exchange of trace concentrations of strontium compared with macroconcentrations of calcium on sodium-saturated hydrobiotite. There is no apparent "leakage" of either ion before the appearance of the normal breakthrough wave. When EDTA is added in solutions with pH 9, EDTA complexes are formed which are quite stable (pK_{Ca} 10.59 to 10.77 and pK_{Sr} 8.63), and the concentrations of ionic calcium and strontium are reduced. Since the Ca-EDTA complex is nearly 100 times as stable as the Sr-EDTA complex, the calcium is complexed in preference to strontium. Since both are complexed, there is a finite "leakage" of both calcium and strontium before the breakthrough wave. The leakage concentration can be predicted from the relative concentrations of EDTA and calcium and the stability constants of the calcium and strontium complexes. In addition to the "leakage," there is a delay in the time required for the breakthrough wave to appear which is directly related to the fraction of the calcium complexed.

If other cations are present which form more stable complexes with EDTA (i.e., iron or aluminum, common in soils), they will be complexed in preference to calcium. In this case the leakage of calcium and strontium would be reduced from that predicted for passage through a sodium-saturated exchange column.

Disposal in Deep Wells. — A number of minor modifications have been made to the injection plant since the completion of the second injection. They include the addition of a spray ring in the surge tank to make washup easier, the addition of more lights in the cells and in the surge tank to improve visibility, the addition of glare shields at several points to improve visibility, painting of the cell interior, procurement of a surface blower to improve the air-handling system, procurement of a power swivel to eliminate the hazardous job of rotating the tube string by hand during a slotting operation, and procurement of a variable-orifice jet-mixer to eliminate blockage at the mixing port during injection.

An injection of 33,000 gal of ORNL waste, whose chemical composition was modified to simulate evaporator concentrate, was made on April 8 at a depth of 912 ft. The waste was mixed with about 14 lb of cement-base mix per gallon, and the injection required 3 hr. On April 17 an injection of 36,000 gal of ORNL waste mixed with about 10 lb of cement-base mix per gallon was made at a depth of 900 ft. The injection required 3 hr for completion. The activity in both injections averaged 50 curies, and in both injections the activity was detected in the observation well (updip at 150 ft north of the injection well) at depths consistent with conformable horizontal fractures. Following the injections, fluctuations of the water level in the rock-cover leak test well were observed; these are presumably due to pressure effects caused by the injections.

Foam Separation. — The two-step Foam Separation Process for decontaminating low-radioactivity-level process waste water was tested in a series of three radioactive tracer runs with sludge-bed and foam-column feed flow rates equivalent to 25 and 75 gal ft^{-2} hr^{-1} respectively. Each run lasted approximately 12 hr. Sludge-bed precipitation was done at pH 11.3 (0.005 M each in NaOH and Na_2CO_3) in the presence of 9 ppm ferric ion coagulant; the average calculated surfactant concentration in the liquid phase of the foam column was 60 to 70 ppm. All the foam condensate was recycled to the sludge bed.

Radiochemical analyses were done by conventional methods and also by a more rapid method based on least-squares resolution of the complex gamma-ray spectra obtained from process solutions using a multichannel analyzer. The strontium decontamination factor ranged from 7.3 to 12.7 in the sludge-precipitation step and from 3.4 to 7.8 in the foam-separation step, representing an overall maximum of 89.0. Overall decontamination factors for ^{137}Cs, ^{60}Co, ^{106}Ru, ^{95}Zr-Nb, and $^{141,144}Ce$ were in the ranges 1.2 to 1.9, 5.0 to 15.0, 2.3 to 8.0, >2.0 to 23.0, and >100 to 150 respectively. Since no Grundite clay was added to the sludge bed in these runs, the low cesium decontamination factor was expected. An increase in entrainment of solids containing calcium in the sludge-bed effluent stream (i.e., foam-column feed) was noted. This probably was caused by the recycle of foaming agents to the sludge bed and in turn caused the decrease in strontium decontamination factor.

Development of Continuous Melting Unit for Producing Glassy Solids. — Development of the continuous melting unit for fixation of high-level waste has continued. The present system is limited by the heat output of the furnace. Excessive temperature (required for good melting) has reduced the operating life of the furnace elements. Corrosion rates in the continuous unit, for type 304 ELC stainless steel, have been as high as 1 mil/hr at 1000°C.

Installation of the induction-heating furnace (16 in. in diameter and 6 ft long) was completed. The initial test in the unit will be the calcination of simulated Purex FTW-65 waste (formaldehyde-treated waste, 1965).

High-Activity-Waste Calcination. — Studies designed to evaluate the effects of varying the six major constituents (Na_2O, Li_2O, Al_2O_3, P_2O_5, Fe_2O_3, and SO_3) of lithium phosphate ceramics for fixation of Purex waste have resulted in the formation of a number of low-melting (<700°C) compositions which are also apparently insoluble in water. Final evaluation, including determination of sulfate retention and corrosivity, will be made after the current preliminary studies have been completed.

Cadmium, tin, and lead all reacted too vigorously with simulated TBP-25 (aluminum) waste to allow their substitution for copper in packed columns for removal of mercury from this type of waste. Both cadmium and tin reacted too vigorously to be used with simulated Purex waste.

Intermediate-Activity Waste. — Laboratory studies are under way to evaluate methods for converting intermediate-activity wastes to disposable solids. In initial studies, evaporator concentrates corresponding to miscellaneous wastes from an atomic center were incorporated in emulsified asphalt. No tests were made with solid sludges derived from treatment of

low-activity wastes. These studies showed that waste solutions or slurries are more easily incorporated (at lower temperatures and with less stirring) into emulsified asphalt than into the asphalts and tars, such as those used at Mol, Belgium, that are more or less rigid at room temperature. The leach rate of ^{137}Cs from an asphalt product at the end of 17 weeks was 4×10^{-4} g cm^{-2} day^{-1} when the leaching agent (distilled water at 25°C) was circulated over the product at 100 ml/min. Under similar conditions, the leach rate from the cement product was 4×10^{-2} g cm^{-2} day^{-1}. The ^{137}Cs leached from an asphalt product at the end of four weeks was 2×10^{-4} g cm^{-2} day^{-1} when the water was not circulated, as compared with about 5×10^{-4} when the water was circulated at 100 ml/min. The asphalt product in each test contained 62 wt % solids ($NaNO_3$, NaOH, and Na_2SO_4). The leach rate of ^{106}Ru from a similar product was 1.5×10^{-5} g cm^{-2} day^{-1} at the end of two weeks (water was not circulated). The leach rate of ^{137}Cs is higher than, and the rate of ^{106}Ru is comparable to, the rates reported from Mol for a product containing about one-third as much solids (20%) as those described above.

Low-Activity Waste: Pilot-Plant Work. — The 4-ft-diam agitated clarifier that was recently modified was tested with the scavenging-precipitation head-end and the foam-separation head-end flowsheets, using tap water feed. With the scavenging-precipitation head-end, the lowest values of total hardness in the clarifier effluent for 10- and 5-gpm feed rates were 11.8 and 4.1 ppm (as equivalent $CaCO_3$) respectively. With the foam-separation head-end (0.005 M each in NaOH and Na_2CO_3 instead of 0.01 M NaOH) at a 5-gpm feed rate, the total hardness of the clarifier effluent was less than 2 ppm. The clarifier operated smoothly at all times. There was no channeling of clarifier influent through the sludge blanket.

The scavenging-precipitation ion exchange equipment was modified by adding a fluidized bed of alumina to remove phosphate from the low-activity waste, by providing for the addition of Grundite clay to the alumina column effluent, and by altering the piping to permit recycling the resin column eluate to the clarifier. Phosphate is removed to prevent its interfering with the precipitation of calcium hardness from the waste, and addition of clay with eluate recycle is expected to increase cesium removal in the scavenging-precipitation step sufficiently to eliminate the eluate as an effluent waste stream from this process.

Low-Activity Waste: Laboratory Work. — In the scavenging-precipitation ion exchange process, more than about 1 ppm of phosphate originating from decontaminating agents causes abnormally high residual hardness after the scavenging step. As a result, the capacity of the ion exchange resins for radioactive contaminants is reduced. In an experiment with actual ORNL waste containing 1 to 3 ppm of phosphate, chromatographic-grade alumina possessing a capacity for phosphate of about 0.4 meq per ml of Al_2O_3 removed enough phosphate from 15,000 bed volumes of waste to prevent the residual-hardness problem. After regeneration with NaOH and HNO_3 in succession, the alumina regained essentially its original phosphate-removal ability. Analyses of the regenerant solutions indicated that the phosphates are removed from the alumina by the caustic.

Disposal in Natural Salt Formations. — Essentially all of the topside renovations have been completed at the Lyons mine, and access has again

been gained to the mine workings. Topside work remaining to be completed includes the renovation of the hoist building and general area cleanup and fencing.

The mining machinery is being disassembled and lowered into the mine. Underground work currently under way is the drilling of holes for the installation of plastic flow gages. A new map of the underground workings near the experimental area has been prepared.

Design of the fuel-element canisters, hole liners, and surface carrier has been completed. Fabrication is in progress on the hole liners, and work on the canisters and carrier is being initiated.

Engineering, Economic, and Safety Evaluation. — Tritium is a unique constituent of fuel processing wastes in that it does not lend itself to decontamination from the wastes by the conventional methods applied to other fission product contaminants. About 75% of the tritium in the irradiated fuel is currently discharged to the environment in low-level aqueous wastes, but future plants situated less remotely than those of today may be restricted in the quantity they can release to their immediate environs.

It is estimated that, under present regulations, relatively little tritium could be released to surface streams, but plants processing fuel at rates equivalent to as much as 100,000 thermal megawatts of reactor power might disperse the tritium safely to the atmosphere. Larger plants must consider containment of the tritium by internal recycle of aqueous streams. Additional work is needed, however, to establish environmental tolerances for tritium as well as the feasibility of recycling the necessary process streams within the plants.

PHYSICAL RESEARCH

PHYSICS AND MATHEMATICS

High-Energy Physics. – Pictures from a 3.29-Bev π^+ exposure of the BNL 20-in. deuterium-filled bubble chamber are being analyzed in search of the neutral decay mode of the f^0. Pictures containing reactions where two identifiable protons emerge have been measured. Events that fit the reaction $\pi^+ + d \rightarrow p + p + \pi^+ + \pi^-$ show two prominent peaks which can be identified as ρ and f^0. Events that fit the reaction $\pi^+ + d \rightarrow p + p +$ neutral exhibit an η peak, an ω^0 peak, and an f^0 peak. The ratio of the observed decays to neutral and charged pions implies an isotopic spin of zero for the f^0.

High-Energy Electronuclear Machines: The Separated-Orbit Cyclotron. – A more accurate evaluation of the cost and complexity of the Separated-Orbit Cyclotron (SOC) has followed from measurement of the magnetic fields in model magnets and calculation of the losses of flared rf cavities. It was shown that a considerable cost reduction can be made by reducing the frequency from the region of 200 Mc/sec to 50 Mc/sec. The lower frequency allows higher voltage per cavity and a reduction in the number of cavities; in addition, the sensitivity to dimensional errors is reduced. Single-plane construction, rather than the beehive, appears possible for energies up to 800 Mev. Instead of some 6000 individual magnets, there would be about 30 magnet yokes with about 750 adjustable pole tips. Success of this method depends on obtaining the required magnetic-field gradients to allow a minimum turn separation of about 4 in. Preliminary cost estimates show that for the same current an SOC with a 100% duty cycle would cost less than a linac with a 5% duty cycle. An optimized design for a linac with 100% duty cycle for use as an SOC injector was completed. The high cost of the rf structure and the continuous rf power lead to design values of voltage gradient just below breakdown.

Cyclotron Operations: The Isochronous Cyclotron. – Operation of the ORIC continued on a schedule of seven days a week, 16 hr per day. Experimental bombardments and realignment of experimental equipment now occupy about 50% of the cyclotron time. Some 30% of the time is scheduled for the installation of experimental equipment and completion of control circuits for the ion-optics system. The remaining 20% of the time is used in ion dynamics development studies. All quadrupoles on the beam lines into the small experiment room are now installed, connected, and checked out for operation, as well as the five shield shutters where the beam pipes pierce the shield wall. The heavy-particle and the proton-reaction target chambers were installed and optically aligned; they are now being aligned with an ion beam. The equipment for the neutron physics experiment is being aligned with the proton beam. The control of ion beams in the ion-optics system has been very satisfactory. The high-quality beam obtained from the ORIC and the arrangement of the focusing elements in the ion-optics system make it possible to obtain well-focused beams about 1 mm in diameter.

High-Voltage Experimental Program: The $^{14}C(^{3}He,\alpha)^{13}C$ and $^{14}C(^{3}He,p)^{16}N$ Reactions. — The differential cross section for the reaction $^{14}C(^{3}He,\alpha_0)^{13}C$ has been measured for incident ^{3}He energies of 2, 6, 8, and 10 Mev. At 2 Mev the angular distribution is peaked forward, with an appreciable cross section at the back angles. As the bombarding energy is increased, some structure appears at intermediate angles. At 8 and 10 Mev there are definite secondary maxima which occur at approximately 80 and 140°. For the $^{14}C(^{3}He,p)^{16}N$ reaction, angular distributions have been measured at an incident ^{3}He energy of 2 Mev for p_0, p_4, p_5, and p_6. The plane-wave stripping calculations of Newns [Proc. Phys. Soc. (London) 76, 489 (1960)] have been used in an attempt to fit the experimental data. From these fits tentative assignments are made for J^{π}. They are as follows for states in ^{16}N: ground, 0^-, 1^-, 2^- in agreement with the known 2^- value; fourth, 0^+, 1^+; fifth and sixth, 0^-, 1^-, 2^-.

High-Voltage Experimental Program: Resonance Neutron Capture and Scattering in Sulfur, Iron, and Lead. — Resonances in both the capture and the total cross section for ^{32}S, ^{56}Fe, ^{206}Pb, ^{207}Pb, and ^{208}Pb were investigated in the energy range 10 to 80 kev. Total and radiative widths, and in some cases spins, parities, or both were assigned, and isotopic identifications of resonances were made. Previously unknown resonances, mostly due to $\ell > 0$ neutrons, were found in all of these nuclei. The p-wave level density for ^{206}Pb and ^{207}Pb was found to be more than twice as high as one would expect from the s-wave density. The total radiative widths for $\ell_n = 0$ vs $\ell_n = 1$ resonances differed by a factor of 10. The effective nuclear radius, R', for lead was found to be 8.5 ± 0.2 fermis, in agreement with optical-model expectations.

High-Voltage Experimental Program: Coulomb Excitation of States in ^{92}Mo and ^{119}Sn. — Gamma-ray spectra taken in coincidence with the inelastically scattered heavy-ion projectile were used to measure the Coulomb excitation of states in ^{92}Mo and ^{119}Sn. Oxygen ions with energies of 38 to 49 Mev were obtained from the Tandem Van de Graaff. The ions that were scattered at angles between 151 and 165° were detected with an annular solid-state counter. The 1.54 ± 0.02 Mev gamma ray from excitation of the 2^+ state in ^{92}Mo was not detectable above the background in a normal gamma-ray spectrum measured with an isotopically enriched ^{92}Mo target. However, the coincidence measurement produced a 1.54-Mev gamma-ray peak which was 30 times the background level. The B(E2) ↑ was found to be $(9.3 \pm 1.4) \times 10^{-50}$ e^2 cm^4, which corresponds to an enhancement of 7. The results for ^{119}Sn indicate Coulomb excitation of states at 0.92, 1.07, and 1.33 Mev. The B(E2) ↑ for the 0.92-Mev state is $(1.1 \pm 0.2) \times 10^{-49}$ e^2 cm^4, whereas those for the 1.07- and 1.33-Mev states are about 1/5 and 1/10 as large respectively. The 0.92-Mev gamma-ray peak is 10% too wide for a single gamma ray; this indicates an appreciable decay of the 0.92-Mev state to the low-lying 25-kev state in ^{119}Sn.

Mass Spectrometry and Related Techniques. — By using rhenium metal foil as the thermal ionization surface to produce positive ions in the two-stage mass spectrometer, the isotopic composition of an 0.018-μ sample of

californium was found to be as follows: mass 249, (5.269 ± 0.002)%; 250, (15.319 ± 0.003)%; 251, (4.690 ± 0.001)%; 252, (74.721 ± 0.003)%. Curium-248, the daughter of ^{252}Cf, was found to be present.

Stable Isotopes Development. — The 255° separators have demonstrated the feasibility of providing 70% ^{33}S to be used as starting material for ^{33}P production. The highest purity of ^{33}S previously available from conventional calutrons was 25%, and initial samples of ^{33}S from the 255° system were ~40% ^{33}S. A purity of 71.3% ^{33}S was achieved after technical and system modifications which included the following: differential pumping of source and receiver regions, use of the new internally valved feed system with CS_2 charge, collection in cadmium-lined receiving pocket, and chemical separation of thermally deposited sulfur from the cadmium sulfide formed by high-energy ion bombardment. The purity attainable with sulfur appears to be limited by the presence of neutral sulfur in background gases of the system, and equipment has been fabricated to test the feasibility of reducing the sulfur background by use of calcium vapor getter-pumping. A similar approach has been formulated for the calutron, where a two-arc ion source is expected to provide a beam of S^+ from the top arc and a beam of Ca^+ from the bottom arc. This arrangement would provide a continuous calcium-getter deposit in the collector region to supplement other forms of pumping.

One calutron has been equipped with an improved vacuum system and has been used to dope 200 silicon wafers with phosphorus. A special receiver permits the processing of 100 targets (each 1 cm^2) in a single run lasting 5 to 6 hr. The energy of ion bombardment can be chosen between the limits of 10 and 80 kev at currents of ~1 μa, and the quantity deposited per square centimeter is controllable up to the point of saturation. In practice, ten targets are each given the same treatment, and ten such sets are available per run.

Test runs incorporating internally valved feed control of SeO_2 charge show a 100% increase in output and a 300% improvement in process efficiency over values established in conventional equipment. Assays of the material separated at these higher values are not yet available.

Special Separations. — A 0.292-g sample of 99.91% and a 1.360-g sample of 99.89% ^{242}Pu resulted from the second-pass processing of 11.7 g of 85+% ^{242}Pu feed acquired from plutonium separation series "a." Recovery of the unresolved feed is incomplete; however, 82% of the original enriched feed material has been recovered to date.

Developmental techniques for electrodeposition of plutonium on nickel have progressed to the point that 0.2 mg of ^{240}Pu was deposited satisfactorily on six nickel targets 1 in. in diameter and 0.002 in. thick. Electrodeposition was also used in plating six nickel cylinders with ^{237}Np and in preparing 18 high-resolution ^{241}Am sources in the activity range 0.1 to 1.0 μc.

CHEMISTRY

Analysis of Molten Salts by Electrochemical Methods. — The apparatus for containing the molten fluorides under test was modified in order to provide better control of the vacuum or the inert cover gas over the melt.

More graphite electrolysis cells were fabricated; they were cleaned by an ultrasonic method to minimize the amount of graphite dust, which previously has been observed to float on top of the melt. Abnormal amounts of the dust could possibly cause an electrical short circuit within the cell.

A vacuum dry box was received and installed. It will be used for handling and transferring the various fluoride salts that are being analyzed. Leak-rate tests on the box revealed that it conforms to the manufacturer's specifications (not to exceed 1 μ/hr at 10 μ). Argon is being used as the inert cover gas inside the box; it is passed through a trap containing hot titanium sponge to remove traces of moisture and oxygen.

Work is in progress on the preparation of a melt of $LiF-BeF_2$ (66-34 mole %), which is to be the coolant for the MSRE. It is planned to make a more systematic study, by controlled-potential voltammetry, of an unidentified anodic wave that has been observed in the electroanalysis of this melt.

Protactinium Chemistry. — Nearly all work continues to be directed toward the purification and recovery of the protactinium borrowed from England, because it must be returned in the near future. About 36 g of protactinium has been recovered in the first two products. The rest of the material, including all scrap from the ^{232}U program, was purified by the standard anion exchange process, thus nearly completing the recovery of this protactinium. The third (and last) product, containing about 3.5 g of protactinium, was precipitated with ammonium hydroxide and ignited to the oxide. The oxide weighed 6.70 g, but analysis is not yet complete. All the protactinium has been recovered except about 150 to 200 mg contained in several liters of liquid derived from process solutions and from solutions used to clean the equipment and the hot cell.

Spectrophotometry of Solutions at High Temperature. — The effects of temperature upon the vibration-rotation bands of liquid NH_3, H_2O, and D_2O in the region of the third harmonics of the NH, OH, and OD stretching modes have been reported (ORNL-3590). Our analyses clearly indicated that these absorption bands are much more sensitive to specific molecular interactions such as hydrogen bonding than are the simpler, much-studied bands of the respective fundamental vibration frequencies.

For comparison with these hydrogenic band spectra we have examined the near-infrared spectrum of carbon dioxide in the corresponding harmonic region of the O-C-O stretching and bending modes. The spectrum between 1.19 and 1.66 μ exhibits nine principal bands. We measured their temperature dependences in a frozen sample from −80° and 13 psia to the freezing point (−56.6° and 75 psia), in the liquid from the freezing point to the critical point (31.1° and 1072 psia), and in the gas from the critical point up to 65° and about 2000 psia.

These absorption bands are quite sharp in liquid CO_2 at its freezing point. The band widths range from 10 to 22 cm^{-1}, as compared with 200 for NH_3 and about 1000 for H_2O. However, the bands exhibit considerable temperature broadening due to kinetic effects, characteristic of the relatively weak van der Waals forces. The increase in band width is 75 to 300% at the critical point, as compared with 24% for NH_3. Freezing of the liquid abruptly increases the maximum band heights and decreases the band widths by at least a factor of 2, and these effects are accompanied by the appearance,

in some cases, of weak satellites in the tails of the bands.

The effect of temperature upon the positions of the maxima of the CO_2 bands is extremely small and linear from the freezing point up to 0°C; $d\nu/dt$ averages 0.05 $cm^{-1}/°C$, as compared with 0.27 for NH_3 near its freezing point and for H_2O and D_2O above 100°. Above 0°C $d\nu/dt$ increases rapidly, reaching 0.2 to 0.5 for the CO_2 bands in the transcritical region, which is comparable with the temperature coefficient for NH_3 above its critical point. The effects of temperature and change of phase upon these near-infrared bands are consistent with the presence of weaker intermolecular forces in CO_2 than in the hydrogen-containing liquids.

Radiation Chemistry. — When alkane hydrocarbons are irradiated, the initial products include unsaturated hydrocarbons, which act as scavengers for free radicals. Because their steady-state concentrations are low, the importance of these unsaturates was not readily assessed. Recent developments in chromatographic techniques of purification and in flame ionization analysis have permitted the study of methane radiolysis at very low conversions (radiation doses of less than 10^{19} ev/g).

The presence of oxygen even in trace amounts (e.g., 50 ppm) markedly alters the radiolysis of gaseous methane. An induction period has been observed during which the production of hydrogen, ethane, and propane is suppressed and during which ethylene is produced linearly with dose. As the oxygen is consumed, the ethylene concentration rises to a peak and then falls to a low steady-state value. The length of the induction period has been varied by varying the initial oxygen concentration.

The radiolysis of methane proceeds very differently if 100 to 200 ppm of oxygen is added together with 170 ppm of hydrogen. The induction period in ethane and propane yield occurs, but now ethylene yields are also suppressed; in fact, added ethylene is efficiently consumed.

Knowledge of the induction period helps to explain the reports of an apparent dependence of ethane yield on conversion. Measurement of the initial ethylene yields will allow their inclusion in the mechanism of alkane radiolysis.

High-Temperature and Structural Chemistry. — In the continued study of solutions of metals in molten salts, most of the essential features of the phase diagrams of the systems barium—barium bromide and barium—barium iodide were established. As was expected, the minimum temperature of complete miscibility of metal with salt (critical solution temperature) was found to decrease from 1010°C in the chloride system to 960° in the bromide and 915° in the iodide system. The corresponding critical composition also changes regularly from 55 to 61 and 71 mole % barium metal in this series. Existing literature data showing no closing of the miscibility gap were proved to be in error because of inadequate experimental technique. Spurious effects in cooling and heating curves and strange x-ray patterns of the cooled solid metal-salt mixtures, which had earlier been tentatively connected with the possible existence of intermediate solid phases (solid "subhalides"), disappeared almost completely on improved purification of the barium metal used. They seem to have been caused by the formation of oxyhalides, mixed hydride halides, or mixed nitride halides.

Chemical Physics: Neutron Diffraction. — The crystal structure of potassium hydrogen chloromaleate has been solved from neutron diffraction

data. This crystal contains the shortest oxygen-to-oxygen hydrogen bond yet observed, 2.04 A, and the hydrogen atom is situated at the center.

A computer program for preparing stereographic illustrations of crystal structures, including the thermal displacements of the atoms, has been completed.

Physical Chemistry of Gaseous Thermodynamic Working Fluids: Thermal Transpiration. — Calibration of the thermal transpiration apparatus with argon has been completed; this constitutes the preliminary stage of investigations of inelastic collision processes in the gas phase by means of the transpiration phenomenon. Only part of the data obtained with nitrogen have been analyzed, but these have led to the following conclusions: (1) The present apparatus is unsuitable for studies of the rate of approach to steady-state conditions under a temperature gradient, although such studies at constant temperature gave excellent correlation between the results for argon and nitrogen. (2) The pressure transducer currently used to determine the transpiration effect appears to be affected by the nature of the gas. A comparison of the pressure drops measured by the transducer with those determined by means of a dibutyl phthalate manometer gave for argon the relation

$$\Delta p = (0.00740 \pm 0.00003)R - (0.003 \pm 0.001) ,$$

and for nitrogen

$$\Delta p = (0.00762 \pm 0.00004)R - (0.005 \pm 0.002) ,$$

where Δp is the pressure drop in millimeters of mercury and R represents the pressure-transducer signal as read from a recording potentiometer.

The thermal transpiration studies are being continued with carbon dioxide as the gas.

Physical Chemistry of Gaseous Thermodynamic Working Fluids: Gaseous Diffusion. — Gaseous diffusion is a particularly useful phenomenon for use in the investigation of unlike-molecule interactions, primarily because of its almost total insensitivity to like-molecule collisions.

After calibration of the apparatus with mixtures of helium and argon over the temperature range 0 to 120°C, the diffusion coefficient of the helium-xenon system was determined at 120°C. The result is in excellent agreement with a value obtained indirectly from measurements which were made by others on the viscosities of helium-xenon mixtures.

Target Preparation. — By use of electron bombardment and/or resistance heating techniques, pure metal samples of four rare earths and of calcium were prepared from their respective oxides. This technique entails the reduction of europium, samarium, or ytterbium oxide with powdered lanthanum; the reduction of erbium oxide with zirconium powder; and the reduction of calcium oxide with aluminum. In each case the reduced metal was subsequently distilled from the reaction vessel and collected in a polycrystalline button suitable for rolling into foil. Yields of >70% were observed; metal purity analysis indicated that <0.005% contamination by the reductant was introduced. As little as 20 mg of metal can be prepared in this manner.

Continuing studies of tritium target preparation have shown that aluminum overcoating of tritium-saturated titanium films did not enhance the target half-life during deuterium bombardment. However, without aluminum overcoating, an increase of titanium thickness from 2 to 4 mg/cm^2 enhanced the target half-life by a factor of >2. Apparently, migration of tritium within thick titanium-tritium "alloy" is sufficiently rapid under bombardment conditions to replenish the tritium in the target face that had reacted or had been released from the target under the action of the deuteron beam.

TRANSURANIUM-ELEMENT PRODUCTION

Chemical Process Development: Preparation and Evaluation of Polyaminopolycarboxylic Acids. — Six additional Versene-type compounds were synthesized and evaluated for actinide-complexing strength. The compounds that have been prepared are 1,2,3-triaminocyclohexanehexaacetic acid, 1,2-diaminocyclohexanetetrachloroacetic acid, 1,3-diamino(β-hydroxyethyl)tetraacetic acid, and ethylenediaminetetraacetamide. All these compounds except 1,2-diaminocyclohexanetetrachloroacetic acid complex americium more strongly than cerium or europium; however, none was as effective as diethylenetriaminepentaacetic acid, which is used in the TALSPEAK process. The presence of a chloro substitution on the acetic acid chain appeared to diminish the chelating strength of the ligand. Additional compounds are being synthesized in an attempt to correlate chelating strength with compound structure.

Chemical Process Development: New Actinide-Lanthanide Extraction Systems. — Numerous tests were made of Reversil-4 (a diatomaceous silica treated with dimethyldichlorosilane) as a support for extractants in extraction chromatography. A high degree of separation between americium and europium was apparently obtained by eluting the americium with mixtures of carboxylic acids and sodium diethylenetriaminepentaacetate from a column containing di(2-ethylhexyl)phosphoric acid absorbed on Reversil-4. The europium was eluted subsequently with dilute nitric acid. However, after periods of an hour or more, significant additional quantities of europium (probably contaminated with residual americium) could be eluted. Rates of diffusion within the stationary extractant were apparently even lower than the low rates of elution used (about 3 to 4 bed volumes per hour). The same limitation to separations was observed with all other extractant supports tested thus far. In an attempt to obtain higher elution rates, other tests are being made at elevated temperatures. However, the increased temperatures may decrease the amount of extractant that can be held on the support.

Chemical Process Development: Ion Exchange Separations with 1,2-Diaminocyclohexanetetraacetic Acid (DCTA). — Stability-constant data indicated that DCTA may be useful in separating transcalifornium elements by ion exchange. Optimal conditions for transcalifornium separations were determined with Am, Cm, Cf, and Eu, and the following separation factors have been found: Cf/Eu = 4.3, Cf/Am = 8.8, and Cm/Am = 1.47. A sample of ^{252}Cf is being irradiated in the ORR to produce tracer quantities of einsteinium and fermium, which will be used to evaluate this system further.

Curium Recovery Facility. — Cells 3 and 4 in Building 4507 are being equipped to test transuranium process chemistry at full-scale activity levels and to recover gram quantities of ^{242}Cm and ^{244}Cm. Design and installation of equipment in the cell 4 complex are nearly complete, and cold runs of the chemical process are in progress. The cell 3 complex is in early stages of installation. Operations during this report period include continued equipment modifications, laboratory investigation of mixer-settler emulsion problems, and full-scale tests of the Tramex flowsheet, Clanex flowsheet, Clanex feed adjustment, aluminum dissolution, and Tramex feed adjustment with aluminum present. (The acronym "Clanex" is derived from co-lanthanide-actinide-nitrate extraction; "Tramex" is derived from tertiary-amine—rare-earth—actinide extraction.)

During initial testing of the Tramex process, severe emulsions were encountered because of a high molybdenum content in the LiCl brine. With pure LiCl feeds, good operations were obtained in the extraction section; however, unexplained emulsions are still formed in the stripping section. The first demonstration of the Tramex feed adjustment with aluminum present resulted in aluminum precipitation. In laboratory-scale feed adjustments, this problem has not been encountered, although the aluminum concentration is very near the solubility limit in the adjusted feed. The amount of hydrogen gas coming from the stored concentrate, containing 100 g of ^{243}Am, 100 g of ^{244}Cm, and associated rare-earth fission products, has been reconfirmed at 5 ml/min.

HFIR Target Development. — Several decisions were reached which markedly affect the design of the remote-fabrication equipment. For instance, we decided that pellets should be measured and weighed after pressing to establish density and oxide loading on a more quantitative basis. Also, the collapse of the tube around the pellets will be carried out at elevated temperatures to produce the minimum possible gap between the pellet and the tube wall in the as-fabricated condition. This should reduce the possibility of extreme central temperatures occurring in any of the pellets. As a result of these and some other minor revisions, the total design effort required has been increased by about 7%.

The seven prototypic target rods containing ^{242}Pu were completed and shipped to the Savannah River Laboratory for irradiation. One of the targets being irradiated at the Engineering Test Reactor was removed for a scheduled examination. Results will not be available until June.

Transuranium Facility. — Construction of the Transuranium Processing Plant has progressed to the point where the building is entirely closed in and the rear walls of the cell and waste-pit have been poured to the first-floor level. The first high-density concrete was poured in the front cell wall successfully. Nooter's schedule for fabrication of the cell-cubicle floor pans has been advanced to July 10. The conveyor housing schedule at Blickman Company slipped to a May 1 completion, a few days beyond the April 27 contractual date, at which time the housing is scheduled to be delivered to Blount Brothers. Fabrication of stainless steel tanks and the conveyor mechanism is proceeding satisfactorily.

Drawings were issued this month for local-shop fabrication of three more of the ten chemical process equipment racks, an ion exchange rack for cubicle 7, a batch solvent extraction contactor for berkelium recovery in

cubicle 6, and the back rack (containing a sampler station and product pumps) in cubicle 5. Fabrication of six other major components is under way. Design of the chemical process equipment is now 54% complete; overall design on all equipment for the facility is 61% complete.

Corrosion. — Preliminary data indicate that there is no beneficial effect of coupling platinum with tantalum to prevent hydrogen pickup in the latter during exposure in hot hydrochloric acid solution. It had been reported that platinum and other noble metals in contact with tantalum were very effective in preventing hydrogen embrittlement of the tantalum when exposed to hydrochloric acid at elevated temperatures, but in those tests the corrosion process involved generation of hydrogen directly on the tantalum surface.

The current tests presented a different situation, however. In order to simulate the dissolution of an aluminum-clad HFIR target rod in a tantalum vessel, the tantalum was bolted between two pieces of type 6061-T6 aluminum and exposed in 6 M HCl at about 100°C. Thus the tantalum was placed in intimate and continuous contact with molecular hydrogen produced by the dissolving aluminum. Between 10 and 15 dissolutions were made in the above manner, which required 6.5 hr. Analysis of the tantalum specimen showed a hydrogen content of 54 ppm, as compared with the 2 ppm present initially.

A second similar test was run in which a small piece of platinum (0.5 cm^2) was tack-welded to the tantalum specimen (7.7 cm^2). After 15 dissolutions requiring 7 hr, the hydrogen content of the tantalum was 110 ppm. Thus no beneficial effect was achieved. Studies to determine whether a more even distribution of the platinum on the tantalum surface will be beneficial are to be carried out.

METALLURGY AND MATERIALS

Preparation of Pure Materials: Zone Melting of LiF. — A one-year fellowship of the International Atomic Energy Agency is nearing completion in which the principal subject of study was the purification of fluoride mixtures by zone-refining techniques. Several crystals of very pure lithium fluoride had previously been produced in nickel capsules at ORNL by using a modified Stockbarger method for crystal growth and purification; the only cationic contaminants were quite small amounts of sodium, magnesium, and manganese. The segregation behavior of these cations in LiF has been examined by using zone-melting techniques in order to have a guide for obtaining higher-purity LiF. For this purpose commercial LiF doped with about 1000 ppm each of NaF, CaF_2, MgF_2, and MnF_2 was zone-melted under a variety of experimental conditions. The apparatus consisted of a silica tube, lined with nickel foil to prevent contact between LiF vapor and the silica. A nickel boat was used to hold the sample. Molten zones were produced by resistance heaters, and their length was measured by means of a thermocouple in an internal well. Curves showing relative solute concentration as a function of distance were compared with those computed from theory for various numbers of zone passes and found to be in fair agreement.

Experimental values of the segregation coefficient for the doping materials were obtained by comparison, as follows: NaF, < 0.1; CaF_2, < 0.1; MgF_2, 0.7 to 0.8; MnF_2, 0.2 to 0.3. The usual zone travel rate was chosen as 1 to 2 cm/hr. Faster zone travel rates resulted in poorer separation of MnF_2 and MgF_2. Impurity levels for Na, Ca, and Mn were reduced to the photoelectric analysis detection limit with 12 zone passes.

Preparation of Pure Materials: Vacuum Distillation of LiF. — Distillation of commercial LiF doped with about 1000 ppm each of NaF, CaF_2, MgF_2, and MnF_2 was carried out under a pressure of 50 μ at 990°C over a period of 90 hr in a nickel pot. A cold finger was installed to localize the condensation of more volatile components. Analytical data obtained from samples taken from different regions of the condensate showed the order of distillation to be MnF_2 and NaF (first), LiF, MgF_2; practically all of the CaF_2 remained in the residue. This order of distillation corresponds to the order of the boiling points. The impurity level of the LiF produced by this method was found to be less than the photoelectric analysis detection limit for Ca, Na, Mn, and Mg.

Reactions at Metal Surfaces. — Our previous work indicated that regions of lattice disarray in the oxide film on a metal, by providing paths of easy diffusion through the oxide, are important to the oxidation mechanism. We have obtained additional support for this idea in a study of the oxidation rate of the (111) plane of copper. The oxide formed on this plane in the thin-film stage of oxidation was highly oriented and heavily twinned. In most instances the two possible twin orientations in the oxide occurred in equal amounts, thus establishing an array of incoherent twin boundaries through the film along which enhanced diffusion can occur. We discovered, however, that the presence of small concentrations of certain surface contaminants, particularly carbon tetrachloride, increased the fraction of one twin orientation relative to the other. As a consequence, all other factors remaining constant, the total length of the incoherent twin boundaries in the oxide was reduced. Twelve different (111) specimens were studied. Nine samples exhibited oxide films in which the concentrations of the two twin orientations were very close to equal, and the oxidation rate curves (extent of oxidation vs time) for these specimens all fell into a single narrow scatter band. The remaining three specimens were slightly contaminated, and the ratios of the twin concentrations in the oxide varied from 8 to 9. There was also a corresponding reduction in the oxidation rates of these samples; their oxide thicknesses after a 30-min oxidation at 185°C were roughly half those of the corresponding uncontaminated specimens. These experiments provide another correlation of changes in the degree of lattice disarray in the oxide film with corresponding changes in the rate of oxidation.

Deformation of Crystalline Solids. — The mechanisms by which metals deform under stress are incompletely understood. We are using several approaches to investigate these mechanisms.

Continuing our study of the mechanism of yielding and the yield drop phenomenon (upper yield stress minus the lower yield stress), we have examined the effect of temperature on the yield drop of tantalum containing interstitial elements and of silver alloyed with 6 at. % aluminum. The

temperature dependence of the yield drop and how this temperature dependence differs for the two materials can be accounted for in terms of the activation volume, which is a parameter of dislocation motion. For each material, a graph of the yield drop vs temperature strikingly resembles the graph of the ratio of the temperature to the activation volume vs temperature.

We have investigated the effect of increasing the carbon concentration on the stress-induced ordering of carbon atoms that takes place in an iron-carbon alloy as a result of the stress field of a dislocation. Previously (ORNL-3561, p. 38) we found for one composition that when the strain rate was varied, the activation energy for dislocation motion showed a maximum. As predicted by a theoretical analysis, we have now found that the strain rate corresponding to this maximum does not depend on carbon content. We have also found that in the high strain-rate range the strain rate is an exponential function of stress, whereas in the low range it depends linearly on stress.

Spectroscopy of Ionic Media. — Quantum mechanics is fundamental to materials science, but its application to this subject has been very slow because most of the interesting problems involve great mathematical complexity. We have made progress in utilizing electronic computers to overcome some of the mathematical hurdles in the key step of calculating electronic wave functions via quantum mechanical principles. These calculations have been successfully applied to the F-center defect (electron trapped at an anion vacancy) in alkali halide crystals, first in the approximation of neglecting interactions between F-center electrons and other electrons in the crystal, and second in the approximation of including the effect of electrons associated with the nearest neighbor ions. In addition, we have calculated the energies of the ground states and first excited states of the helium atom, the lithium atom, and helium-like ions using wave functions superior to the older (orbital) approximation in that we included angular interelectronic coordinates.

Theory of Alloying. — Systematic development of improved alloys requires better understanding of the fundamental physics of the metal crystal. Accordingly, we are continuing to measure fundamental properties of the early transition elements, Zr, Nb, Mo, Hf, Ta, and W, which have found use in the technologies of nuclear energy, space, high temperatures, and superconductivity. We have measured galvanomagnetic properties of single crystals of zirconium at 4.2°C in magnetic fields up to 31 kilogauss. Preliminary results suggest that the Fermi surface in zirconium is closed and compensated (number of electrons equal to number of holes). The magnetic-field dependence of the resistivity and the Hall field deviate from the theories for pure compensated metals as predicted by Kaganov and Peschanski [Soviet Phys. JETP 8, 734 (1959)] for imperfect compensation due to impurities. The Hall field is large, about two to four times that of copper, and it changes sign from positive to negative during magnetic-field rotation, while the resistivity varies only by a factor of 1.11. There is no indication of open orbits along the c axis such as were suggested by earlier de Haas—van Alphen experiments of Thorsen and Joseph [Phys. Rev. 131, 2078 (1963)].

Fundamental Research in X-Ray Diffraction. — X-ray diffraction investigations of irradiated single crystals provide a unique picture of the average nature of the damage that the crystal structure has sustained. The results of these studies are important both to the development of practical reactor materials and to the understanding of fundamental physical properties. We have continued our diffraction studies of neutron-irradiated single crystals of beryllium oxide with the measurement of lattice parameters, physical densities, and rocking-curve breadths for crystals grown from several fluxes and irradiated to fast-neutron doses of 1 to 7×10^{20} neutrons/cm^2 at 147 and 670°C. An important result of these measurements has been the establishment of a threshold for defect agglomerate growth at $(5 \pm 2) \times 10^{20}$ neutrons/cm^2 at 100 ± 50°C. This threshold seems to be relatively insensitive to the method by which the crystal was grown or to its preirradiation degree of perfection.

Crystal Physics. — Fundamental understanding of the properties of many materials is aided by experiments with single crystals. Suitable single crystals are frequently difficult to obtain, particularly for refractory substances. Therefore, we are conducting a continuing program on crystal growth, both to provide crystals needed in research and to devise and improve methods for growing crystals.

Our efforts to prepare lanthanide germanomolybdates have continued with the aim of determining the range of substitution of the lanthanide or somewhat similar trivalent ions in this particular tetragonal structure (scheelite type) and in the hope of discovering compounds with unusual magnetic properties. Crystals of the ninth isostructural compound, Eu_2GeMoO_8, have been synthesized, but similar attempts to prepare Ce_2GeMoO_8 and La_2GeMoO_8 failed. Only minor incorporation of iron(III) into this structure was achieved. Analysis of x-ray data indicated that the iron ion probably substituted at gadolinium sites.

We have extended our hydrothermal synthesis of micas that contained Fe^{3+} substituted for Si^{4+} in tetrahedral coordination with oxygen to produce a series of compounds analogous to natural zeolites and feldspathoids with similar substitution of Fe^{3+}. While natural micas may contain iron in either the 2 or 3 oxidation state, it typically is in octahedral coordination with oxygen. Also in natural micas, feldspars, zeolites, and feldspathoids, Al^{3+} substitutes for Si^{4+} in the tetrahedral sites. In preliminary experiments in the temperature range 370 to 450°C at pressures of 15,000 to 20,000 psi, we have produced ferrigermanate analogs of natural micas, feldspathoids, and zeolites, in which both germanium and iron are substituted for tetrahedrally coordinated silicon and aluminum. Powder camera x-ray data for the potassium, rubidium, and cesium ferrigermanate micas show a (001) interplanar spacing 0.2 to 0.4 A greater than that of synthetic ferrisilicate micas, variations in intensity of several reflections, and the absence of certain reflections.

Fundamental Investigation of Radiation Damage in Solids: Resistive Transitions and Critical Fields in Pb-Tl Superconducting Alloys. — Investigations have been performed on a series of superconducting lead-thallium alloys, containing up to 50% thallium, in both cold-worked and fully annealed conditions. Magnetization curves yielded constant values of H_{c2} for alloys of each composition, and these values correlated well

with the measured normal residual resistivity in the type of analysis made from the theory of Ginzberg, Landau, Abrikosov, and Gorkov. Studies of critical currents were also made, and, in particular, the resistive transitions above H_{c2} with current parallel to the field gave constant values of H_{c3}, the upper nucleation field, in annealed wire specimens. The ratios of H_{c3} to H_{c2} agree well with those predicted in the recent theory for superconducting-phase nucleation fields.

Fundamental Investigation of Radiation Damage in Solids: Triboluminescence Studies on Irradiated and Additively Colored KCl. — Room-temperature triboluminescence experiments have been performed on gamma-irradiated and additively colored KCl with an Instron machine and a photomultiplier. In material colored by gamma rays, the intensity of the luminescence reaches a maximum near 430 mμ (2.88 ev), and the apparent width of the peak at half maximum is 0.7 ev. For all doses used, the light intensity varies as the same power of the crosshead speed over more than two orders of magnitude but saturates at high crosshead speeds. The luminescence intensity grows in upon irradiation directly as the F-center concentration, but does not anneal directly as the F-center concentration. The luminescence and the M center, however, anneal in the same way with temperature, each showing second-order kinetics with an apparent activation energy of 0.80 ev. Preliminary experiments indicate that additively colored crystals do not exhibit triboluminescence, even though an emission centered at 430 mμ having a width at half maximum of 0.19 ev can be stimulated by ultraviolet light in both irradiated and additively colored material.

Fundamental Investigation of Radiation Damage in Solids: Effect of Impurities on the Hardening and Coloration of Room-Temperature-Irradiated KCl. — The incremental increase in flow stress for irradiated KCl is proportional to the square root of the F-center concentration and is probably due to interstitial atoms produced simultaneously with the F centers. However, there is some evidence that first-stage coloration does not contribute to the radiation hardening. Therefore, the coloration and hardening of a series of KCl crystals doped with Ca^{2+} and Sr^{2+} were investigated. It was found that the hardening for early-stage coloration is not proportional to the square root of the F-center concentration, which indicates that interstitials are not formed during the production of these centers. The amount of first-stage F-center coloration induced by impurity is not always proportional to the total impurity concentration. This suggests that some of the impurity is associated or precipitated and does not contribute to the F-center coloration.

Fundamental Investigation of Radiation Damage in Solids: Recovery Characteristics of Thermal Neutron Damage in Cadmium. — Damage resulting from recoils from the (n,γ) reaction in cadmium at low temperatures was studied over a much wider defect concentration range (10^{-6} to 2×10^{-3}) than has been achieved for any single type of radiation damage in any other metal. This was made possible by the very high neutron capture cross section and the relatively low residual resistivity (6×10^{-9} ohm-cm) of available 99.9999% pure cadmium. The purity is retained because of the total absence of contamination by transmutation. A mean recoil energy of 136 ev in the (n,γ) event makes the damage "soft," with only one or two

interstitial-vacancy pairs per event. Detailed isochronal annealing up to complete recovery was studied in a ribbon-shaped resistivity sample 1.22×10^{-3} in. thick after irradiation in liquid helium at 3.55°K. The first annealing peak centers at 5.2°K. This and nine or ten more peaks up to completion at 160°K were resolved consistently over the dose range. With increasing dose there is a very pronounced suppression of all peaks below 26°K and enhancement of those above. Some undergo temperature shifts; others do not. The very precise temperature measurement and control required to make these studies meaningful was provided, in part, by two innovations on the pulse annealing technique. These are use of nonlinear gas thermometry and a miniature Calrod type of heater soldered to the exterior of the sample can.

Fundamental Investigation of Radiation Damage in Solids: Suggested Model for Thermal Neutron Damage in Cadmium. — The isochronal recovery of (n,γ) damage in cadmium does not seem to resemble recovery in the noble metals, which shows low-temperature recovery peaks attributed to the annihilation of "close pairs." Through the several recovery stages from 5 to 26°K the percentage recovery is reduced, fairly uniformly, by an increase in the initial damage concentration, even though the corresponding damage curves are linear. It must be regarded as possible that close pairs are unstable at the temperature of bombardment (3.5°K) and that the initial recovery stage is due to the long-range migration of interstitials. In general terms the suppression of the recovery can be explained on the basis of a model involving the simultaneous action of three mechanisms: (1) vacancy-interstitial annihilation, (2) interstitial clustering (di-interstitial, tri-interstitial, etc.), and (3) disappearance of interstitials at unsaturable sinks. The recovery above 26°K is relatively enhanced with increasing damage concentration. A prominent first-order recovery peak centered at 60°K, which shows this enhancement, may be due to the breakup of interstitial clusters, or alternatively to the onset of vacancy mobility.

Fundamental Investigation of Radiation Damage in Solids: Nature and Yield of Photon- and Neutron-Induced Defects in Semiconductors. — The sensitivity of certain semiconductors to high-energy photons (0.667 to 2.76 Mev), thermal-energy neutrons, monoenergetic neutrons (0.2 to 14.1 Mev), fission-spectrum neutrons, pulsed-reactor neutrons, and americium-beryllium neutrons has been studied in detail. Using the apparent change in carrier concentration as the index of damage, a variety of specimens of gallium arsenide, germanium, and silicon were investigated. Gallium arsenide was particularly sensitive to gamma rays. Germanium and silicon were less sensitive to radiation than predicted by theory for both photons and energetic neutrons. In neutron bombardment, for which disordered regions form the dominant type of lattice disorder, germanium was found to saturate for neutron energies in excess of about 0.7 Mev, whereas silicon exhibited a linear increase in damage rate with neutron energy up to about 4 Mev. These latter observations are consistent with the space-charge model for disordered regions in semiconductors.

CONTROLLED THERMONUCLEAR RESEARCH

Plasma Physics. — Image converter studies of the velocities of moving striations in inert gases as a function of background pressure have been interpreted in terms of an ionic sound wave model. In theory a local density disturbance is shown to propagate in the direction of the cathode by a strong local field produced by an ionic sound wave phenomenon superimposed on the uniform field of the positive column. Experimental observations of striation velocities, relative positions of strong electric fields, regions of maximum brightness, and regions of maximum density are in complete agreement with the model and with the published observations of others.

DCX-2 Facility. — During much of the last two months, DCX-2 has been inoperative because of rectifier failure in the 600-kv power supply. Recent performance of the device has been the same as that described previously (ORNL-3590) except for the operation on the afternoon of April 10. During this run the fast-ion density as indicated by the integrated charge-exchange current was a factor of 2 greater than the best previous results, and the decay times were considerably longer. The time to reach half value was approximately 150 msec. Radio-frequency signals at the ion cyclotron frequency were visible for 8 sec after the beam was turned off. Attempts to repeat these results have failed in spite of apparently identical operation conditions.

Vacuum. — Because of the presence of traces of a pure diffusion-pump oil (bis-2-ethylhexyl phthalate) in the ultrahigh-vacuum test facility, it was possible to make studies of the effects of various typical thermonuclear conditions on contaminated surfaces. The effects of electron bombardment, baking, and exposure to both hot tungsten and hot thoriated iridium filaments were studied. Electron bombardment energies up to 25 kev and currents up to 50 ma were found to yield ethylenic hydrocarbons (5 parts), hydrogen (7 parts), paraffinic hydrocarbons with molecular weights up to at least 72 (3 parts), carbon monoxide (2 parts), and carbon dioxide (1 part). The reactions that occurred on the heated filaments were related to the partial pressure of water and were distinguished from the effect of electron bombardment. The use of electron bombardment to assess the cleanness of practical systems and the use of a hot filament to increase system exhaust rates were established and are being studied further. These findings have been correlated with the results of earlier ionization gage calibration studies in a system contaminated with oil.

BIOLOGY AND MEDICINE

TERRESTRIAL AND FRESH-WATER ECOLOGY

Radiation Profiles of Insects. — Changes in insect populations as a consequence of irradiation may be due to direct biochemical effects or

to indirect effects on food, predators, or environment. Laboratory studies describing the relative radiosensitivity of the various life-history stages ("radiation profiles") are a necessary first step in the interpretation of results from contaminated areas. Insects were irradiated in a ^{60}Co source at 3 or 30 kr/min and given total doses of 1 to 400 kr in 60% increments. Doses of 400 kr were immediately lethal; 2.5 kr or less did not affect survival as compared with controls. Graphs of LD_{50} or LD_{90} plotted as functions of the time and the logarithm of the dose were essentially straight lines. Crickets (Acheta domestica) were more sensitive than flour beetles (Tribolium confusum), grain beetles (Tenebrio sp.) or milkweed bugs (Oncopeltus fasciatus). Radiation profiles showed that larvae of grain beetles were less radiosensitive than pupae or adults, but cricket nymphs and adults were equally radiosensitive. Data are now being acquired on the radiosensitivity of additional life-history stages for these and other insects.

Biological Half-Life of ^{134}Cs in Carp and Two Aquatic Insects. — The biological half-life of ^{134}Cs in aquatic organisms was determined as part of the aquatic food-chain study. Organic detritus was tagged with ^{134}Cs and fed to carp (Cyprinus carpio) and to two aquatic insects, mayfly nymphs (Ephemera varia) and midge larvae (Chironomus commutatus).

The retention curves derived from whole-body counts of the carp are described by the sum of two exponential rate functions and demonstrate an initial rapid elimination of the ^{134}Cs followed by further elimination at a reduced rate. The retention equation for carp at 12.5°C is

$$R = 3.0e^{-0.06242t} + 3.79e^{-0.00396t} ,$$

and for carp at 20°C

$$R = 3.27e^{-0.10505t} + 3.30e^{-0.00706t} ,$$

where R is the percentage of the ingested ^{134}Cs retained and t is the time in days. The sum of the two coefficients in each equation indicates the percentage of the ingested ^{134}Cs initially assimilated by the fish, 6.79% in the cold water and 6.57% in the warm water. The initial rate function corresponds to a biological half-life of 11.1 days for carp at 12.5°C and 6.6 days for carp at 20°C (Q_{10} = 2.0). The second rate function corresponds to a biological half-life of 174 days for carp in cold water and 98.1 days for the fish in warm water (Q_{10} = 2.15). The increase in metabolism of fish in the warmer water is thus demonstrated by a more rapid elimination of the ^{134}Cs.

Mayfly nymphs initially retained 16.8% of the ingested ^{134}Cs and demonstrated a biological half-life of 8.3 days. Midge larvae, while initially assimilating 39% of the ingested isotope, had a shorter biological half-life of 3.5 days.

Field Dosimetry. — Toshiba low-Z metaphosphate glass-rod dosimeters were used to estimate the radiation dose to the bottom organisms in White Oak Lake. Twelve Lucite-shielded and unshielded rods were submerged in

the radioactive mud for four weeks. The average dose for the 12 shielded rods (gamma rays) was 3 rads for the four-week period. The beta-ray dose was calculated from the difference between shielded and unshielded rods. The calculations were based on an experiment where shielded and unshielded rods were submerged in a ^{137}Cs solution and the response of Toshiba low-Z rods to cesium beta rays was determined. Since the average beta-ray energy from a composite sample of the radionuclides from White Oak Lake is approximately the same as the average beta-ray energy of ^{137}Cs, the response of the rods to cesium was used to estimate the beta-ray dose from the mixed radionuclide sample. The beta-ray dose was calculated as 15.4 rads for the four-week period. The total dose was estimated to be 239.2 rads/year. This is in close agreement with a dose rate of 230 rads/year calculated on the basis of the radionuclide content of the bottom sediments. However, the radionuclide contents were based on samples collected three years ago, and the percentage of nuclides in the samples could have changed.

Analog Computer Models and Terrestrial Productivity Data. — A review of the gross and net production of terrestrial vegetation was made in order to relate information on plant production to box diagram models for a terrestrial ecosystem and to the corresponding analog computer simulation circuit previously described as part of ECOS-A. The methodology of the computer simulation was related to the methodology and results of field studies. (1) Biomass change, or accumulation of dry matter, energy, or carbon, is expressed as a biological variable V (or a corresponding computer voltage). The rate of change of V is the derivative V', which is to be resolved into terms for income and loss rates in the formulation of ecological models. The analog computer output gives the integral of V' as a continuous function of time: $V = \int V' \, dt = \int (\text{income rate}) \, dt - \int (\text{loss rate}) \, dt$. Of the numerous forest harvest studies, only a few (such as those at Oak Ridge and some in Britain, Denmark, and elsewhere) have developed methods for resolving changes over periods of several years into annual or shorter-term rates, with an accounting for diverse losses as well as simultaneous income. (2) Field studies of net primary production or net assimilation (the difference between income by photosynthesis P and loss by respiration R) on the other hand have relied heavily on short-term (minute, hour, or day and night) measurements of P and R. Very few projects (such as those at Brookhaven and certain agricultural stations) have made a start on the major problems of integrating valid estimates of cumulative assimilation over long periods, by sampling, interpolation, extrapolation, or theoretical calculation. (3) The calculation of gross primary production or photosynthesis per unit ground area is a subtle problem, involving physiological questions and model assumptions regarding the relative importance of respiration as a "property tax" (approximately proportional to the variable V under consideration) or as an "income tax" (proportional to V' or to the income portion of this derivative). An extensive body of literature was reviewed as a basis for estimating appropriate parameter values in analog computer models for fractional transfer f_{JK} of organic material from compartment J to compartment K. Since the results of this survey show scanty data on the relations

between root and top growth and turnover, and since our tracer experiments suggest that root turnover is of major importance in the ^{137}Cs-tagged forest (ORNL-3590), further experimental studies of this problem are particularly needed.

Cesium-137 Variation in Soil of Tagged Liriodendron Forest. — The overall budget of ^{137}Cs in the tagged *Liriodendron tulipifera* forest indicated that almost half of the total radiocesium burden of the plot reached mineral soil (or fine roots) within five months after tagging (ORNL-3590). Statistical analysis of the distribution showed significant differences (1) between the six depths within 1-ft soil cores, (2) between 20 subplots in the 20 × 25 m tagged plots, and (3) between ten cores within each 5 × 5 m subplot. (1) In view of earlier results on high root activities, the depth profiles (averaging 163, 106, 64, 35, 27, and 20 $\mu c/m^2$ in successively deeper 5-cm layers, totaling 414 $\mu c/m^2$) can be interpreted as representing contributions primarily from irregularly distributed roots in the lower portion of the profiles, and even higher root contributions (plus surface contributions from rainout and litter fall) in the surface layers. (2) The gross spatial variations fitted a reasonable pattern relative to the chance distribution of tagged trees, ranging from 125 and 169 $\mu c/m^2$ (profile total) in two edge subplots with no tagged trees to 672 (west corner) and 742 (southeast edge of the plot). (3) The variability within subplots was high and skewed, apparently because of sporadic root distribution. The coefficients of variation of the profile totals ranged from 40 to 109% of the plot means. Square-root and logarithmic transformations helped to normalize the data and indicated that the intensive sampling provided means within a few percent of the actual radiocesium content, in spite of the high variance and nonnormal distribution.

Evaluation of Fission Product Distribution and Movement in White Oak Drainage System. — A series of four bottom sediment samples has been collected since January 1 at each of eight sediment ranges in White Oak Creek for particle size and radionuclide analyses and for mineral identification, for the purposes of measuring changes in sediment distribution in the channel with time and the radionuclides sorbed by the sediments. Channel profiles have been measured at the sediment ranges on four occasions following significantly high water. Analytical results for the sediment samples are not complete. Results of the profile measurements indicate that considerable shifting of sediments occurs during floods and that a channel distribution of sediment very similar to that existing prior to flooding is reestablished, probably during recession.

During the high water of March 25, a series of water samples was collected at the gaging station designated "White Oak Creek Below ORNL" for determination of suspended sediment concentration, particle size distribution, and radionuclide loads associated with the water and with the sediments. Also, a series of water samples was obtained at White Oak Dam during the flood of April 6–7 for similar analyses. Analyses of these samples are incomplete.

RADIOLOGICAL PHYSICS, HEALTH PHYSICS, AND RADIATION INSTRUMENTATION

Radiation Physics and Dosimetry. — There appears to be a lack of general agreement concerning the mechanism of the very low frequency (VLF) emission from auroras in the theory proposed by Gallet and Helliwell [J. Res. Natl. Bur. Std., D63, 21 (1959)]. This mechanism cannot be based on the Cerenkov effect produced by a solar stream because there is no Cerenkov radiation in the direction of the stream. It has been shown that the VLF emission as described by Gallet and Helliwell is represented by a cyclotron wave emitted by charged particles moving with velocity $v_P > v_W$, where v_W designates the phase velocity of the wave. The relationship $v_P > v_W$ required for the occurrence of cyclotron radiation implies a different physical mechanism than the relationship $v_P = v_W$ assumed by Gallet and Helliwell. This situation is clarified by taking into account that protons (and not electrons) are effective in producing the VLF emission and that the radiated frequency is very large when compared with the proton gyrofrequency.

Health Physics Research Reactor Studies. — The second HPRR core, completed in August 1963, was installed and operated in March 1964. This core affords low-level exposure to systems for long periods of time with a high ratio of neutron dose to gamma-ray exposure. A complete dose mapping of the experimental area was done in order to make the best use of the reactor operating time. The primary applications of the reactor continue to be those associated with dosimetry, animal irradiations, instrumentation response to mixed fields of neutrons and gamma rays, radiation scattering, and shielding.

NUCLEAR ENERGY CIVIL EFFECTS

Dosimetry Applications. — The shielding factors for typical Japanese houses in Hiroshima and Nagasaki have been developed for the prompt radiation from the nuclear bombs dropped on those cities in 1945. Through the use of multiple regression and correlation techniques, simple empirical equations were developed from the data accumulated during operations at the Nevada Test Site. These equations define the dose distribution in houses, relative to the free field, to within a probable error of ±6% based on experimental data. This information has been transmitted to the shielding sections in the Atomic Bomb Casualty Commission so that it may be used, in individual cases, in reducing the overall error in the estimates of the doses received by some 50,000 survivors in both cities.

TRAINING, EDUCATION, AND INFORMATION

Professional Health Physics Training. — A course in "Applied Radiation Physics" is being conducted at Vanderbilt University and the University of Tennessee. Eighteen AEC Fellowship students and four Vanderbilt students

are enrolled in the course at Vanderbilt, and three AEC Fellowship students, one Advanced Health Physics Fellow, and one citizen of India are enrolled at the University of Tennessee. Twenty-one AEC Fellows will report to the Laboratory in June for three months of training.

Assistance is being given to the Oak Ridge Institute of Nuclear Studies in promoting the AEC Fellowships in Health Physics at various colleges and universities around the country.

Numerous lectures and seminars were presented at universities, ORNL, ORINS, and professional meetings and for civic groups. A group from the U.S. Public Health Service in Cincinnati received special training in current health physics practices. A 30-hr course, including two field trips, was given by ORSORT. One citizen of Pakistan, one of Austria, and one of India have received practical training at the Laboratory.

Four of the AEC Fellows (1962–63) who received extensions of their Fellowships elected to do their research work for the Master's degree at the Laboratory.

The AEC Fellowship program in Health Physics will have approximately 18 Fellows in 1964–65 (14 at Vanderbilt University and four at the University of Tennessee).

ISOTOPE DEVELOPMENT

Recovery of Fission Products. – Engineering studies of a solvent extraction flowsheet using a substituted phenol, 4-sec-butyl(α-methylbenzyl)phenol, as the solvent for recovery of cesium from Purex-type waste have been made in pulsed columns. Flooding tests have shown no operational difficulties. The flow capacity at a pulse amplitude of 1 in. and a frequency of 50 cpm is 870 gal hr^{-1} ft^{-2} for the extraction section, 500 for the scrub, and 700 for the strip.

Radioisotope Research and Development. – A study was made of the proton beam penetration into a nickel flat-plate target by exposing stacked 0.001-in. foils at an angle of 6° to the incident deflected beam. The 0.511-Mev and the 1.37-Mev lines of the ^{57}Ni activity were followed through three half-lives with a gamma spectrometer. More than 98% of the ^{57}Ni activity was contained in the first two 0.001-in. foils. This result confirms an earlier experiment with a thick nickel target in which the first 0.002-in. surface depth of the target contained > 98% of the ^{57}Co activity formed by the $^{58}Ni(p,2p)^{57}Co$ and $^{58}Ni(p,pn + p,2n)^{57}Ni \xrightarrow{36\ hr} {}^{57}Co$ reactions (ORNL-TM-663).

The ^{56}Co yield in a 23-Mev proton irradiation of $^{56}Fe_2O_3$, contained in a standard plugged aluminum capsule, was determined by using ion exchange chromatography in an HCl system for the separation and by using gamma spectrometric measurements for the assay. A yield of 445 μc/hr was found for the production of radiochemically pure, carrier-free ^{56}Co (no detectable ^{57}Co, ^{58}Co, or ^{60}Co activities).

The possibility of polymerization in $^{32}PO_4^{3-}$ preparation was investigated. Standard product solutions and experimental solutions have shown essentially no polymerization when examined by paper chromatography,

solvent extraction, and ion exchange. The examinations verified that < 0.5% of the ^{32}P was in the form of a polyphosphate. Periodic examination of inactive pyrophosphate solution samples irradiated in the cobalt garden for approximately one month showed a slow depolymerization effect.

A 0.1-g silver sample which had been irradiated for a three-year period in the ORR was processed for ^{109}Cd produced by the

$$^{107}Ag(n,\gamma)^{108}Ag \xrightarrow{\beta} {}^{108}Cd(n,\gamma)^{109}Cd$$

reactions. The silver was separated from ^{109}Cd by solvent extraction (30% triisooctylphosphothionate in hexane + 8 M HNO_3). The recovery of ^{109}Cd was >99.9%; no detectable ^{110m}Ag was observed in the ^{109}Cd. Approximately 75 mc of ^{109}Cd and 1.52 curies of ^{110m}Ag were separated by this process. No ^{115}Cd activity was detected in the ^{109}Cd fraction. Isotopic mass analysis of the ^{109}Cd and ^{110m}Ag was used to calculate cross sections:

Reaction	Cross Section (barns)	
	Experimental	Literature
$^{107}Ag(n,\gamma)^{108,108m}Ag$	33.8	30
$^{107}Ag(n,\gamma)^{108}Ag$ (≧5-year half-life)	0.4	None available
$^{107}Ag(n,\gamma)^{108m}Ag$ (2.3-min)	33.4	30
$^{109}Ag(n,\gamma)^{110,110m}Ag$	99.1	113
$^{109}Ag(n,\gamma)^{110}Ag$ (24-sec)	96.9	110
$^{109}Ag(n,\gamma)^{110m}Ag$ (270-day)	2.2	2.8
$^{108}Cd(n,\gamma)^{109}Cd$ (470-day)	0.22	2.7 ± 0.9

Radioisotope and Stable Isotope Production. — Ion currents equivalent to 3768 g of separated isotopes were monitored during March and April. Isotopes of Ba, Ca, Mg, Ni, S, Si, and W were separated and collected by use of 28 of the calutrons associated with the program.

OPEN LITERATURE PUBLICATIONS

Arakawa, E. T., R. J. Herickhoff, and R. D. Birkhoff, "Detection of Plasma Radiation from Electron-Bombarded Al and Mg Foils," Phys. Rev. Letters 12, 319 (1964).

Auerbach, S. I., J. S. Olson, and H. D. Waller, "Landscape Investigations Using Caesium-137," Nature 201, 761 (1964).

Bate, L. C., J. F. Emery, G. W. Leddicotte, W. S. Lyon, and M. J. Pro, "Application of Activation Analysis to Forensic Science — I. Physical Evidence," Intern. J. Appl. Radiation Isotopes 14, 549 (1963).

Bopp, C. D., "Measurement of Thermal Conductivity with Mercury Contacts," J. Am. Ceram. Soc. 47, 151 (1964).

Boyd, G. E., F. Vaslow, and S. Lindenbaum, "Calorimetric Determinations of the Heats of Ion Exchange Reactions. I. Heats of Exchange of the Alkali Metal Cations in Variously Crosslinked Polystyrene Sulfonates," J. Phys. Chem. 68, 590 (1964).

Bradley, M. J., J. H. Goode, L. M. Ferris, J. R. Flanary, and J. W. Ullmann, "Hydrolysis of Neutron-Irradiated Uranium Monocarbide," Inorg. Chem. 3, 454 (1964).

Bradshaw, R. L., W. J. Boegly, Jr., F. M. Empson, H. Kubota, F. L. Parker, J. Perona, and E. G. Struxness, "Ultimate Storage of High-Level Waste Solids and Liquids in Salt Formations," pp. 257–68 in International Colloquium on Retention and Migration of Radioactive Ions in Soils, Centre d'Etudes Nucleaires de Saclay, France, October 16, 17, and 18, 1962 (1963).

Brown, G. M., and R. E. Marsh, "The Crystal and Molecular Structure of 2-Amino-3-methylbenzoic Acid," Acta Cryst. 16, 191 (1963).

Brown, G. M., and H. J. Zabsky, "Unit Cell and Space Group of 4-Aminopyridine," Acta Cryst. 16, 852 (1963).

Busing, W. R., and H. A. Levy, "The Effect of Thermal Motion on the Estimation of Bond Lengths from Diffraction Measurements," Acta Cryst. 17, 142 (1964).

Cowser, K. E., "Movement of Ruthenium in the ORNL Waste-Pit System," pp. 229–41 in International Colloquium on Retention and Migration of Radioactive Ions in Soils, Centre d'Etudes Nucleaires de Saclay, France, October 16, 17, and 18, 1962 (1963).

Cowser, K. E., W. S. Snyder, and M. J. Cook, "Preliminary Safety Analysis of Radionuclide Release to the Clinch River," pp. 17–38 in Transport of Radionuclides in Fresh Water Systems, TID-7664 (1963).

Cowser, K. E., and T. Tamura, "Significant Results in Low-Level Waste Treatment at ORNL," Health Phys. 9, 687 (1963).

Dietze, H.-D., "Theory of Coercive Force for Randomly Distributed Lattice Defects and Precipitations," Phys. kondens. Materie 2, 117 (1964).

Dodd, C. V., and W. E. Deeds, "Eddy-Current Coil Impedance Calculated by a Relaxation Method," pp. 300–314 in Symposium on Physics and Nondestructive Testing, Southwest Research Institute, San Antonio, Texas, 1964.

Dunaway, P. B., and S. V. Kaye, "Cotton Rat Weights in Relation to Season, Breeding, and Environmental Radioactive Contamination," Am. Midland Naturalist 71, 141 (1964).

Feldman, C., and T. C. Rains, "The Collection and Flame Photometric Determination of Cesium," Anal. Chem. 36, 405 (1964).

Finch, C. B., L. A. Harris, and G. W. Clark, "Single Crystal Synthesis and Properties of Heavy Lanthanide Germano-Molybdates," Fourth Rare Earth Conference, Phoenix, Arizona, April 22–25, 1964, Session I.

Halbert, E. C., "Optical-Model Analysis of Elastic Deuteron Scattering," Nucl. Phys. 50, 353 (1964).

Halperin, J., C. R. Baldock, R. E. Druschel, J. H. Oliver, and R. W. Stoughton, "Half-Life of ^{208}Bi," J. Inorg. Nucl. Chem. 26, 391 (1964).

Hammond, J. P., J. D. Sease, and C. Hamby, Jr., "Uranium Monocarbide Fabrication with UAl as Sintering Aid," pp. 145–53 in The 4th Uranium Carbide Conference, East Hartford, Conn., May 20–21, 1963, TID-7676 (1964).

Jacobs, D. G., "Ion Exchange in the Deep-Well Disposal of Radioactive Wastes," pp. 43–53 in International Colloquium on Retention and Migration of Radioactive Ions in Soils, Centre d'Etudes Nucleaires de Saclay, France, October 16, 17, and 18, 1962 (1963).

Koehler, W. C., H. L. Yakel, E. O. Wollan, and J. W. Cable, "The Magnetic Structures of Rare Earth Manganites $RMnO_3$," Fourth Rare Earth Conference, Phoenix, Arizona, April 22–25, 1964, Session I.

Lehmann, Christian, and M. T. Robinson, "Truncated Matching Potentials in the Classical Theory of Elastic Atomic Scattering," Phys. Rev. 134, A37 (1964).

Levy, H. A., and P. A. Agron, "The Crystal and Molecular Structure of Xenon Difluoride by Neutron Diffraction," pp. 221–25 in Noble-Gas Compounds, ed. by H. H. Hyman, University of Chicago Press, 1963.

Levy, H. A., and M. D. Danford, "Diffraction Studies of the Structure of Molten Salts," pp. 109–25 in Molten Salt Chemistry, ed. by Milton Blander, Wiley, New York, 1964.

Lietzke, M. H., and R. W. Stoughton, "The Activity Coefficients of Hydrochloric Acid and Sodium Chloride in Hydrochloric Acid–Sodium Chloride Mixtures," J. Tenn. Acad. Sci. 39, 30 (1964).

Lomenick, T. F., "Movement of Ruthenium in the Bed of White Oak Lake," Health Phys. 9, 835 (1963).

Lomenick, T. F., "Movement of Ruthenium in the Bed of White Oak Lake," pp. 217–27 in International Colloquium on Retention and Migration of Radioactive Ions in Soils, Centre d'Etudes Nucleaires de Saclay, France, October 16, 17, and 18, 1962 (1963).

Lyon, W. S., "180° Compton Scattered-Annihilation Gamma-Ray Sum Peak Observed in Gamma-Ray Spectrometry," Anal. Chem. 36, 682 (1964).

McClung, R. W., "Inspection de componentes nucleares," Ingenieria (Madrid) 12(144), 11 (1963).

Moore, F. L., and J. S. Eldridge, "Direct Nondestructive Method for the Determination of Californium-252. Application of Prompt Gamma Rays from Spontaneous Fission," Anal. Chem. 36, 808 (1964).

Nelson, D. J., "Interpretation of Radionuclide Uptake from Aquatic Environments," Nucl. Safety 5, 196 (1963).

Nelson, F., T. Murase, and K. A. Kraus, "Ion Exchange Procedures. I. Cation Exchange in Concentrated HCl and $HClO_4$ Solutions," J. Chromatog. 13, 503 (1964).

Owen, L. W., and G. R. Satchler, "Multipole Moments of a Rounded Charge Distribution," Nucl. Phys. 51, 155 (1964).

Parker, F. L., "Clinch River Studies," pp. 161–80 in Transport of Radionuclides in Fresh Water Systems, TID-7664 (1963).

Rainey, R. H., "Differences in the Removal of Activity from an Irradiated Thoria-Urania Slurry and from a Slurry Containing Adsorbed Activity," Nucl. Sci. Eng. 18, 530 (1964).

Reagan, P. E., F. L. Carlsen, and R. M. Carroll, "Fission-Gas Release from Pyrolytic-Carbon-Coated Fuel Particles During Irradiation," Nucl. Sci. Eng. 18, 301 (1964).

Roberts, L. D., and J. O. Thomson, "A Study of the Magnetic Properties of Gold in Alloys with Iron, Cobalt, and Nickel at 4.2°K by the Recoilless Radiation Method," pp. 267–68 in Low Temperature Physics LT8 (Proceedings 8th International Conference on Low Temperature Physics, London, England, September 1962), ed. by R. O. Davies, Butterworths, London, 1963.

Russell, F. M., "Phase Focusing for Isochronous Cyclotrons," Nucl. Instr. Methods 25, 40 (1963).

Stiegler, J. O., J. T. Houston, and M. L. Picklesimer, "Transmission Electron Microscopy of Omega Phase in a Zr–15% Nb Alloy," J. Nucl. Mater. 11, 32 (1964).

Sweet, R. F., K. H. Bhatt, and J. B. Ball, "The Low-Lying Levels in Nb^{92} and the Ground State of Nb^{93}," Phys. Letters 8, 131 (1964).

Sworski, T. J., "Photochemical and Radiation Chemical Reduction of Ceric Ion in Aqueous Sulfuric Acid Solutions. Effect of Formic Acid," J. Phys. Chem. 67, 2858 (1963).

Tamura, T., "Selective Ion Exchange Reactions for Cesium and Strontium by Soils Minerals," pp. 95–104 in International Colloquium on Retention and Migration of Radioactive Ions in Soils, Centre d'Etudes Nucleaires de Saclay, France, October 16, 17, and 18, 1962 (1963).

Tamura, T., and E. G. Struxness, "Reactions Affecting Strontium Removal from Radioactive Wastes," Health Phys. 9, 697 (1963).

Tamura, Taro, and Tokuo Terasawa, "Optical Model Plus Resonance Analysis of the Elastic Scattering of Protons by C^{12}," Phys. Letters 8, 41 (1964).

Terry, Anne A., "Integrated Assembly for Generation, Storage, and Delivery of Standard Chromium(II) Solutions," Chemist-Analyst 53, 63 (1964).

Thurber, W. C., K. J. Kelly, C. J. Klamut, L. Rosenblum, and J. W. Semmel, Jr., "Corrosion of High-Temperature Materials in Alkali Metals," Nucleonics 22(3), 37 (1964).

Walter, F. J., H. W. Schmitt, and J. H. Neiler, "Fragment Mass Distributions for Thermal Neutron Induced Fission of Pu^{239} and Pu^{241}," Phys. Rev. 133, B1500 (1964).

Whittaker, R. H., N. Cohen, and J. S. Olson, "Net Production Relations of Three Tree Species at Oak Ridge, Tennessee," Ecology 44, 806 (1963).

Wittels, M. C., J. O. Stiegler, and F. A. Sherrill, "An Investigation of Transmutation Effects in Crystalline Solids," Phys. status solidi 4, 533 (1964).

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