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STATUS AND PROGRESS REPORT

NOVEMBER 1960

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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

NOVEMBER 1960

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Oak Ridge, Tennessee
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for the
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CONTENTS

SPECIAL NUCLEAR MATERIALS PROGRAM..... 1
Radiochemical Processing Pilot Plant..... 1

REACTOR DEVELOPMENT PROGRAM..... 1
THERMAL-BREEDER REACTOR PROGRAM..... 1
Homogeneous Reactor Program..... 1
Homogeneous Reactor Test..... 1
HRT Chemical Pilot Plant..... 2
Thorium Blanket Studies..... 2
Reactor Analysis..... 2
Metallurgy and Ceramics..... 3
In-Pile Solution Corrosion Tests..... 3
Supporting Radiation Corrosion Studies..... 4
Out-of-Pile Blanket Materials Tests..... 4
In-Pile Blanket Materials Tests..... 4
Evaluation Studies..... 5
Thorium-Breeder-Reactor Evaluation Studies..... 5
MOLTEN-SALT REACTOR PROJECT..... 6
MSRE Design..... 6
Component Development..... 6
Remote Maintenance..... 7
Pump Development..... 7
Chemistry..... 7
Metallurgy..... 8
Corrosion Tests..... 8
Reactor Analysis..... 9
Fuel Processing..... 9
HIGH FLUX ISOTOPE REACTOR..... 9
Physics..... 9
Heat Transfer..... 11
Corrosion..... 11
Metallurgy: Fuel-Element Core Preparation..... 11
Metallurgy: Fuel-Plate Fabrication..... 12
Metallurgy: Fuel-Element Assembly..... 12
Reactor Design..... 12
Target Design..... 12
MARITIME REACTORS PROGRAM..... 12
ARMY PACKAGE POWER REACTORS..... 13
ANP PROGRAM..... 13
Shielding Research..... 13
Columbium Alloy Research..... 13
Beryllium Oxide Research..... 14
Liquid-Metal Technology..... 14
GAS-COOLED REACTOR PROJECT..... 15
Irradiation Experiment Evaluation..... 15
GCR-ORR Loop No. 2..... 16
ORR Capsule Irradiation Tests..... 16
Transport Studies in Low-Permeability Materials..... 17
Removal of Radioactive Impurities from Cooling Gases..... 17

Out-of-Pile Materials Compatibility Tests..... 17
Compatibility of Beryllium with Water Vapor..... 18
Identification of Phases in UO_2-ThO_2-BeO..... 18
Stress Analysis of Through Tubes for EGCR Experimental Loops..... 18
NUCLEAR TECHNOLOGY AND GENERAL SUPPORT..... 18
Fuel Element Catastrophe Studies..... 18
Reactor Evaluation Studies..... 19
Radiation Detector Development..... 19
Chemical Behavior of Thermoelectric Materials..... 20
Zirconium Metallurgy..... 20
Fuel Element Development..... 20
Nondestructive Test Development..... 20
Mechanical Properties Research..... 21
Fuel Cycle Technology..... 21
Reactor Controls Development..... 21
Power Reactor Fuel Processing: Darex Process..... 22
Power Reactor Fuel Processing: Mechanical Processing..... 22
Power Reactor Fuel Processing: Purex Corrosion Tests..... 23
Power Reactor Fuel Processing: Graphite-Uranium Fuel Processing..... 23
Power Reactor Fuel Processing: Uranium-Molybdenum Fuel Processing..... 23
Power Reactor Fuel Processing: Zircex Process..... 23
Power Reactor Fuel Processing: Zirflex Process..... 23
Power Reactor Fuel Processing: Solvent Extraction Studies..... 24
Power Reactor Fuel Processing: Sulfex Process..... 24
Power Reactor Fuel Processing: Beryllium-Uranium Fuel Processing..... 24
Fluoride Volatility Processing: Chemical and Engineering Development..... 24
Fluoride Volatility Processing: Pilot Plant..... 25
PHYSICAL RESEARCH PROGRAM..... 26
Reactor Operations..... 26
Waste Disposal..... 26
Hot-Cell Operations..... 26
PHYSICS AND MATHEMATICS RESEARCH..... 26
Neutron Diffraction..... 26
Theoretical Physics..... 26
Fast-Chopper Time-of-Flight Spectrometer..... 27
Low-Temperature, Nuclear and Solid State Physics..... 27
High-Voltage Experimental Program: Neutrons from the He^3 Bombardment of Some Light Nuclei..... 27
High-Voltage Experimental Program: Coulomb Excitation of the Second 2^+ States in Tungsten, Osmium, and Platinum Nuclei..... 28
CHEMISTRY RESEARCH..... 28
Spectrophotometric Studies of Solutions at Elevated Temperatures and Pressures..... 28
Raw Materials Research and Development..... 28

Solvent Extraction Research..... 28
Ion Exchange Studies..... 29
Chemical Engineering Research..... 29
Physical Chemistry of Molten Salts..... 29
High-Temperature Aqueous Solution Chemistry..... 30
Nuclear Chemistry: Characterization of Short-Lived Fission Products..... 31
Electrochemical Kinetics and Its Application to Corrosion..... 31
Chemical Separation of Isotopes..... 31
Chemical Applications of Nuclear Explosions..... 32
METALLURGY AND MATERIALS RESEARCH..... 32
Ceramics Research..... 32
CONTROLLED THERMONUCLEAR RESEARCH..... 32
Cross-Section Studies..... 32
DCX-1 Facility..... 33
DCX-EPA..... 33
Ion Source Development..... 33
Theory..... 34
Ball Lightning Survey..... 34

BIOLOGY AND MEDICINE PROGRAM..... 34
RADIATION EFFECTS ON BIOLOGICAL SYSTEMS..... 34
Genetic and Cytogenetic Effect of Radiations..... 34
Cell Growth and Reproduction..... 34
Pathology and Physiology..... 35
Biophysics: Magnetic Resonance Studies..... 35
Biophysics: Ultraviolet Studies..... 35
COMBATING RADIATION DETRIMENTAL EFFECTS..... 35
Radiation Protection: Living Cells..... 35
Mammalian Radiation Recovery..... 36
Radiation Immunology..... 36

TRAINING, EDUCATION, AND INFORMATION PROGRAM..... 37
International Reactor Program at ORNL..... 37

OPEN LITERATURE PUBLICATIONS..... 38

VISITORS..... 42

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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

November 1960

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

SPECIAL NUCLEAR MATERIALS PROGRAM

Radiochemical Processing Pilot Plant. – Cleanup of contamination resulting from the November 1959 evaporator explosion was continued. The remaining unpainted surfaces in the penthouse were cleaned to painting specifications. Cleaning was also completed in cell 3, and painting of the cell walls was started on November 18. Internal decontamination of all process equipment in cells 4 through 7 was completed, and the penetrating radiation background was reduced to allow entry to cell 6 for external decontamination.

Approximately 3 tons of block and miscellaneous debris from the explosion were removed without incident from cells 6 and 7. A high-pressure solution spray was used to remove loose surface contamination in the cells. More than 100 g of plutonium was removed by the spray, and surface smears showed reductions by several orders of magnitude compared with measurements made in the spring.

Equipment was installed in cell A, Building 3505, to recover by anion exchange approximately 1 kg of plutonium flushed from the equipment in Building 3019.

REACTOR DEVELOPMENT PROGRAM

THERMAL-BREEDER REACTOR PROGRAM

Homogeneous Reactor Program

Homogeneous Reactor Test. – The HRT has resumed nuclear operation (run 22) with the flow modified so that the fuel solution is now pumped through the core vessel from top to bottom. The principal goal of run 22 is to measure the effect of the core modifications on reactor behavior. The initial approach to full power, now in progress, will require several weeks because data must be collected at a number of intermediate power steps.

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Prior to bringing the reactor to criticality on November 7, the reactor components and piping were drained and rinsed of light water and the reactor was operated at 280°C and 1400 psig to pretreat the high-pressure system. The pretreatment consisted in operation with oxygenated D_2O for 50 hr and then with dilute fuel for 50 hr.

Nearly 12 moles of H_2SO_4 was added to the fuel solution to adjust the acid-to-sulfate ratio to 0.35. At this ratio the fuel solution should be chemically stable under all the operating conditions proposed for the present run.

Studies of chemical data and power fluctuations are being made at the current power level of 1 Mw. In the coming month the power will be raised in approximately 500-kw steps after a satisfactory analysis of information is made at each operating level.

HRT Chemical Pilot Plant. – The hydroclone solids-collection system of the HRT has operated continuously since the beginning of run 22. Only 100 g of corrosion products was removed in the 50-hr period of operation with D_2O, which preceded pump-up of the fuel solution. The solids composition was similar to that from run 21, analyzing 53% Zr, 10% Fe, 7% Cr, and 3.3% U. The system will be operated for 500 hr before isolation and dissolution of the second batch of solids.

Thorium Blanket Studies. – The feasibility of coating ThO_2 pellets with nickel, chromium, Al_2O_3, Ta_2O_5, ZrO_2, or TiO_2 by use of the plasma jet apparatus was studied. Powders, with particles –325 mesh, were fluidized by argon or argon and hydrogen mixtures and passed through the arc and deposited on the pellets held in the jet stream 3 to 5 in. from the hot exit. The arc was struck in argon or argon-hydrogen at 25 v and at 325 or 700 amp. At the higher power settings, pellets were successfully coated with the above metals and oxides.

Only the nickel-coated pellets, which had been postannealed at 1200°C in hydrogen, showed greater resistance to attrition in the spouting-bed test than did the original thoria pellets. For the first two of six successive 1-hr tests the nickel-coated pellets showed weight losses of 0.07 and 0.04%/hr. After the third hour the coat stripped from the pellets, evidently as a result of shearing at sharp edges in the thoria pellet.

Reactor Analysis. – Calculations were made of the pressure rise in the HRT following various ramp reactivity additions, assuming that the blanket pressurizer was blanked off. Core-tank hole areas up to 0.5 in.^{2} were considered as well as blanket-to-core fuel ratios between 0 and 1. With a 0.1-in.^{2} hole, a blanket-to-core fuel ratio of 0.3, and a ramp rate of 2% Δk_e/sec, the core pressure rose about 2200 psi and the blanket pressure rose about 1200 psi.

Criticality studies for the HRT under operating conditions were extended by using multigroup calculations to give critical concentrations for core temperatures between 240 and 280°C, blanket temperatures between 150 and 280°C, and blanket-to-core fuel concentration ratios from 0 to 0.3. The concentrations ranged from 4 to 7.3 g of U^{235} per liter in the parameter ranges considered.

Calculations for the HRT replacement vessel show that use of a beryllium or beryllium oxide reflector permits power densities of the order of 7 kw/liter per megawatt of reactor power at a core fuel concentration

of 9 g of U^{235} per liter. The corresponding U^{233} concentration was about 6 g/liter. Calculations on spherical reactors with thorium-blanket regions containing 5000 g of Th per liter indicate breeding ratios larger than unity in pressure vessels having an inside diameter of about 5 ft, with the use of beryllium.

Metallurgy and Ceramics. – Thickness measurements were made in the conical sections of the HRT core vessel during the shutdown following run 21. A new manipulator provided for this purpose allowed measurements to be made at any point in either cone. Unfortunately, the roughness of the surfaces and the presence of the remains of the diffuser screen limited the area of measurement to a few specific latitudes above the sixth screen, which had not been removed. Ultrasonic techniques were used, and the error is believed to have been less than 4%. These measurements were an extension of, and consistent with, those made earlier in the spherical portion of the vessel.

The most significant result noted was that the greatest corrosion loss (0.030 in.) occurred in the upper regions of the 90° cone and that the corrosion loss decreased at the lower elevation where the solution velocity was higher (e.g., the loss was 0.020 in. in the top of the 30° cone). This was consistent with the results of the hydrodynamic studies.

It should be noted that only the loss due to generalized corrosion was measured; measurements could not be made where there was much pitting or other roughness.

In-Pile Solution Corrosion Tests. – The results of a review and correlation of many of the past data for Zircaloy-2 radiation corrosion in uranyl sulfate solutions indicate that the following relationship prevails between corrosion rate, R (mils/yr), fission power density in solution, P (w/ml), and temperature, T (°K), for the conditions tested (values of P up to 110 w/ml, temperatures in the range 225 to 330°C, and a variety of solution compositions and velocities):

$$\frac{1}{R} = \frac{2.3}{P\alpha_{280}} + 2.25 \times 10^{-11} \exp\left(\frac{11,500}{T}\right) ,$$

where α is the factor by which the effective power density at the corroding surface is greater than that in solution because of uranium sorption on the surface, and α_{280} is the α value determined at 280°C in a given solution. The value of α and thus the effect of sorbed uranium changes with solution composition and velocity, but this is the only way in which these variables affect the corrosion.

Using these concepts and the equation in a further review of the in-pile autoclave results obtained at 280°C, it was found that a correlation exists between the initial copper concentration in solution and the amounts of sorbed uranium. The effects of sorbed uranium in systems containing initial copper concentrations of less than 0.01 m were generally greater than those in otherwise similar solutions containing more than 0.01 m Cu. Changes in the effects of sorbed uranium ranging up to a maximum of about 3.5-fold were correlated with copper concentration changes in four different sets of experiments.

The review of the autoclave data indicated that radiolytic-gas pressures (which are affected by copper concentration) in the range 0 to 650 psi, at least, probably do not affect the uranium sorption.

It is suggested that these effects may be related to fuel instability in the HRT since reported observations for run 13 indicate a possible relationship between low copper concentration and fuel instability in that run.

Supporting Radiation Corrosion Studies. – When a Zircaloy-2 specimen is exposed to dilute sulfuric acid solution at elevated temperatures for several days, the corrosion rate becomes quite low and consequently the rate of film growth also becomes low. Since the rate of film growth is low, measurements concerning the effect of temperature on the corrosion rate are performed at essentially constant film thickness. From the results of these measurements, the activation energy for the corrosion reaction may be calculated. Using the electrochemical polarization technique, such measurements were made for specimens of Zircaloy-2 exposed at 208, 258, and 277°C, during the film growth periods. The results at 208°C gave a value of 15.5 kcal/mole for the activation energy. The results at 258 and 277°C implied an increase in activation energy with exposure at higher temperatures. At 258°C the activation energy was 25 kcal/mole, and at 277°C, 46 kcal/mole. These two latter measurements, however, can be questioned. Each specimen exposed at these higher temperatures developed (nonprotective) white oxide over a small portion of the surface. Consequently, until measurements are made on a sample which does not develop white oxide, the results cannot be unambiguously evaluated.

Out-of-Pile Blanket Materials Tests. – In one phase of an investigation aimed at studying variables which affect the attrition of 0.2-in.-diam thoria pellets, a series of laboratory tests was carried out, using 3.75-in.-ID rubber-lined ball mills of 800-ml capacity, in which the effect of mill charge (pellets and water), mill length, and rotational speed on wear rate of pellets was studied. Wear rates were proportional to both increased rotational speeds from 100 to 200 rpm and to increased pellet charge over the range 10 to 100 pellets. The amount of water, 50 to 800 ml (filled), charged to the mill or changing the length of the mill from 4-1/2 in. (800-ml capacity) to 2-1/4 in. (400-ml capacity) had no detectable effect on the wear rate of the pellets.

The fines which resulted from repeated milling of the pellets had an average particle size of 2 μ.

Thin (~0.3-mil) coatings of zirconium which were applied to ThO_2 pellets by an experimental electron vaporization technique were penetrated after 1 hr exposure in a spouted-bed test, and spalling of the coating was noted after autoclaving the pellets in water at 260°C.

Experimental 0.16-in.-diam ThO_2 pellets obtained from Nuclear Materials and Equipment Corporation displayed high weight loss rates (1.1×10^{-3}%/hr) in static autoclave tests at 260°C and in ball-mill tests (1.5%/hr) with 100 pellets at 150 rpm and spouted-bed tests (1.3 to 1.5%/hr) with 10 pellets at 0.2-fps superficial velocity. High attrition rates were attributed to numerous cracks and pores in the pellets.

In-Pile Blanket Materials Tests. – The 5-gpm in-pile slurry loop experiment L-2-27S, installed in LITR beam hole HB-2, was terminated after 3115 hr of slurry circulation, of which 2220 hr (July 19 to October 19, 1960) was with continuous operation in-pile, and 1839 hr was under irradiation at 3-Mw LITR power. At the time of insertion, the circulating

slurry inventory was 1350 g of Th per kg of D_2O (980 g of Th per liter at 280°C). The slurry contained 0.5 wt % enriched uranium based on thorium and 0.019 m Pd as a recombination catalyst. The loop was operated at 280°C under an oxygen atmosphere. During the irradiation, withdrawal of six samples reduced the circulating inventory concentration to 960 g of Th per kg of D_2O (735 g of Th per liter at 280°C). Six terminal samples were also withdrawn. Although some holdup of solids in the sampling system was indicated, sampling procedures operated entirely without difficulty.

Before removal of the loop from the reactor, essentially all slurry and associated radioactivity were readily drained and flushed from the loop.

Radiolytic-gas levels during in-pile operation remained below 10 psi. Recombination as a result of the absorption of reactor gamma radiation was estimated to be sufficient to account for this. As a result, the efficiency of the palladium recombination catalyst was indeterminate.

The flow rate through the filter remained at a level of 0.3 to 0.4 cc/sec, declining to such values from a level of 3 to 4 cc/sec shortly after the beginning of irradiation.

Generalized corrosion during the irradiation period, based on corrosion-product analysis and on oxygen partial-pressure measurement, appeared to be less than 1 mil/yr, comparable with rates observed during the out-of-pile preirradiation period.

There appeared to be substantial degradation of slurry particle size as irradiation proceeded, with the average diameter decreasing from a value of 1.7 μ before irradiation to a value of 0.3 μ after 1460 hr of irradiation. Concurrently the surface area changed from 1.5 to 25 m^2/g. No substantial effects on circulating characteristics were associated with the degradation. In-pile slurry autoclave experiments at comparable doses have not shown similar degradation; consequently the effect is attributed to the combination of pumping and irradiation. The present loop run also subjected the slurry to more passes through the pump (a major degradation cause) than has any other ORNL slurry run.

Evaluation Studies

Thorium-Breeder-Reactor Evaluation Studies. — Further calculations on aqueous homogeneous reactors showed that a variation of 10% in the epithermal value of η^{23} resulted in an uncertainty of about 1%/year in the fuel yield and about 0.04 mill/kwhr in the fuel cost. Decreasing the absorption resonance integral of Pa^{233} from 1200 to 900 barns increased the fuel yield about 0.5%/year and caused a negligible decrease in fuel cost.

Optimization of the fuel- and fertile-stream processing rates in the molten-salt breeder reactor was performed, taking into consideration resonance absorption by the fission products. The new results are appreciably different from those obtained without consideration of resonance absorptions. It is now estimated that the maximum fuel yield is about 7%/year at a fuel cost of 1.5 mills/kwhr; under operating conditions associated with minimum fuel cost (about 0.6 mill/kwhr) the reactor has essentially a zero fuel yield.

MOLTEN-SALT REACTOR PROJECT

MSRE Design. – About 72% of the main-component design drawings are complete and are ready for comment. A favored poison scheme has been selected, and the reactor-vessel drawings are being modified to include the poison thimble. An INOR-8 thimble (1/16-in. wall and 1.3-in. OD) is inserted into a hole in the center piece of graphite. This thimble is connected through a 3/4-in. pipe to a small storage tank outside and above the reactor thermal shield. A 1/4-in. gas "snorkel" tube is inserted through the tank and into the poison thimble. An additional gas line is brought to the top of the storage tank. A mixture of Li^6F and BeF_2 is placed in the storage tank and, by means of gas control in the two gas supply lines, can be transferred from tank to poison thimble as desired.

The revised primary-system layout reported last month was completed, and a stress analysis indicates that stresses will be substantially below allowable values both at zero power and at design power. Design of a neutron shield to surround the reactor was started. Design of the reactor heaters and thermal insulation was also begun.

The drain-tank arrangement was revised to facilitate replacement of the line to the reactor cell. A scheme was developed for removing spent fuel from the system for chemical processing.

Drawings for building shielding and structural concrete were issued for comment. Final conceptual design of primary and secondary containment areas was accepted. Air-handling criteria were finalized, and design is proceeding. Waste pond, holdup tank, and basic water requirements are established. Items (cranes and manipulators) for remote handling have been established as to kind, number, and size.

Component Development. – Seven corrosion pump loops of INOR-8 have operated with various fluoride salts at 1300 or 1500°F at 200° ΔT for periods of from 5700 to 19,800 hr.

Two INOR-8 thermal-convection tests are being made for investigating the behavior of graphite and molybdenum in molten-salt environment.

A frozen-lead shaft seal of a small centrifugal pump circulating molten salt at 1200°F has now accumulated 21,600 hr. An engineering test loop to be used for MSRE component development is being designed, and fabrication has begun.

Testing of a 72% Ag–28% Cu alloy freeze valve for use with the enricher-sampler, to determine its leak-tightness and probable length of useful service, is continuing. The total time at 1500°F to date is 42.7 hr, and 30 cycles have been completed. No change in the melting point or wetting characteristics has been detected.

Design and construction of parts for testing an enricher-sampler were started. Tests were made on different volute designs in the 1/5-scale hydraulic model of the core. The most satisfactory hydraulic and mechanical arrangement incorporates a constant-flow-area ring into which this fluid enters and an orifice plate between the inlet ring and the core-vessel cooling annulus. An uneven spacing of holes around the orifice provides a uniform flow distribution to the cooling annulus.

Thermal cycling of a 3-1/2- and a 4-in. freeze flange continued in the thermal-cycle facility. A total of 57 cycles has been completed with

no detectable cracking due to thermal stresses. The resilient clamp ring was installed on the 3-1/2-in. flange and has essentially eliminated the increased leakage that formerly resulted during each cool-down.

Cycling of both the resistance-heated and the induction-heated freeze valves continued. The resistance valve has been cycled 55 times, with an average melt-out time of 3.5 min at an average power input of 1.8 kw. The induction valve has been cycled 52 times with an average melt-out time of 0.5 min at an average power input of 12 kw.

Remote Maintenance. — The remote-maintenance demonstration facility was operated successfully with salt at 1200°F after being disassembled and reassembled remotely. This completes the remote-maintenance demonstration phase for the facility.

Work was begun on a 1/12-scale MSRE model to be used as a design aid. A facility is being constructed for testing methods of assembling freeze flanges. Alignment during the final flange closure is considered to be a problem. The design was started for a sliding-shield maintenance facility which will serve 4- by 8-1/2-ft openings in the primary reactor shield. A proposal was made for the arrangement of the primary shield blocks to permit the use of this facility.

The test program for small manipulator-operable disconnects for auxiliary reactor piping and off-gas lines continued.

Pump Development. — The molten-salt pump containing a salt-lubricated journal bearing has operated for 5268 hr with $LiF-BeF_2-UF_4$ (62-37-1 mole %) at 1225°F, with 71 start-stops and with no oil leakage from the shaft seal.

The Inconel centrifugal pump (PKP type) has operated for 1538 hr at 1225°F, circulating $LiF-BeF_2-ThF_4-UF_4$ (65-30-4-1 mole %) at 1950 rpm and 510 gpm, with upper and lower seal oil leakage rates of 11 and 16 cc/day.

The MSRE primary pump and water test loop were assembled, and testing was started. Preliminary tests were performed to evaluate the effectiveness of the pump in stripping gas from the liquid. Head, flow, speed, and power data are being obtained.

Drawings for the prototype hot-test primary pump were released for fabrication. The test-loop design drawings are being checked prior to release for fabrication.

The radiation hazards in the event of sudden release of Kr^{85} to the test area during the MSRE back-diffusion experiment have been evaluated. By properly protecting the storage cylinder against impact blows, by providing additional ventilation in the immediate area, and by providing a line restrictor to limit the rate of discharge in the event of a line rupture, the experiment can be run with safety. A radiation-gas monitor is being installed in the area.

Chemistry. — Quenched samples from the $LiF-BeF_2-ZrF_4$ ternary system were studied in an effort to further characterize the first phase which precipitates on cooling the MSRE fuel ($LiF-BeF_2-ZrF_4-ThF_4-UF_4$; 70-23-5-1-1 mole %). The phase contains equal parts (mole basis) of BeF_2 and ZrF_4 and melts semi-incongruently in the ternary system to LiF and a liquid at 475°C; the formula is probably $\underline{n}LiF \cdot BeF_2 \cdot ZrF_4$, where $\underline{n}$ is at least 6 and less than 8.

The density of the MSRE fuel over the temperature range 450 to 700°C as determined from buoyancy with a platinum bob is

$$\rho\ (g/ml) = 2.84 - 0.00056t°C \pm 0.01 \quad ,$$

and the temperature coefficient is known to ±5%.

Two 100-kg batches of fuel for engineering experiments were processed this month; 600 kg has been manufactured to date.

Metallurgy. – Undesirable oxygen contamination was removed from graphite in capsule tests by purging with molten salts. Different specimens of AGOT graphite were exposed to $LiF-BeF_2-UF_4$ salts and to $NaF-ZrF_4-UF_4$ salts at 1300°F, and subsequently these purge salts were replaced with $LiF-BeF_2-UF_4$, which by precipitating UO_2 acts as a sensitive indicator for oxygen. No precipitate was observed after the latter operation, indicating that all the undesirable oxygen contamination was removed from the graphite. Since a prior flush with a molten salt is anticipated on the MSRE to remove oxygen from the metal system, the use of one of the afore-mentioned salts would serve a dual purpose: to clean the metal components and to remove oxygen from graphite.

A standard graphite compatibility test was completed with the $LiF-BeF_2-ZrF_4-ThF_4-UF_4$ salt proposed for the MSRE. Radiographic examination of the system revealed a precipitation reaction which went to completion within the first 100 hr of exposure. This precipitate was found to be predominantly monoclinic ZrO_2.

Corrosion Tests. – INOR-8 forced-convection loop 9354-3 was terminated for examination on October 10 after 20,000 hr of operation. Results of posttest metallographic and chemical examinations are being reviewed in connection with INOR-8 forced-convection loop MSRP-12, which operated for 14,500 hr. Operating conditions for both loops were as follows:

	Loop 9354-3	Loop MSRP-12
Salt mixture	84*	134*
Maximum salt-metal interface temp, °F	1200	1300
Bulk salt temp, °F	1150	1250
ΔT, °F	150	200
Flow rate, gpm	2	1.8
Reynolds number	3000	2300

*Salt compositions: 84 – $NaF-LiF-BeF_2$ (27-35-38 mole %)
134 – $LiF-BeF_2-ThF_4-UF_4$ (62-36.5-1-0.5 mole %)

Metallographic examination of hot-leg specimens removed from loop MSRP-12 revealed no apparent attack. However, the presence of a light surface film 1/3 mil thick was noted.

Loop MSRP-12 was equipped with a salt-sampling device, in order to monitor the buildup of chromium in the salt during loop operation. Chemical analyses of the salt circulated showed an increase in chromium concentration from an initial value of 450 ppm to a level of 500 ppm after 1200 hr. Within a spread of ±60 ppm, this level remained constant throughout the test. The concentrations of iron and nickel remained at 75 ± 25 and 200 ± 50 ppm, respectively, during the test.

Reactor Analysis. – Preliminary calculations were made in order to obtain an estimate of the worth of a proposed control rod for the MSRE. The results indicate that a 1-in.-diam rod would have a worth of about 4% $\delta k/k$ when fully inserted.

The MSRE shielding-thickness requirements were estimated to be 3.6 ft of barytes concrete for the fuel drain tanks, 3.4 ft of barytes concrete for the fuel storage tanks, and 10 in. of lead for the spent-fuel transfer casks. Multigroup calculations for the heat exchanger gave an effective multiplication constant of 0.03.

Multigroup one-dimensional calculations were performed to obtain estimates of critical masses, power-density distributions, and fissioning spectra for some homogeneous molten-salt reactors having outer reflectors and central "islands." For a 6-in.-radius beryllia island, an 18-in.-thick fuel annulus, and a 10-in.-thick beryllia outer reflector, the computed core critical mass was 40 kg of U^{235}; about 62% of the fissions occurred at thermal energies; the computed power density at the island-fuel interface was about twice the average power density in the fuel annulus.

Fuel Processing. – Recent work was concerned mainly with investigation of the $LiF-SbF_5$ compound. Several preparations were made by precipitation in anhydrous HF solution. A good x-ray diffraction pattern was obtained with this product. Material resulting from reaction of SbF_5 vapor with LiF is being tested to see if it is the same as the compound mentioned above. Qualitative investigation of the thermal stability of the $LiF-SbF_5$ compound indicated that it will not decompose under 1 atm of SbF_5 until the temperature is over 600°C. This high stability indicates that LiF might be a useful reagent for removal of SbF_5 (and perhaps NbF_5) from gas streams in the fluoride volatility process or from liquid HF.

Experiments with the laboratory-model steady-state fluorinator were completed. Four experiments were made which demonstrated that uranium could be recovered from a salt continuously. The primary problem was indicated to be corrosion. A design for a second model has been made, but no further work is planned at this time.

HIGH FLUX ISOTOPE REACTOR

Physics. – For the final set of HFIR critical experiments a revised set of calculations was made for determining the proper initial radial fuel and burnable poison distribution, the core lifetime, and the variation of control plate position, maximum power density, and neutron fluxes with time. As a result of these studies the design of the fuel region

was changed to the extent of adding a 1-cm-wide water annulus between the two equal-thickness annuli, increasing the metal-to-water ratio in the fuel annuli from 0.8 to 1.0 (50-mil plates and channels instead of 40-mil plates and 50-mil channels), and increasing the active length of the core from 18 to 20 in. The purpose of the greater metal-to-water ratio and the narrow water annulus is to decrease the maximum power density without jeopardizing reactivity and thus decrease the initial radial fuel gradients and the weight per cent of uranium in the uranium-aluminum fuel-plate core. The length of the core was increased to make up the difference in heat transfer surface area.

Results of calculations made for the modified core indicated that a U^{235} loading of 8.1 kg would provide a fuel cycle of approximately 14 days, during which time the maximum power density did not exceed the permissible value, the peak thermal flux in the island varied by ±3%, and the peak thermal flux in the reflector increased by a factor of 2.2. At the beginning of the cycle the reactivity ($k_{eff} - 1$), with the control plates withdrawn, was 0.13, which included reactivities of −0.04 for burnable poison (located in the fuel plates of the inner fuel annulus) and an estimated −0.02 for experimental facilities, including beam holes. By the end of the second day at 100 Mw the potential reactivity was reduced by 0.05, and at the tenth day the reactivity associated with xenon-samarium and fission products ($\sigma_{a_{th}}$ = 52 barns, $\sigma_{a_{fast}}$ = 11.2 barns) was calculated to be −0.051 and −0.026 respectively. Calculations have also been made in connection with xenon and samarium poisoning during step power cutbacks and for the particular case of complete shutdown. In the former case, step power reductions of 50, 80, and 90% were considered for a core that had been operated at 100 Mw for a period of one day. At the end of this period, but prior to power reduction, the potential reactivity was 0.085; in 60 min at 10% full power and 130 min at 20% full power the potential reactivity was reduced to zero. The maximum decrease in k_{eff} for a core reduced to 50% power was 0.028.

Three to five days after a complete shutdown, both xenon (decaying) and samarium (building up) are significant in determining the potential reactivity, and after about five days the poisoning is attributed almost entirely to the samarium. Thus a minimum poisoning effect occurs at about four days, the difference in reactivity between four days and ten days (essentially infinite time) after shutdown being, respectively, 0.002, 0.005, 0.007, and 0.010 for 1, 3, 6, and 10 days of operation at 100 Mw. In comparison with the values of k_{eff} that exist during normal operation at the times specified above, k_{eff} for a core that has been shut down for at least ten days is different by +0.02, +0.007, −0.013, and −0.024 respectively; and an extrapolation of these results indicates that the above core, shut down as late as 11 to 12 days after the original commencement of full power operation, could be restarted and operated at full power for the rest of the 14-day cycle.

When studying the xenon and samarium poisoning effects in the HFIR, a source of samarium from the direct fission product Pm^{147} was considered. In this case, Sm^{149} was indirectly produced by the absorption of neutrons

in Pm^{147} and Pm^{148}, with the eventual decay of Pm^{149}. Results of calculations for the HFIR show that in comparison with the concentrations resulting from the decay of the direct fission product Nd^{149}, the Pm^{149} concentration associated with Pm^{147} is respectively 0.02, 0.1, 0.2, and 2 times as much for 2, 5, 10, and ∞ days of operation at 100 Mw. [These results are based on the recently measured cross sections (J. Halperin, ORNL, October 1960) for Pm^{147} and Pm^{148} of σ_{th}^{147} = 250 barns, I_{∞} (Pm^{147}) = 2500 barns, $\sigma_{th}^{148} = 2 \times 10^4$ barns.]

Heat Transfer. – Tests with a heated, vertically oriented HFIR aluminum test section in an essentially infinite environment of atmospheric air have shown that the maximum metal temperature reaches 1020°F (200° below the melting point) at a heat flux of 5150 Btu hr^{-1} ft^{-2}. The afterheat flux should decrease to this value approximately 1 hr and 35 min after reactor shutdown.

Recent natural-circulation heat-transfer work, including studies of the HFIR geometry, are described in ORNL-3026 (to be issued).

Corrosion. – Two heat-flux corrosion tests with specimens measured before and after test have been completed. In both tests the specimens were made from 6061 aluminum, the heat flux was 1.5×10^6 Btu hr^{-1} ft^{-2}, the inlet and outlet water temperatures were 186 and 218°F respectively, the flow rate of the water was 40 fps, and the pH of the water was 5 (HNO_3). In the first test, which lasted ten days, the pressure on the system was 900 psi. During this period the maximum rate of temperature rise of the aluminum due to the formation of a film of aluminum oxide on the surface was about 6°F/day. After descaling the specimen at the conclusion of the test, the maximum penetration of the aluminum, 1.3 mils, occurred near the exit end of the specimen. The second test lasted 20 days and the pressure was 150 psi. The rate of temperature rise of the aluminum was approximately the same as in the first test, but the extent of corrosion was considerably less. The maximum penetration of the aluminum occurred near the inlet end of the specimen and was 0.8 mil. Since boiling could not have occurred in the first test and since boiling was only possible at the aluminum–aluminum oxide interface during the last few days of the 20-day test, it was not responsible for the apparent difference in corrosion damage between the two tests.

Regardless of the lack of agreement between the two tests, both show that under conditions expected to exist in the HFIR, corrosion of the aluminum fuel-element cladding should not be serious during the relatively short life of the reactor core.

Metallurgy: Fuel-Element Core Preparation. – The use of cast alloys to make boron-containing fuel cores was discontinued because of the lack of control on boron content in materials made with this method. Attempts to correlate boron loss with uranium content, temperature, and holding time were unsuccessful.

Preliminary studies have established the suitability of hot forging powder compacts composed of Al and U_3O_8 into fuel cores. Flat-shaped starting compacts were found to give results equivalent to tapered-shaped starting cores. The condition of the starting compacts (i.e., annealed or cold pressed) was not found to affect the final product.

Metallurgy: Fuel-Plate Fabrication. – A series of 0.050-in. plates containing contoured U-Al alloy fuel sections was manufactured. Ten inner annulus plates were assembled by using forged fuel cores and machined inserts. Core components for the seven outer annulus plates were machined to size. Dimensional analysis of the plate has shown that: (1) it is possible to produce U-Al alloy-base fuel plates with acceptable transverse fuel profiles; (2) the active core length tolerance should be relaxed from ±0.25 to 0.50 in. to avoid excessive rejections.

Of the 17 plates fabricated, 60% were found to contain blisters after the 500°C blister test.

Experiments with audioradiography of fabricated fuel plates have shown that it is possible to identify the orientation of fuel within the fabricated plate. It is recommended that this method, or possibly gamma scanning, be used to augment identification of fuel orientation.

Metallurgy: Fuel-Element Assembly. – Only minor variations in the channel spacing occurred during the welding of reinforcement bands of secondary welds on the mark IIA-1 element. The longitudinal weldment fabrication procedure was demonstrated by utilizing one of the early mark IIA display elements which had previously been reinforced by nine circumferential bands welded at 2-in. intervals. A band of weld approximately 2 in. wide was made completely around the outer circumference of the element between two adjacent circumferential bands. Interplate measurements at positions immediately adjacent to the welds indicated the channel spacings to be consistently 0.005 in. less than the original channel dimension. They were essentially unchanged at radial locations farther than 3/4 in. away from the weldments.

Both Linde "short-arc" and Air Reduction "dip transfer" MIG welding methods are currently being investigated to establish the feasibility of automatic procedures for making the longitudinal weldments.

Reactor Design. – Title I concept drawings of the reactor core and pressure vessel were completed. Detail design of the fuel element, the control plates, the control-plate drives, and the beryllium reflector will follow. Specifications and drawings, giving the design criteria of the reactor pressure vessel, are being submitted to prospective vendors for detail design and fabrication proposals.

Target Design. – The present concept of the irradiation facility for transplutonium production is one in which the target array is composed of 31 rods. Each rod is a 3/8-in.-OD aluminum tube containing about 10 g of Pu^{242} as the oxide. The PuO_2 is mixed with aluminum powder and compacted into pellet form before insertion in the tube. Calculations indicate that a metallurgical bond between the pellets and the aluminum tube wall is not necessary (G. Samuels to C. E. Winters, "HFIR Target Elements," Nov. 21, 1960).

MARITIME REACTORS PROGRAM

Irradiation of experiment assembly No. 1 was completed in the ORR pressurized-water loop. The experimental specimens, which consisted of

six 18-in.-long, 1/2-in.-diam, swaged UO_2 fuel rods, received irradiation during one 16-, one 20-, and one 30-Mw ORR cycle. The estimated peak burnup was 1700 Mwd per metric ton of UO_2, and the estimated maximum heat flux was 190,000 Btu hr^{-1} ft^{-2}.

ARMY PACKAGE POWER REACTORS

Postirradiation examination of a stationary fuel element and a control-rod fuel element after exposure for 10.6 Mwyr in the SM-1 reactor has been essentially completed. A peak fission burnup of 32% of the U^{235} atoms was measured in an outer plate of the control-rod fuel element. Metallurgical examination of sectioned plates revealed no fuel matrix damage attributable to the fission process. However, in approximately 5% of the specimens examined, cracks were evident in the fuel-plate cladding outer surface. In one case the cracks penetrated to the core-cladding interface. It is suspected that the cracks are associated with fracture along grain boundaries containing carbide and boride precipitates. Rather extensive corrosion of brazed joints (Coast Metals NP) between the side plates and the fuel plates was also observed. Approximately two-thirds of the contact area of each joint had been destroyed; however, in no case was a joint completely removed.

ANP PROGRAM

Shielding Research. – The modifications of the Tower Shielding Reactor II (TSR-II) were nearly completed. Water flow tests on the annular fuel elements demonstrated that 5-Mw operation of the TSR-II can be achieved with a flow rate of 700 gpm at a pressure in the core of 300 psig. The fuel element assemblies were placed in the reactor with thermocouples attached to some elements to provide for determinations of the temperature profile during high-power operation. Revisions to the control-mechanism housing were almost finished. Upon completion of the TSR-II assembly, low-power operation at 100 kw will be initiated, and a series of shielding experiments will be conducted at that power level.

Experiments were conducted at the Lid Tank Facility to obtain data on the penetration of radiation through various arrangements of lead, steel, lithium hydride, and boral. These data will be used by NDA for comparisons with results obtained from moments-method calculations. Experiments were begun which will provide data for calculating the optimum arrangement of the above-mentioned shielding materials.

Columbium Alloy Research. – The following alloys were evaluated for oxidation resistance in air at a pressure of 5×10^{-4} mm Hg and a temperature of 1200°C: 7% Mo–93% Cb; 1% Mo–99% Cb; 5% W–95% Cb; 7% Ti–3% Al–3% V–87% Cb; 5% W–2% Ce–93% Cb; and 5% Sn–95% Cb. No significant improvement over unalloyed columbium was observed.

Four heats of high-purity Cb-Zr alloy (0.7% Zr with 20, 110, 180, and 370 ppm C, respectively, and less than 50 ppm total O_2 and N_2) were solution-annealed at 2912°F, aged 0, 50, 100, or 200 hr at 1700°F, and

tensile-tested at 1700°F. No evidences of aging reactions were found. The alloy containing 370 ppm C was the strongest (22,000 psi ultimate tensile strength at 1700°F) in the as-annealed condition. The strength changed only 2000 psi during the 200-hr aging period. The high-purity alloy containing 20 ppm C was the weakest. Its tensile strength in the as-annealed condition was 16,000 psi at 1700°F. Again, there was little variation in strength with aging time. The tensile strengths of the other two heats fell between the values given above.

A study was made of the aging of electron-beam welds in heat XM-339 of Cb–1% Zr alloy. Bend tests made on welds aged at 1500°F for up to 48 hr indicated that they remained ductile. A 100-hr aging treatment at 1500°F caused embrittlement. Aging at 1600°F for as little as 24 hr led to indications of embrittlement in the bend test. It is evident that the aging tendency is not eliminated by this low-contamination welding technique. The chemical analysis of the base metal was 120 ppm O_2, 170 ppm N_2, 2 ppm H_2, 190 ppm C, and 1.25% Zr, and the analysis of the weld metal was 140 ppm O_2, 110 ppm N_2, 4 ppm H_2, 120 ppm C, and 1.04% Zr.

Samples of composite tubes of type 446 stainless steel–columbium and type 304 stainless steel–copper–columbium were received from Superior Tube Company. An attempt to metallurgically bond the type 446 stainless steel–columbium composite by cold drawing and annealing at 1650°F was unsuccessful. Somewhat favorable results were obtained with the type 304 stainless steel–copper–columbium samples. Bonding improved by increasing the annealing temperature from 1650 to 1800°F. A sample annealed above the melting point of copper showed evidence of grain-boundary penetration of copper into the stainless steel. Bonding temperatures between 1800°F and the melting point of copper will be investigated.

An in-pile experiment was designed for determining the rupture strength of Cb–1% Zr alloy in the presence of neutron bombardment, and the equipment was assembled and inserted in the poolside facility of the ORR. This experimental assembly contains seven tube-burst-type specimens of a Cb–1% Zr alloy and three zirconium gettering trains. The specimens will be tested at temperatures of 1800 to 2000°F in a helium atmosphere. Internal helium pressures of up to 2000 psi will be used to stress the tubular specimens.

Beryllium Oxide Research. – The irradiation of the 0.8-in.-diam, 1-in.-long BeO specimens in the ETR (test 5) was completed. The assembly which had been inserted on July 8, 1960, was removed from the reactor on November 1, 1960, after an exposure of 10,032 Mwd. This exposure was estimated to correspond to integrated neutron fluxes of 1.5×10^{21} thermal and 1×10^{21} fast (above 1 Mev). The thermocouple readings indicated that the center temperatures of the specimens were as high as 950°C and that the radial temperature differences were as large as 130°C. Test assembly No. 5 was replaced with the water-cooled low-temperature test assembly No. 4 for further irradiation; test assembly No. 4 had previously received an exposure of 6257 Mwd.

Liquid-Metal Technology. – A potassium refluxing test in a type 310 stainless steel capsule was completed after 1000 hr of operation at a boiler temperature of 1600°F. Sleeve-type inserts lined the inside of the test capsule. In general, weight-change measurements on the inserts indicated the same general pattern as that observed in previous tests

with other metals, that is, a weight loss on specimens located in the vapor zone and a weight gain on the insert specimens from the liquid (boiler) region. A greater total weight loss was found to have occurred in the type 310 stainless steel inserts located in the vapor zone than in an Inconel system operated under similar conditions.

Two hundred pounds of potassium was purified by hot trapping and subsequently cold trapping. The hot trapping was carried out for 250 hr at 650°C, using titanium sponge as the oxygen-gettering agent. During the hot purification treatment the oxygen content was reduced from 269 ppm to 20 ppm. Samples taken at various time intervals indicated that almost all oxygen removal occurred during the first 50 hr of the hot-trapping operation. Oxygen determinations made on samples taken at 100-hr intervals during the 500-hr cold-trapping treatment indicated that no significant purification of the potassium occurred during that treatment.

GAS-COOLED REACTOR PROJECT

Irradiation Experiment Evaluation. — Examinations were made of the UO_2 pellets from four LITR-irradiated miniature EGCR-type fuel capsules. Immersion-density measurements gave values for the UO_2 pellets that were slightly lower than the preirradiation values, for example, 10.3 vs 10.51 g/cm^3. Representative fuel fragments from the central section of each capsule were dissolved and analyzed for burnup. The burnup for capsule L-7xa was found to be ~15,000 Mwd/ton, for capsule L-7xb it was ~14,000, and for capsule L-11b it was ~22,000. Metallographic examination revealed several large voids in the fuel of capsules L-7xa and L-7xb. Small voids were also present, but they were concentrated in different locations in the two specimens. Both specimens were found upon etching to have uniform, small, equiaxed grain structures.

Examinations were also made of five group I ORR-irradiated EGCR-type fuel capsules. Immersion-density measurements showed little effect of irradiation. One of these capsules (capsule 06-1) contained a BeO central plug. It has been postulated that a gray-white film found on the UO_2 pellets of this capsule was formed by the water vapor within the capsule causing the BeO to hydrolyze at the high central temperatures experienced during irradiation. The $Be(OH)_2$ migrated to the cooler surfaces, where it dissociated into BeO and H_2O. The BeO remained as a deposit on the cool surface and the water returned to the BeO center plug to continue the reaction-migration-deposition cycle. The deposit was too thin for sampling, and an attempt to identify the film by x-ray analysis proved unsuccessful. It was interesting to note that the fuel-pellet axial expansion space remained between the top fuel pellet and the MgO spacer but not between the MgO and the BeO plug. It appears that the BeO plug expanded in length and pushed the top MgO spacer against the top end plug. In fact, a small nib of BeO extended into the MgO weep hole. Calculations indicate that the axial thermal expansion of the BeO exceeded that of the fuel by some 25 mils.

The nondestructive portions of the postirradiation examinations of eight group II capsules have been completed. The maximum change of diameter found for this group of capsules was 7 mils. Some ridges in

capsule 02-2 were raised about 5 mils above the normal portion of the cladding. Profile measurements showed maximum bowing of 24 mils. Gamma scans indicated gaps between individual pellets and the possibility of broken pieces in some areas between pellets.

The first thin-plate UO_2 sample irradiated in the LITR for instantaneous-fission-gas-release measurements was examined. The UO_2 had been oxidized and then reduced during irradiation, and temperature measurements had indicated that the sample had crumbled during the reduction process. The UO_2 was found to be in powder form when the capsule was opened. The particle size of the powder ranged downward from 0.050 in.

Density measurements were made on irradiated specimens from a second high-temperature beryllium metal swelling experiment. The results indicate that, for an exposure equivalent to a 2000-Mwd/ton fuel exposure in the EGCR, density decreases of 0.2 to 0.5% (±0.2%) occurred in specimens irradiated at 500 to 700°C. Density measurements on specimens held at 700°C in the absence of irradiation for an equal time indicate swelling values of 0.2 to 0.3% (±0.2%). On the basis of this evidence, it is concluded that the swelling of beryllium under these conditions is smaller than the experimental error in the density measurements. Bend tests of these specimens indicate no deleterious effects on the strength and ductility of the beryllium as a result of irradiation at 500, 600, and 700°C. Preliminary results of bend tests of specimens from the cold beryllium experiment indicate that the specimens were embrittled by the low-temperature irradiation. These specimens were irradiated to $\sim 8 \times 10^{20}$ nvt (>1 Mev).

GCR-ORR Loop No. 2. – Construction of the containment cell for the loop is in progress. The barytes concrete walls and roof have been poured, and 85 tons of lead shielding has been installed under the floor of the cryostat room. Preparations are being made for installation of the stainless steel cell liner. Drawings were completed and procurement was initiated for the shields for the regenerator, the sidestream carbon trap, the copper oxide bed, and the evaporator. A test section for handling horizontal fuel elements was designed. In this design an effort was made to prevent neutron activation of the stainless steel components outside the shield plug.

ORR Capsule Irradiation Tests. – Irradiation of the eight group III capsules continues. Temperature fluctuations have been noted, and an effort is being made to reduce their magnitudes. Small flow circulators are being prepared for installation in the control gas circuit to eliminate the He-N_2 composition gradient resulting from thermal-diffusion separation. An unusually high failure rate of the stainless-steel-sheathed, grounded, Chromel-Alumel thermocouples has been experienced. The beryllium-clad capsules 03-3 and 07-3 each have one operating thermocouple and capsule 05-3 has two satisfactory thermocouples remaining out of six. Thermocouples have also failed in the other three beryllium-clad capsules, but none have failed in stainless-steel-clad capsules 01-3 and 08-3. The tungsten-rhenium thermocouple for measurement of the central temperature in capsule 01A-3 is operating satisfactorily and is indicating a temperature of approximately 1850°F.

Transport Studies in Low-Permeability Materials. — Permeability data were obtained for three different gases passing through the same piece of graphite. The graphite specimen was a 5-in. length of type CEY pipe, 1-1/4 in. OD by 7/8 in. ID. The gases employed were helium, argon, and carbon dioxide. The permeability values obtained as a function of mean pressure and corrected to 25°C varied from 6.46×10^{-5} to 7.78×10^{-5} cm^2/sec for helium at mean pressures of 0 to 1.5 atm. For argon the values ranged from 1.32×10^{-5} to 2.85×10^{-5} cm^2/sec. For CO_2 the values ranged from 1.32×10^{-5} to 3.37×10^{-5} cm^2/sec. When the permeability values were extrapolated to infinite pressure, that is, $1/P_{mean} = 0$, the permeability constant was essentially the same for all three gases. This indicates that the permeability constant is almost exclusively a characteristic of the graphite. The definite slope of the data plots in all cases indicates that both viscous- and slip-flow components are present under the test conditions, with slip flow predominating, particularly in the case of helium.

Removal of Radioactive Impurities from Cooling Gases. — Studies are being made of methods for the removal of radioactive iodine vapor from high-temperature helium streams. Two experimental runs at 320°C were made with silver-plated copper ribbon (10 wt % Ag) as the iodine-removal material. The bed was 6 in. deep and was operated for 166.5 hr at helium sweep velocities ranging from 2.7 to 42.6 fpm to test its iodine-removal efficiency and to measure any velocity effects. It was determined that 99.3% of the injected iodine vapor was retained by the bed. A second bed, 0.33 in. deep, was studied to obtain data on the characteristics of iodine release from silver surfaces. This bed was operated for 193 hr, and 94.7% of the injected iodine was found in the bed at the termination of the run. A BPL charcoal bed of similar construction tested previously retained 16% of the injected iodine after 144 hr of operation. It is not possible at this time to define quantitatively the characteristics of release of iodine from charcoal or silver, but it appears that silver is a promising iodine adsorbent for application at high temperatures under EGCR conditions.

Out-of-Pile Materials Compatibility Tests. — Low-pressure thermal-convection loop test assembly No. 14 containing type AGOT graphite and various metal test specimens at 1100°F and a type 304 stainless steel heated element at 1500°F has completed 975 hr of operation with a system pressure of 30 psig. The impurities in the helium being circulated in this loop have been maintained during the past 600 hr at approximately 100 ppm of both CO and CO_2 and 20 ppm of H_2.

Three additional water-injection tests conducted for periods ranging from 1 to 7 days have been completed in conjunction with the tests of a prototype EGCR helium purification system installed on a forced-circulation test loop. The tests consisted in injecting water vapor into the loop and operating the CO_2- and water-adsorber portions of the purification system. Results of these tests indicated that, although there was a slight increase in the H_2 level in the loop, the addition of water vapor to the gas in the loop presented no serious problem in the operation of the purification system.

Compatibility of Beryllium with Water Vapor. — Tests are being run to determine the effects on beryllium metal of exposure to flowing helium containing 25 to 30 mm of H_2O vapor at 600°C. The test material is −200 +230 mesh beryllium powder, and the test duration is approximately 200 hr. Log-log plots of the weight change data vs time from two tests show two straight lines intersecting at log t ≈ 5 hr. One line, with a slope of ~1, indicates that the reaction product does not form a protective film. The other line, with a slope of ~2, indicates the formation of a protective film.

It can be tentatively concluded from these data that the first part of the log-log plot (slope of ~1) is not due to a reduction in surface area of the sample, that is, the complete oxidation of the fines in the −200 mesh powders. Rather, the data indicate that the point of inflection is due to a change in the rate-controlling process from the hydrolysis of Be_2C in the first part of the test to the oxidation of beryllium in the second part. If this is true, there should be a correlation between the carbon content of the starting material and the weight change at the point where the change in slope occurs.

Identification of Phases in UO_2-ThO_2-BeO. — A pellet consisting of 13 vol % UO_2, 13 vol % ThO_2, and 74 vol % BeO sintered at 1700°C was found to have three phases. A petrographic thin section showed a large amount of the highly birefringent BeO compound, a trace of UO_2 (undetected by x ray), and an unidentifiable phase (not ThO_2). X-ray diffraction studies showed strong lines of BeO and a UO_2-ThO_2 solid solution phase. By crushing a small portion of the sample and using oils matching the index of refraction of BeO, ThO_2, and UO_2, the identification of BeO and UO_2 was verified. However, the third phase could not be matched, and it was therefore assumed to be a ThO_2-UO_2 solid solution.

Stress Analysis of Through Tubes for EGCR Experimental Loops. — A collapse test was conducted using an 8.0-in.-OD, 9-ft-long, type 304 stainless steel tube, with a wall thickness of 0.25 in. Although the specimen was to be held at a uniform temperature of 1200°F, the furnace design was defective and the temperatures at the time of collapse were ~600°F near the upper end, 1200°F at the center, and ~1000°F near the lower end. The collapse pressure of 800 psig found in this test is in good agreement with that predicted from model tests.

NUCLEAR TECHNOLOGY AND GENERAL SUPPORT

Fuel Element Catastrophe Studies. — Diffusion as well as melting experiments were extended in recent fission product release studies on sintered reactor grade PWR-UO_2 irradiated to tracer level only. Because of the active interest in fission-gas release rates at temperatures above 1400°C, where grain growth may be expected to accelerate the diffusion, a single trial experiment was completed at each of the following temperatures: 1500, 1600, and 1700°C. As expected, the fission-gas release for 5-hr heating periods in highly purified flowing helium showed sharply accelerated increases. Bulk rates (including the initially highest rate) for fission-gas release rose from 0.8% at 1400° to 4.5% at 1710°. All

other fission products diffused at uniformly increased rates. Iodine values ranged from 4.0 to 13.2%. Tellurium increased most abruptly from 3.9% at 1400°, to 15% at 1500°, to 35.9% at 1710°. Cesium ranged from 0.02 to 4.4%. Ruthenium remained below 0.1% at 1400° and then rose to 0.4%. Strontium rose from 0.02% at 1400°, to 0.13% at 1600°, to 0.7% at 1710°. Further longer-term diffusion experiments are planned to distinguish the high initial rates from the reduced steady-state diffusion rates.

In continuing the melting studies of UO_2 (using smaller samples contained in BeO, which melted completely in the arc-image furnace), atmosphere effects, comparing helium and air, revealed almost no difference in the percentage of various fission products released promptly (1 to 2 min of heating). For example, in one run with helium, 92% of the rare gases, 70% of the iodine, 72% of the tellurium, 40% of the cesium, and 60% of the ruthenium vaporized. In air, 97% of the rare gases, 93% of the iodine, 70% of the tellurium, 50% of the cesium, and 60% of the ruthenium volatilized. Up to 0.3% of the strontium was released in each atmosphere.

Reactor Evaluation Studies. — Calculations of fuel cost as a function of plutonium value were made in Dresden-type reactors, in which the composition and the amount of plutonium used in a given cycle corresponded to the plutonium product from the previous cycle. With slightly enriched uranium as the initial fuel, the uranium enrichment associated with minimum fuel cost varied from 3.2% U^{235} at a plutonium value of $25 per gram of fissile plutonium to 3.6% at $5/g. The minimum fuel cost varied from 0.96 to 1.08 mills/kwhr (thermal) over this range of plutonium values. In the second cycle, with plutonium from the first cycle blended with uranium, the optimum fuel cost was 1.15 mills/kwhr (thermal) at $12 per gram of fissile plutonium. The corresponding fuel cost for the third cycle was 1.18 mills/kwhr (thermal).

As was the case for the GCR-2 reported previously, the optimum fuel cost for Dresden reactors with a zero plutonium value was lower for the first cycle than for recycle cases. In these calculations a penalty of about $60 per kg of fuel was associated with recycle-fuel fabrication.

Radiation Detector Development. — A theoretical study of the response of NaI(Tl) scintillators to monoenergetic gamma rays, based on a previously developed Monte Carlo code, reveals that the experimentally observed nonlinear response results in an intrinsic line broadening in the measurement of gamma-ray spectra. The line-broadening effect is appreciable only for those gamma rays which can interact with electrons of the NaI(Tl) crystal in either a Compton or pair production event and is thus significant only above about 100 kev. The calculated fractional line width (full width at half maximum) reaches a maximum value of 5% at a gamma-ray energy of 400 kev in a 2-in.-diam by 2-in.-high crystal. The line width has been calculated as a function of gamma-ray energy and crystal size and represents a minimum width which cannot be sharpened by improved optical techniques or by the use of better photomultipliers.

Detailed studies of the scintillation response of CsI(Tl) to gamma rays in the energy interval 10 kev to 3 Mev demonstrate a nonlinear relationship between light intensity and gamma-ray energy over this entire

interval. This behavior is quite similar to that observed at other laboratories in NaI(Tl). These effects are in accord with a recently proposed model of the scintillation process in activated alkali halides.

Chemical Behavior of Thermoelectric Materials. — Design of all-glass apparatus for handling UO_2 samples in controlled atmospheres and vacuum has been completed. The special features of this design are that it permits, without breaking the vacuum or in any other way exposing the samples to air, (1) movement of the sample from the furnace zone to any other location, (2) removal of the specimen from the sample boat, (3) crushing and grinding the specimen, (4) filling of x-ray capillaries, (5) storage of the specimen in a side arm, and (6) retransfer of the specimen to the boat and furnace area.

Zirconium Metallurgy. — A study of the effects of fabrication variables on the preferred orientation, anisotropy of mechanical properties, and anisotropy of strain behavior in Zircaloy-2 plate and sheet has been completed. The preferred orientation and anisotropy data indicated that the theory of anisotropy of mechanical properties developed by R. Hill could not be used to explain the behavior observed. Recent x-ray diffraction data have shown that principal axes of anisotropy in fabricated Zircaloy-2 do not necessarily coincide with principal fabrication directions, that they can lie in directions not contained in the rolling plane, and that they may not be definable in a practical sense for test purposes. Each of these findings violates one or more of the basic requirements of Hill's theory.

Fuel Element Development. — In preliminary examinations of a number of uranium intermetallics as binder phases for liquid-phase sintering of uranium monocarbide, U_3Si_2-bonded uranium carbide emerged as an interesting system. By fabricating with 20 vol % U_3Si_2 as the binder and by cold pressing and vacuum sintering at 1600°C, surprisingly good-quality bodies have been achieved. Metallography shows equiaxed uranium carbide in a continuous matrix with an apparent bulk density higher than 95% of theoretical. X-ray diffraction of fired compacts revealed a large amount of uranium carbide with lattice parameters closely corresponding to published values. Remaining lines did not correspond to known uranium-silicon compounds and probably represent a uranium-silicon-carbon complex or complexes.

Nondestructive Test Development. — The critical coolant-channel spacing between fuel plates in fuel assemblies has raised a need for accurate-measurement techniques, both during fabrication development studies and also during actual fuel element assembly. An eddy-current technique has been developed which will allow these measurements to be made accurately at any point throughout the coolant channel. The specially designed test probe consists of a long, thin strip of flexible steel tape on which is mounted a small flat coil of copper wire and a small steel leaf spring which is attached to one end of the tape and overhangs the coil. The action of the leaf spring causes it and the steel tape to press against opposite walls of the space to be measured, with the copper coil between them. A high-frequency electrical signal will produce a characteristic impedance in the coil. Movements of the

ferromagnetic leaf spring relative to the coil will produce changes in this impedance which can be measured and calibrated in terms of channel spacing.

An early version of such a probe is being used to measure plate spacing for the HFIR core covering a range of measurements from 0.030 to 0.070 in. with an accuracy of ±0.001 in. A model with improved sensitivity has been devised which can gage with an accuracy of ±0.0005 in. A probe of this type will be used for the Fermi fuel elements.

Mechanical Properties Research. – Reactor service conditions generally impose steady-state and cyclic stresses on structural materials such as the fuel elements and the core structure. A program of research is in progress to study the effects of complex stress cycling on materials at elevated temperatures. Stress-cycling tests of Inconel tubes at 1500°F under torsional loading have been completed. The results indicate that the behavior of Inconel under these conditions may be correlated on the basis of the principal stress criterion for fracture. It is interesting to note that similar expressions adequately correlate the fracture of Inconel under static complex stress conditions at elevated temperatures.

The relationships between fracture of metals under monotonic and cyclic creep stresses at high temperatures are being investigated. Analysis of the data for Inconel indicates that a Goodman-type diagram may be constructed to relate the cyclic and mean stresses to produce failure in 1000 hr.

Fuel Cycle Technology. – Steam denitration of thorium nitrate to prepare a water-dispersible thorium oxide was scaled up from 20- to 500-g batches. A total of ~10 kg of oxide was prepared in an externally heated laboratory rotary calciner by passing steam at 375°C over thorium nitrate crystals at a rate of 40 g/min for ~2 hr. The product oxide contained 3.0 to 5.5% volatile matter, and all of the off-gases were condensable. After addition of 5 wt % uranium as ammonium diuranate, the solids were dispersed in water to sols, dried at < 100°C to gels, precalcined slowly to 500°C, air-calcined rapidly to 1200°C, and then hydrogen-fired at 1200°C to reduce the uranium to $UO_{2.00}$. The densities of fragments varied from 99.6 to 100% of theoretical, with less than 1/3 of the products being below 100%. At present, 4.4 kg of the 5% uranium-thorium oxide is ready for vibratory compaction, and 2.4 kg is in process. Particle sizes varied from −200 mesh to +10 mesh, with 85% > 16 mesh. Excessive undispersible residues of oxides resulted (8%) when residual volatile matter was decreased to 3%, but these could be recovered and recycled to the dispersion step by digestion in dilute nitric acid.

Reactor Controls Development. – A new transistor switching circuit has been developed for controlling magnet currents in safety-rod release mechanisms. In contrast to previously available solid-state instruments for this service, the new circuit permits realization of the fast-release capabilities of the magnetic circuit in the controlled device. This is achieved by permitting the inductive voltage surge which appears upon turning off the current to rise to a controlled maximum which may be as high as 200 v. Limiting this surge with a nonlinear device protects the instrument and the magnet coil insulation while allowing the magnetic field to decay very rapidly. The instrument controls currents up to

1.5 amp and is therefore applicable to low-impedance magnet windings for which the voltage surges are compatible with the 200-v limiter. Experiments with presently used magnet configurations, fitted with new low-impedance coils, have shown that holding force and release time are comparable with those obtained with the vacuum-tube equipment now in use. Two different transistorized scram amplifiers have been developed to adapt the switching circuit either to the present 37-v sigma-bus system or to a 12-v scram bus, which is more appropriate for an entirely solid-state system. The new instrument is an essential part of a "second generation" safety system now under development, in which the techniques of redundancy, coincidence, and in-process testing will be applied.

Power Reactor Fuel Processing: Darex Process. – Decladding of a prototype Consolidated Edison fuel pin irradiated to about 20,000 Mwd/ton resulted in a uranium loss higher than that normally found with unirradiated fuel. The uranium loss after a 3-hr decladding in boiling 5 M HNO_3–2 M HCl was 2.2%; the thorium loss was < 0.07%.

In two tests made with Darex dissolver solution in which unirradiated uranium had been dissolved, the time required to decrease the chloride concentration from 0.87 M to 350 ppm was inversely proportional to the NO_2 sparging rate; the sparging rate in one case was five times that in the other. About 1000% of the stoichiometric amount of NO_2 required to form NOCl was introduced. An improved method of contacting may greatly decrease the excess NO_2 required.

Addition of Cr^{6+} to dissolvents containing fluoride ion decreased the corrosion rate of titanium in fluoride enough to permit the use of this metal for both Darex and Zirflex processing equipment. In tests with a modified Thorex dissolvent containing 15 M HNO_3–0.1 M F^-–0.2 M Cr^{6+}, the dissolution rate of ThO_2–2.6% UO_2 pellets of 92% theoretical density was the same as in normal Thorex dissolvent.

In other corrosion tests, titanium was corroded at a maximum rate of 0.06 mil/month during 89 Thorex feed adjustment boildowns. Hastelloys F and C were corroded at maximum rates of 0.09 and 0.43 mil/month, respectively, in Darex decladding solution at 35°C.

Power Reactor Fuel Processing: Mechanical Processing. – Cold operability tests of the SRE core 1 dejacketing equipment in Building 3026 continued to be satisfactory except in the case of the NaK collection system, which is being revised. In general, the schedule for attaining hot operation early in 1961 continues to appear entirely feasible.

Initial tests on the outflow of NaK (22% sodium–78% potassium alloy) from the oil-filled decladder trough indicated that some dispersion of NaK globules in oil occurred. Two oils of lower viscosity and density were procured which allowed much faster separation of NaK particles in laboratory tests. These new oils also conform to existing specifications on clarity, unreactivity, and high flash point. Modifications are now being made to the SRE processing equipment to reduce the dispersive effects to a minimum and to ensure more complete collection of NaK.

An evaluation program is being conducted to determine the feasibility of washing down the interior of a shear to assure good decontamination of the equipment, recovery of fissile and fertile material, control of particulate material, and lubrication of moving parts. Preliminary tests

with talc indicate that dust can be removed from the interior surfaces of the shear by properly sized and located spray nozzles.

Initial tests to determine the mechanical operability of an inclined rotary drum leacher showed excessive friction in the bearings.

Power Reactor Fuel Processing: Purex Corrosion Tests. — The presence of 0.002 M ruthenium in Purex waste solutions increased the maximum corrosion of Hastelloy F from 1.9 to 2.8 mils/month in 500-hr exposures. In Purex waste condensate tests, titanium 45A was corroded at a maximum rate of 2.1 mils/month, as compared with 7.2 mils/month for Ni-o-nel—0.2% platinum.

Power Reactor Fuel Processing: Graphite-Uranium Fuel Processing. — Studies of the 90% HNO_3 disintegration-leach process were made on an unirradiated General Atomic prototype fuel specimen 2-1/4 in. in diameter and 1/4 in. thick. The sample had a 1.5-in.-diam inert graphite core surrounded by a 3/8-in. active annulus containing a graphite—metal dicarbide mixture. The fuel particles were 150 μ in diameter, and the mixture contained 1.18% uranium and 14.3% thorium. The recoveries of uranium and of thorium after two room-temperature leaches with 90% HNO_3 were both 90%. The graphite was washed with water after each leach. The reaction off-gas was a mixture of nitrogen oxides and carbon oxides. The leach solutions were dark red and contained carbon. Addition of 30% H_2O_2 to the hot leach solution lowered the carbon concentration from 0.86 to 0.34 mg/ml. Hydrogen peroxide was more effective in decreasing the carbon content than either 70% $HClO_4$ or 2.5 N $KMnO_4$.

In preliminary engineering tests on disintegrated graphite that had been exposed to boiling 90% HNO_3 for 8 to 48 hr, the average particle size was found to be 75 to 150 μ. The graphite settled rapidly and could be filtered at rates of 3000 to 6000 liters m^{-2} hr^{-1} on a 20-μ-porosity stainless steel filter at 3 in. Hg vacuum.

Reaction of 1 g of uranium monocarbide containing 2 to 5% α-uranium metal with water in a helium atmosphere at either 80 or 90°C produced 92.7 ml of gas consisting of 85% methane, 12% hydrogen, 2.5% ethane, and 0.7% propane. At 80°C, about 0.2% ethylene was also detected. The reaction rate was about the same at the two temperatures.

Power Reactor Fuel Processing: Uranium-Molybdenum Fuel Processing. — The solubility of sodium molybdate in sodium hydroxide solutions at 26°C was found to decrease from about 2.8 to 1.3 M as the hydroxide concentration was increased from 0 to about 4.4 M.

Power Reactor Fuel Processing: Zircex Process. — Processing of TRIGA fuel (8% U—ZrH) by the Zircex (hydrochlorination) process appears feasible. The fuel behaved similarly to uranium-zirconium alloy during hydrochlorination and no new problems developed.

In prior work it was found that uranium-molybdenum fuel can be hydrochlorinated with HCl-air mixtures. Corrosion tests indicated that Haynes 25, INOR-8, Nichrome V, and Pyroceram were all corroded at rates < 0.1 mil/month during 48 hr exposure in 15% HCl—85% air at 400°C.

Power Reactor Fuel Processing: Zirflex Process. — Zirflex decladding of zirconium-clad uranium-molybdenum fuels was found to be impractical because of high uranium losses.

In corrosion tests, Hastelloys F and C were corroded at maximum rates of 0.05 and 0.03 mil/month, respectively, in Zirflex decladding solutions at 35°C.

Power Reactor Fuel Processing: Solvent Extraction Studies. – Results of performance studies on the intermediate-scale mixer-settlers using the five-stage IMMI mockup and the standard Purex flowsheet indicate that stage efficiencies for uranium stripping can be increased to 80% by modified impeller design and impeller speeds up to 950 rpm. A volumetric throughput of 338 ml/min or more should be attained with the actual 11-stage IMMI stripping bank. For the Purex flowsheet, this is equivalent to an aqueous feed flow rate of 92 liters/day, or a uranium mass throughput of 29.5 kg/day.

Power Reactor Fuel Processing: Sulfex Process. – In one test in which a prototype stainless-steel-clad Consolidated Edison ThO_2-UO_2 fuel pellet, irradiated to about 20,000 Mwd/ton, was declad in boiling 6 M H_2SO_4 for 3 hr, the soluble losses of uranium and thorium to the decladding solution were 0.06 and 0.07% respectively.

Power Reactor Fuel Processing: Beryllium-Uranium Fuel Processing. – The Hastelloy X cladding from the GCRE fuel (70% UO_2–30% BeO) dissolves at rates of 6 to 28 mg min^{-1} cm^{-2} in boiling 1 to 5 M HNO_3 solutions containing 4 or 5 M HCl. Either 10 M HNO_3, 5 M HNO_3–2 M HCl, or 3 M HNO_3–3 M H_2SO_4 appears suitable as a reagent for leaching the uranium from the declad fuel pellets.

Fluoride Volatility Processing: Chemical and Engineering Development. – Various oxides were dissolved in fused fluorides with gaseous HF. Three of the oxides were dissolved in 31 LiF–24 NaF–45 ZrF_4 (mole %) at 650°C: UO_2 fired at 1650°C, density 10.4 g/cc, was hydrofluorinated at a rate of 11.5 mg cm^{-2} min^{-1}; high-fired ZrO_2, 94% of theoretical density, at 1.1 to 1.4 mg cm^{-2} min^{-1}; and PWR core 2 seed elements (no Zircaloy cladding) at 1.0 to 1.2 mg cm^{-2} min^{-1}. High-fired BeO was dissolved in 49 NaF–40 LiF–11 BeF_2 at 600°C at rates of 0.56 to 0.60 mg cm^{-2} min^{-1}. All these rates appear satisfactory from a process viewpoint.

In absorption of gaseous MoF_6 on NaF, NaF/MoF_6 mole ratios of 15.9/1, 9.3/1, 5.7/1, 6.0/1, and 5.0/1 were obtained, respectively, at 50, 75, 100, 150, and 200°C. The absorption of UF_6 on NaF usually results in approximately a 6/1 ratio over a widely varying temperature range. The MoF_6-NaF complex decomposed at about 245°C at atmospheric pressure.

Breakthrough times in three sorption tests of the UF_6-NaF system were 77, 59, and 163 min when the UF_6 concentrations in the feed were 8.4, 8.4, and 3.8 mole % and the total gas feed rates were 0.15, 0.14, and 0.14 mole/min respectively. The tests were made in a 4-in.-diam bed containing 800 g of NaF (~6 in. deep) at 30°C. Bed loadings measured after a run time equal to twice the breakthrough time were not dependent on feed concentration.

The averaged dissolution rates of Zircaloy-2 determined in the INOR-8 prototype vessel tests were correlated (±10%) by the expression

$$r = K_1 \left(\frac{\nu}{1.0}\right)^{-0.333} \ln \frac{W}{0.40} ,$$

where r = pounds of Zircaloy-2 per hour per square foot of initial area; ν = salt kinematic viscosity, ft^2/hr; 1.0 = a constant, ft^2/hr; W = HF feed rate, lb/hr; 0.40 = a constant, lb/hr; K_1 = a constant, 0.0435 lb hr^{-1} ft^{-2}.

Fluoride Volatility:Processing: Pilot Plant. — Modifications to the Volatility Pilot Plant for processing of zirconium-uranium alloy fuel were completed. In cold dissolution runs with Zircaloy-2 elements, dissolution rates were 0.5 to 1.1 mg cm^{-2} min^{-1} and HF utilizations were 11 to 30% with HF flow rates varying between 40 and 150 g/min and molten salt temperatures from 490 to 650°C.

The most important problem was carryover of very fine particles (~1 μ) in the hydrofluorinator off-gas stream. In tests, steel wool and copper mesh cartridges were very effective in removing solids, but these are not readily disposed of. Wire mesh and porous metal filters showed pressure drop increases of about 1 psi per run, which would necessitate a blowback system.

A 2-in.-diam cyclone, which was tested prior to installation, showed an efficiency of 90% when the gas flow was 200 std ft^3/hr; the particulate matter was Arizona road dust which analyzed 40% in the size range from 0 to 5 μ.

PHYSICAL RESEARCH PROGRAM

Reactor Operations. — The ORR is operating routinely on an eight-week cycle, and the cycle which ended November 20 had the fewest shutdowns of any to date. Only three fuel reloadings were required, and one of these was made necessary by the failure of an experiment.

Waste Disposal. — Waste-disposal monitoring instruments in the stacks have been effective in determining the source of minor releases of activity. Monitoring instruments in the liquid-waste system are not yet complete, and with the monitoring available it is not possible to determine the source of some of the strontium which now enters the river. Additional monitoring in the creek is expected to be complete soon, and this should give better data as to the source of the strontium.

The intermediate-level liquid waste has about twice the volume that can be disposed of in the present seepage trench, making continued use of the open pits necessary. A new seepage trench is being designed which should permit all of this waste to be handled in covered trenches. Once this is done it will be possible to seal the open pits.

Hot-Cell Operations. — Operation has begun in cells 4 and 6 of the Building 3025 hot cells, and it is hoped that cells 1, 2, and 3 will be ready for operation in December.

PHYSICS AND MATHEMATICS RESEARCH

Neutron Diffraction. — Neutron diffraction measurements were made on erbium single crystals in the temperature range from 298 to 4.2°K. The material is antiferromagnetic below 80°K and ferromagnetic below 20°K. In the antiferromagnetic region the magnetic scattering consists in satellite reflections corresponding to a modulation of the magnetic scattering amplitude along the c axis. The spacing and the intensity distribution of these satellites show two distinct subregions of antiferromagnetism. In the upper region, between 80 and 53.5°K, the data suggest a sinusoidal modulation of the magnitude of the c-axis component of magnetic moment with a period of $3.5c_0$. Between 53.5 and 20°K the wavelength of the modulation varies continuously from $3.5c_0$ to $4.0c_0$. In addition there is a squaring up of the modulation and a simultaneous ordering of the component of the moment normal to the c axis. Below 20°K the material is basically ferromagnetic, with a moment of 7.3 Bohr magnetons directed parallel to the c axis.

Theoretical Physics. — The distorted wave Born approximation theory of direct reactions has been used to interpret the experimentally observed angular correlation of gamma rays following the inelastic scattering of protons and alpha particles at medium energies. The distorted waves were generated from optical potentials which give a good description of the elastic scattering at the same energies, and the calculations were performed on an IBM 704 computer. Both single-particle and collective (surface coupling) transitions were considered. The results were compared with the adiabatic approximation ($Q = 0$), which predicts symmetry about

an axis bisecting the angle between the incident and scattered directions when spin flip can be neglected [Blair and Wilets, Bull. Am. Phys. Soc. 4, 460 (1959)]. The circular polarization of the gamma rays was predicted. At lower energies the direct interaction gamma-ray distribution was compared with the predictions of the statistical model of the compound nucleus.

Fast-Chopper Time-of-Flight Spectrometer. — Two codes have been written for the IBM 704 computer in order to obtain parameters of Breit-Wigner resonances from transmission data. The first code is an area analysis code which determines the neutron widths of the resonances for assumed total widths. The second code is a shape fit code (used when the Doppler and resolution widths are less than or approximately equal to the total widths of the resonances) which determines the resonant energies, the total widths, and the neutron widths of the resonances. Both codes assume that the cross section can be represented by the sum of single-level Breit-Wigner formulas, with interference between resonance and potential scattering but no interference between resonances; that the Doppler broadening is Gaussian; and that the resolution can be represented by a Gaussian. For the area analysis code the transmission is analyzed in groups, with no more than 12 resonances in any group. The cost of analyzing a typical 1024-channel transmission run with 30 resonances is about $100.00. The shape analysis code solves for the resonant energies, the total widths, and the neutron widths of as many as four resonances at once by the least-squares method for about $40.00.

The ORNL fast chopper and the associated 180-m flight path were utilized in measuring the total cross sections of Np^{237} (from 10 to 86 ev) and Am^{241} (from 5.4 to 25 ev) with approx 0.2% energy resolution. The data were analyzed with the IBM 704 area analysis code.

Low-Temperature, Nuclear and Solid State Physics. — A study of the hyperfine splitting of Au^{197} alloyed in iron has been made by the Mössbauer method. The nuclide Au^{197} has a $3/2^+$ ground state and a $1/2^+$ first excited state at 77 kev. Although gold is normally nonmagnetic, when it is alloyed in iron it partakes of the ferromagnetism of the latter through a magnetic polarization process (Proceedings of International Conference on Low-Temperature Physics, Toronto, Aug. 29 to Sept. 3, 1960, p 415). The resulting hyperfine splitting of the above two gold levels has been studied for an alloy of 1 at. % gold in iron. The measurements were made at helium temperatures by the Mössbauer method with Pt^{197} in platinum metal as the source and the above gold-iron alloy as the absorber. In a preliminary experiment two lines were observed, each being an unresolved triplet. The separation of these lines is approx 1.1 cm/sec with a line width of about 0.6 cm/sec. A quite large chemical shift of about 0.5 cm/sec was found. For the excited state these measurements give $|\mu_n H_0| = 4.5 \times 10^5$.

High-Voltage Experimental Program: Neutrons from the He^3 Bombardment of Some Light Nuclei. — The ion source for the ORNL 3-Mv accelerator has been modified to provide a peak beam of about 500 μa of singly charged He^3 ions. This beam has been pulsed in the Van de Graaff terminal at a repetition rate of 2 Mc to give pulses of about 20 nanoseconds duration.

After acceleration and magnetic analysis, a 2- to 3-nanosecond pulse is separated from the 20-nanosecond burst by a newly installed pulser operated at 12 Mc and synchronized with the terminal pulsing frequency. In order to detect the neutrons a large-volume plastic scintillator on a 4-in. photomultiplier was used. The over-all system resolution has been about 4 nanoseconds for neutrons. Other elements of the time-of-flight system have been described previously [Phys. Rev. 109, 926 (1958)]. The reactions $Li^7(He^3,n)B^9$ (Q = 9.346), $Be^9(He^3,n)C^{11}$ (Q = 7.565), and $C^{13}(He^3,n)O^{15}$ (Q = 7.126) have been studied, and neutron time-of-flight spectra have been obtained.

High-Voltage Experimental Program: Coulomb Excitation of the Second 2^+ States in Tungsten, Osmium, and Platinum Nuclei. — The location of a second 2^+ state has been established for six even-even nuclei by means of Coulomb excitation produced by 4- to 5-Mev protons. The relatively weak excitation of these states was detected by a measurement of the gamma-ray yields from singles spectra and from coincident measurements of the cascade gamma rays. The B(E2)'s for decay of the second 2^+ state to the ground state by the crossover transition exhibit some uniformity for the even-even isotopes of tungsten and osmium, being about six times the single-particle value. The cascade/crossover ratio for the second 2^+ state is known for these nuclei. The upper cascade B(E2)'s exhibit enhancements of 10 to 60 times the single-particle value. The ratios of the B(E2)'s for decay of the first and second 2^+ states were compared with the predictions of several collective models. For five of these nuclei the E2/M1 ratio is known for the upper cascade transition. The B(M1) values obtained are exceedingly small compared with the single-particle estimate. This result is in qualitative agreement with the collective models which predict that M1 radiation is forbidden in the decay of vibrational excitations.

CHEMISTRY RESEARCH

Spectrophotometric Studies of Solutions at Elevated Temperatures and Pressures. — The design of the optics of a high-temperature high-pressure spectrophotometer was modified to allow visual observation of the contents of a processing cell at temperatures up to 330°C and pressures up to 200 atm. An adjustable slit system was designed which will make possible independent quantitative measurements on both phases of two-phase systems.

Raw Materials Research and Development. — Preliminary evaluations of a solvent extraction procedure for recovering nitric acid from uranium refinery waste streams were encouraging. Nitric acid is extracted with a secondary amine in kerosene-alcohol diluent and stripped by contacting the amine nitrate with a lime slurry. The calcium nitrate thus produced is reacted with sulfuric acid to yield 5 to 6 M nitric acid.

Solvent Extraction Research. — In the development of flowsheets for final-cycle plutonium recovery by extraction with amines, isotherms for the extraction of plutonium(IV) from 1.5 M HNO_3 by 0.3 M trilaurylamine and other similar tertiary amines were fitted over a useful range by the

empirical expression $E_a^o \approx 2500\ (\underline{M}_{amine} - 4\underline{M}_{Pu})^2$. Phase stability of the loaded extracts depended on the amine and the diluent as well as on the plutonium concentration. Stable organic phases were obtained at or above 15 g of plutonium per liter with 0.3 M trilaurylamine in Solvesso 100 and with Alamine 336 in 90% Solvesso 100–10% tridecanol, although only at somewhat lower loadings with trilaurylamine in 5% tridecanol–95% Amsco 125-82 and with Alamine 336 in Solvesso 100. These results are favorable for amine extraction with a high concentration factor from a Purex first-cycle plutonium stream without feed adjustment except oxidation to plutonium(IV).

Americium was separated from europium by a factor of at least 10^4 in a five-stage batch countercurrent extraction by 0.5 M Alamine 336–5% tridecanol in Amsco 125-82 from 8 N LiCl–2 N $AlCl_3$. With an organic/aqueous phase ratio of 2.5, americium recovery was about 90% with > 99.9% europium removal. Addition of two extraction stages increased the americium recovery to > 99% with europium removal > 99%. In single-stage experiments the extraction of curium was similar to that of americium, and cerium extraction was similar to that of europium.

Americium was separated from europium by a factor of about 10^4 in a 13-stage batch countercurrent extraction by 1 M tributyl phosphate from 8 N LiCl–2 N $AlCl_3$. This result confirms single-stage data.

Ion Exchange Studies. – From data obtained in experiments on rates of elution of uranyl sulfate from Dowex 21K resin, apparent uranium diffusion coefficients of 1.67×10^{-7} and 1.18×10^{-7} cm^2/sec were calculated for 960- and 820-μ resin respectively. The corresponding apparent coefficients with 1 M sodium chloride were 1.78×10^{-7} and 1.27×10^{-7} cm^2/sec.

Chloride and sulfate self-diffusion coefficients in 1200-μ Dowex 21K were measured as 4.2×10^{-6} and 2.5×10^{-6} cm^2/sec respectively. This explains why uranyl sulfate loading rates are greater on chloride-equilibrated resin than on sulfate-equilibrated resin.

A calculational procedure was developed and coded for machine calculations which may make possible predictions of uranyl sulfate loading and elution rates from self-diffusion coefficients of the ions involved. The code was shown to reduce to the known solution when ions of equal valence and mobility are involved.

Chemical Engineering Research. – The height equivalent to a theoretical stage for extraction of uranium from 3 M nitric acid with 5% tributyl phosphate in Amsco decreased from 2.2 to 1.2 ft as the pulse frequency was increased from 50 to 90 cycles/min in the standard sieve plate (0.125-in.-diam holes, 23% free area) pulsed column operated with the aqueous phase continuous. Changing the flow rates from 20 to 50% of flooding capacity had virtually no effect on the stage height. Stage heights for organic-continuous operation of a nozzle plate (0.125-in.-diam holes, 10% free area) column were 1.4 to 1.6 ft over a range of pulse frequencies, flow rates, and uranium feed concentrations.

Physical Chemistry of Molten Salts. – The lowering of the freezing point of sodium fluoride by tetravalent fluorides has been investigated. The objective of this investigation is to relate the structural properties of various solute cations to their effect on the freezing point of sodium

fluoride. This cryoscopic medium was chosen because, at high concentration, it has very little tendency to form solid solutions with other fluorides. When the isostructural tetravalent fluorides were dissolved in concentrations up to 15 mole %, the freezing-point lowering showed negative deviations from ideality and followed the order $ThF_4 > UF_4 > HfF_4 = ZrF_4$. This order is explainable if it is assumed that in solution the tetravalent ion is coordinated by an average of eight fluorides, as it is in the pure solid. The cation size determines whether all eight fluorides are in contact with the central ion, and, in fact, it is only in the case of Th^{4+} that all eight fluorides have points of contact. As the size of the tetravalent ion increases, more fluorides will be able to make point contact and more work will be required for the sodium ions to attract fluorides; consequently, the freezing point will be lowered.

High-Temperature Aqueous Solution Chemistry. — The solubilities of UO_2SO_4, $CuSO_4$, Li_2SO_4, and $NiSO_4$ have been measured in the supercritical fluids H_2SO_4-H_2O and D_2SO_4-D_2O containing from 0.02 to more than 1 m total sulfate. Below the critical temperatures for these systems the compositional boundaries of the region of unsaturated solution have been determined. The experimental data are conveniently expressed as plots of the metal:sulfate molar ratio vs temperature, and they reveal qualitatively similar behavior for all the salts. For a given total sulfate content there is a nearly linear relationship of increasing temperature with decreasing metal:sulfate ratio which marks the boundary between unsaturated solutions and solutions which either contain saturating solid phases or show liquid-liquid immiscibility. At sufficiently low ratios and high temperatures this boundary intersects a critical curve which is almost independent of the ratio of metal to sulfate. This curve gives the temperature at which a liquid meniscus appears or disappears. Both the critical curve and the linear boundary are affected by the total sulfate content of the system. The solubilities of the sulfate salts in the acid-rich supercritical fluids were surprisingly high when compared with the reported low values for the solubilities of stoichiometric sulfate salts in pure supercritical water. The maximum solubilities in D_2O-D_2SO_4 were as follows:

System	Temperature (°C)	Total Sulfate (m)	Metal Sulfate Solubility (m)
Uranium	397	0.8	0.26
Copper	432	1.0	0.28
Lithium	490	2.5	1.1*
Nickel	400	0.5	0.085
	454	2.0	0.2**

*Extrapolated. **Single point — not maximum.

An important consequence of the high solubility of these salts in acid-rich supercritical fluids is that systems of these compositions, when under externally applied pressures in excess of their critical pressures, can be heated from 25°C to temperatures above 400°C without the appearance or disappearance of any phases.

Nuclear Chemistry: Characterization of Short-Lived Fission Products. — Both natural rhenium and enriched Re^{185} were irradiated in a reactor to form Re^{184} by an (n,2n) reaction. The Re^{184} decay, followed with an end-window proportional counter, was complex, with half-lives of 34 ± 5 days and 165 ± 8 days. In the source prepared from natural rhenium there is an additional weak component with about an 8-yr half-life which is thought to result from Re^{189} formed by double neutron capture. Gamma-ray spectra taken with a sodium iodide spectrometer over a period of about four years showed photopeaks at 0.059, 0.111, 0.162, 0.218, 0.252, 0.320, 0.385, 0.540, 0.640, 0.791, 0.897, and 1.15 Mev. Each of these peaks had a complex decay involving half-lives of about 30 and 170 days. Gamma-gamma coincidence measurements were made for the peaks at 0.252, 0.320, 0.540, 0.111, 0.791, and 0.897 Mev. The measurements for the last three peaks were taken at first on a fresh source and then repeated after most of the 30-day component had decayed in order to determine the change in the population of W^{184} levels by Re^{184}.

Electrochemical Kinetics and Its Application to Corrosion. — In continuing the investigation of the action of corrosion inhibitors of the type XO_4^{n-}, a study was made of the ability of the passive film on iron to enter into ion exchange interactions with such inhibitors. The pertechnetate, chromate, and molybdate ions were used as inhibitors in the concentration range from 10^{-2} to 10^{-4} f and at pH values between 4 and 8. It was found that any retention of the TcO_4^- ion by such a process does not exceed 1% of a monolayer. With CrO_4^{--} and MoO_4^{--} at pH values between 4 and 6 there is definite interaction, the degree depending upon circumstances. In the light of similar specific interactions of ions with bulk oxides, which are probably interpreted best as acid-base interactions, the results strengthen the belief that the passive film also is able to react with protons and anions by virtue of acid-base properties. The difference between the effects of the pertechnetate ion, on the one hand, and the chromate and molybdate ions, on the other, is understandable on this basis, since the pertechnetate ion has no basic properties.

The corrosion characteristics of pure iron in deaerated sulfate-benzoate solutions are being studied for comparison with the results obtained in benzoate and perchlorate-benzoate solutions. It was found that the polarization characteristics of iron are unaffected by the addition of benzoate ion (1×10^{-2} f) to a sulfate solution (5×10^{-1} f) at a pH of 0.3. This behavior contrasts with that found in the perchlorate-benzoate system, in which inhibition was observed.

Chemical Separation of Isotopes. — The solubility of calcium in mercury was found to vary almost linearly with temperature and ranged from 0.56 to 0.91 M over the temperature range 0 to 36°C. Exchange of calcium between aqueous calcium formate and calcium amalgam was rapid. A separation factor of 1.001 per unit mass difference was measured between the aqueous and amalgam phases at room temperature, with the heavier calcium isotopes concentrating in the aqueous phase.

No nitrogen exchange was observed in 6-1/2 hr at −60°C between the diethylamine-NO addition compound dissolved in chloroform and 97% $N^{15}O$ gas at 1 atm pressure.

Chemical Applications of Nuclear Explosions. — In studies on the chemistry of contained nuclear explosions, tritium exchange from HTO to H_2 over $CaSO_4$ was investigated as a function of temperature, flow rate, and mass of $CaSO_4$ with an H_2/HTO ratio of 20. With 12.5 g of $CaSO_4$ and a total flow rate of 400 cc/min, tritium exchange at 380, 600, and 700°C was 0.47, 14.4, and 20.5% respectively. The exchange at 600°C with 3.039 g of $CaSO_4$ increased from 6.7 to 24.2% when the flow rate was decreased from 400 to 100 cc/min. The exchange at 600°C with a constant gas flow rate of 400 cc/min increased from 6.4 to 14.4% when the weight of $CaSO_4$ was increased from 1.00 to 12.5 g.

The stoichiometry of the reduction of $CaSO_4$ by hydrogen in the 850 to 900°C range was determined by direct weight loss measurements, analysis of the solid reduction product for sulfide, and measurement of the H_2S evolved after exhaustive reduction of the sulfate. The sulfate is not reduced at temperatures below 750°C. The reduction takes place according to the reaction

$$CaSO_4(s) + 4H_2(g) \rightarrow (1 - x)CaS(s) + xCaO(s) + xH_2S(g) + (4 - x)H_2O(g)$$

The bulk of the sulfate is reduced to CaS, with 10 to 15% being reduced to CaO. The CaO is undoubtedly formed by hydrolysis of the CaS with the water that is formed by the reduction.

METALLURGY AND MATERIALS RESEARCH

Ceramics Research. — Studies of the sintering behavior of ThO_2 were continued. Photomicrographs of polished surfaces of ThO_2 pellets fired at 1800°C showed no evidence of preferential disappearance of pores at or near grain boundaries. Pores actually on grain boundaries tended to be oblong. Grain sizes were much larger in specimens composed of ThO_2 prepared by decomposition of undigested $Th(C_2O_4)_2$ than in those prepared from 100-hr digested $Th(C_2O_4)_2$. The undigested ThO_2, which had smaller, more irregularly shaped, and more porous particles, sintered to higher density.

The sinterability of ThO_2 compacts at 1800°C was determined as a function of the properties of powder used to prepare the compacts. It was found that the sinterability decreased with increasing crystallite size (determined by x-ray line broadening) and with increasing immersion density of the powder (particle or aggregate density). However, these trends held only for ThO_2 batches which differed as a result of variation in precipitation method and which were converted to ThO_2 at the same calcination temperature. When crystallite size and immersion density were increased by higher calcination temperature, the sinterability trend did not apply, suggesting that structural properties, not necessarily represented or paralleled by particle density or crystallite size, greatly influenced sinterability.

CONTROLLED THERMONUCLEAR RESEARCH

Cross-Section Studies. — During the last month 100 μa of 20-kev H_2^+ was made incident upon a target of electrons of 4 ma and 13.4 v. However,

120-cycle 50% modulation of the H_2^+ beam prevented the detection of the 50-cycle modulation of the electron beam so that no accurate data could be obtained. This 120-cps modulation has now been reduced to less than 0.1% by reducing the ripple of the power supplies of the rf-type source producing the H_2^+. During this time a more efficient electron gun has been put into use.

Calculations indicate that if 1% of the deuterium arc consists of D_2^+ the observed pressures in the DCX could result from dissociative recombination (i.e., $H_2^+ + e \rightarrow 2H^0$). Measurements of the ion cyclotron resonances on a deuterium arc show that at least 90% of the arc is D^+.

DCX-1 Facility. — An energy balance in the DCX-1 has been made by use of the neutral-particle energy spectrometer. For H_2^+ injection currents of 0.1 ma, the energy loss, attributed to cold electrons in the carbon arc, was 20 kev per millisecond of containment time. For H_2^+ currents of 2.3 ma, an additional energy loss of 15 to 35 kev/msec is indicated. With background gas dissociation the energy loss is approximately 6 kev/msec.

Additional deuterium arc experiments have been performed. By enclosing a rotating, water-cooled anode in a well-baffled chamber, heat fluxes of 30 kw/in.^{2} have been extracted without serious damage to the anode surface. Several baffle geometries have been tried with no resulting decrease in the pressure in the region of the trapped plasma.

Two cathode geometries have been used in attempts to secure a decrease in the cross-sectional area of the carbon arc. Tungsten cathodes 1/8 and 1/4 in. in diameter melted due to the high current density needed to vaporize sufficient carbon from the carbon anode.

A specially constructed VacIon vacuum pump has been received from the manufacturer. The pump was designed to be placed in the region between the mirror coils and the extension coils. Tests are incomplete because of insulation failures in the pump unit. Pumping speeds for hydrogen measured to date are about 5000 liters/sec, which are very low compared with the design speed of 50,000 liters/sec.

DCX-EPA. — Installation and assembly of the facility is complete except for the outboard magnetic field coils and the water and electrical connections. Preliminary vacuum tests on the tank alone indicate that a pressure of 3 μ may be obtained with only the Kinney roughing pumps.

Ion Source Development. — Preliminary studies of beam trajectory at low currents have been made on the 600-kv test facility with a scanning probe. They indicate a considerably smaller beam diameter than expected, with correspondingly high power density at the target. The facility is out of operation during the installation of the coils and the tank beneath the manifold. The coils, which will be used later on the DCX-2, provide a field of up to 12 kilogauss on an axis which may be tilted relative to the tank. Injector shield, targets, and beam trajectories will be studied in this added region. During the shutdown, a change in the high-voltage lead arrangement will be made to reduce the corona.

Just prior to shutdown an arc-over in the tube, probably caused by a loose source insert, caused the only damage to the tube structure since the first few days of operation. The electrodes have been repaired.

Theory. – Exact relativistic Fokker-Planck coefficients have been obtained for the case of a plasma which, in zero order, is static, spatially uniform, and has no external electric or magnetic fields. The results include an arbitrary number of species of ions, arbitrary velocity distributions, and an arbitrary energy distribution in the radiation field.

Ball Lightning Survey. – Two physical models of the rare and controversial ball lightning – a possibly stable plasma configuration – have received interest in recent years: the standing electromagnetic wave interference pattern (Kapitza, Watson, Tonks) and the pinched ring current (Shafranov). A survey of a statistical sample of 15,923 Union Carbide Nuclear Company employees in Oak Ridge was made for investigating the probability of purported observations and salient properties. The 515 reports (3.2%) support the generally reported properties of ball lightning and suggest but do not prove that a rotational property may be associated with the internal motion of the fireball.

BIOLOGY AND MEDICINE PROGRAM

RADIATION EFFECTS ON BIOLOGICAL SYSTEMS

Genetic and Cytogenetic Effect of Radiations. – In order to test the hypothesis that the ultraviolet action spectra of one- and two-stranded deoxyribonucleic acid are different, biologically active DNA has been irradiated with monochromatic ultraviolet light under two conditions: (1) when it is double-stranded (at 85°C) and (2) when it is single-stranded (at 98°C). An action spectrum of *Hemophilus influenzae* transforming principle has been obtained at 85°C. Preliminary results of irradiations at 98°C suggest that the action spectrum is different in shape from the 85°C or two-stranded one. The combined effect of ultraviolet light and heat has been studied; the results indicate that a dose of ultraviolet light to transforming principle before heating prevents some of the loss of biological activity on subsequent heating and cooling. This phenomenon is being further investigated to test the hypothesis that ultraviolet light cements the two strands so that they reconstitute more readily after heating.

Cell Growth and Reproduction. – In the ciliated protozoan *Euplotes*, synthesis of deoxyribonucleic acid is localized in two cytologically identifiable bands which move along the rod-shaped nucleus over a period of several hours. Although the main mass of the nucleus contains large amounts of protein and ribonucleic acid, the band regions contain little or none. Deoxyribonucleic acid has been shown to be present in the bands but is highly diluted; possibly it exists here as the single-strand form rather than as a double helix. Isotopic detection of synthesis shows that new protein is synthesized simultaneously with deoxyribonucleic acid. Ribonucleic acid synthesis is continuous in all parts of the nucleus except in the bands; here it is very low or absent. These studies are directly pertinent to the problems of gene, chromosome, and nucleus duplication.

Pathology and Physiology. — The life span of blood platelets in the mouse was estimated by determining the time required to label the entire mass of platelets in the peripheral blood with $Na_2S^{35}O_4$. Labeled sulfate (1 μc/g) was injected each day intraperitoneally into BDF_1 mice, and the radioactivity of the platelets was determined at daily intervals. Platelet radioactivity increased at a constant rate until it reached a maximum four to five days after the first injection. This result suggests that one complete replacement of the peripheral platelet mass takes place in this length of time. By this interpretation, it follows that the average survival time of mouse platelets in the peripheral circulation is four to five days, which is consistent with the time required for development of radiation-induced hemorrhage in this species.

Biophysics: Magnetic Resonance Studies. — Careful measurements of the number of electron spin resonances produced in glycine irradiated with 300-kvp x rays with doses from 300,000 to 30,000,000 r show a definite nonlinearity or saturation effect which cannot be due to thermal effects or decay during irradiation. The apparent saturation limit from measurements four days after irradiation is about 5×10^{18} resonances per gram. There may also be changes in curve shape and decay rates for samples given different doses.

Studies of electron spin resonance signals in unirradiated cells of the bacterium Escherichia coli B/r showed a significant decrease in free-radical signal strength for cells lyophilized in the presence of thiourea. Similar results have been found for sodium iodide. Cysteine appears to give little or no diminution of the radical signals. Extension of these studies to irradiated B/r cells is in progress.

Biophysics: Ultraviolet Studies. — When thymine, in frozen solution, is irradiated by 2537-A ultraviolet radiation the principal product formed is a dimer which is nonabsorbing at wavelengths greater than 2600 A. The dimer when irradiated in liquid solution is split into two thymine molecules [Biochim. et Biophys. Acta 41, 550 (1960)], which absorb strongly at 2600 A. The interconversion between these forms may be followed spectroscopically. The action spectrum for the splitting of the dimer has been obtained. It corresponds roughly to the absorption spectrum of the dimer (which is similar to the absorption spectrum of the short-wavelength band of thymine). Thus this phenomenon does not seem to be related to the biological photoreversal obtained with wavelengths greater than 3000 A. The quantum yield for splitting the dimer is about 0.5.

Studies of the synergistic action of x rays and ultraviolet radiation on chromosome breakage in Tradescantia pollen were continued, with emphasis on the factors governing the sensitivity or magnitude of the phenomenon. Not only does pretreatment with solar radiation appear necessary for the synergism to take place, but the magnitude of the effect is also dependent on the temperature and the humidity of the pollen grains before treatment with x and ultraviolet radiations.

COMBATING RADIATION DETRIMENTAL EFFECTS

Radiation Protection: Living Cells. — The increase in resistance to ionizing radiation produced by growing Escherichia coli in glucose-

containing media has been further investigated. By the use of the porphyrin-requiring Escherichia coli mutant, it has been established that the resistance can develop only in a porphyrin-positive cell and that aerobic growth conditions are not necessary. That is, the development of resistance by growth in glucose somehow involves a porphyrin-dependent, oxygen-independent process. Since porphyrins are usually intimately involved in oxygen-dependent processes, this must be an unusual mechanism, and it will be further investigated.

Mammalian Radiation Recovery. – Cytotoxic tests of nucleated cells have shown that irradiated mice treated with homologous bone marrow and homologous blood carry a transplant of donor-type marrow as long as they live. Irradiated recipients of homologous marrow and isologous blood have a temporary take of donor cells followed by marrow failure and death.

Histologic studies on normal mice receiving sheep red blood cells have shown cellular changes in their lymphatic tissues of the same type as those seen in mice given an injection of foreign bone marrow. These experiments with sheep red blood cells, unlike the experiments with bone marrow, also permit a study of antibodies in the blood serum. The current work completes a long series of experiments on the response of lymphatic tissues of normal mice to a wide variety of antigenic materials. The conclusion drawn from these experiments is that the tissue transplantation antigens cause the same type of cellular change as that caused by other more commonly studied antigens.

Radiation Immunology. – In an attempt to determine whether the immunologically competent cells proliferate faster, slower, or at the same rate as immunologically incompetent cells after sublethal x irradiation, experiments were carried out by the in vivo culture method. Preliminary data suggest that the competent cells proliferate at the same rate as the incompetent hematopoietic cells.

Studies were made in order to establish the minimum time after primary antigenic sensitization necessary for maximum antibody-forming activity of spleen cells. The data suggest that the activity of spleen cells two to three weeks after primary sensitization is almost comparable with that six weeks after primary sensitization and that this increased activity is 100 to 300 times that of the normal control.

One of the problems in homologous transplantation antigens is whether these antigens of nucleated cells remain immunochemically functional after physical treatments which would kill the cells. This problem was investigated by testing the potency of nucleated cells after treatment with ultrasound and x rays. It was found that after a 10-min ultrasonic treatment and exposure to 2000 r a dose of 10^7 cells was required to stimulate the host to reject 50% of the test cells. This finding will make it possible to determine the distribution of antigens in a given cell.

TRAINING, EDUCATION, AND INFORMATION PROGRAM

International Reactor Program at ORNL. — Twenty-eight students representing nine different countries have enrolled in the third session of foreign programs, which officially began November 14. Twenty students are enrolled in Reactor Operations Supervision and eight in Reactor Hazards Evaluation. Both groups will attend classes together for the first nine months; then 16 of the operations students will begin full-time work for three months at one of the Laboratory's reactors. The rest of the operations students will complete their training at the reactors immediately after the first group. The eight hazards evaluation students will be engaged in preparing hazards evaluation reports during the final three months of study.

The countries represented are: Philippines, Puerto Rico, Pakistan, Japan, Viet Nam, Indonesia, New Zealand, Finland, and the United States.

In addition to the two foreign programs, ORSORT is conducting a 12-month training program for 15 newly hired AEC employees from various operations offices throughout the country. Six Tennessee Valley Authority employees are currently enrolled in courses at ORSORT.

The total enrollment for the 1960–61 session is as follows: Hazards Evaluation, 8; Operations Supervision, 20; AEC trainees, 15; TVA trainees, 6; Carbide ORSORT (full or half time), 5; Carbide ORSORT (part time), 46; total, 100.

The ten Hazards Evaluation students of the 1959–60 session of ORSORT have completed their three-month study project, which consisted in the preparation of a report covering a specific problem pertaining to one of three different types of reactor. This program terminated October 28, 1960, and the students have either returned to their homelands or accepted assignments elsewhere.

OPEN LITERATURE PUBLICATIONS

Adler, H. I., and S. D. Haskins, "Heterogeneity of Cultures of Escherichia coli B/r," Nature 188, 249 (1960).

Ajzenberg-Selove, F., and P. H. Stelson, "The $Be^9(\alpha,n)C^{12}$ Reaction and the Parameters of the 7.66-Mev State of C^{12}," Phys. Rev. 120, 500 (1960).

Anderson, N. G., and W. D. Fisher, "Relation of the Physical Properties of Deoxyribonucleoprotein in 1 M Sodium Chloride to Nuclear Structure," p 195 in The Cell Nucleus, ed., J. S. Mitchell, Butterworths, London, 1960.

Ball, J. B., and C. D. Goodman, "An Experimental Study of the Mechanism of (p,t) Reactions at 22 Mev," Phys. Rev. 120, 488 (1960).

Begun, G. M., and W. H. Fletcher, "Partition Function Ratios for Molecules Containing Nitrogen Isotopes," J. Chem. Phys. 33, 1083 (1960).

Berggren, R. G., "Radiation Effects in Ferritic Steels," p 91 in USAEC Conference on the Status of Radiation Effects Research on Structural Materials and the Implications to Reactor Design, Held at Chicago, Ill., Oct. 15–16, 1959, TID-7588 (1960).

Berggren, R. G., W. E. Brundage, W. W. Davis, N. E. Hinkle, and J. C. Zukas, "Tensile and Stress-Rupture Properties of Irradiated Stainless Steels and Inconel," p 205 in USAEC Conference on the Status of Radiation Effects Research on Structural Materials and the Implications to Reactor Design, Held at Chicago, Ill., Oct. 15–16, 1959, TID-7588 (1960).

Billington, D. S., "Radiation Damage to Solids," p 224 in McGraw-Hill Encyclopedia of Science and Technology, vol 11, McGraw-Hill, New York, 1960.

Block, M. M., E. B. Brucker, R. Gessaroli, T. Kikuchi, C. M. Meltzer, A. Pevsner, P. Schlein, R. Strand, H. O. Cohn, E. M. Harth, J. Leitner, A. Minguzzi-Ranzi, L. Monari, and G. Puppi, "Search for Evidence of Parity Nonconservation in K-He Interactions," Phys. Rev. 120, 570 (1960).

Bollum, F. J., "Deoxyribonucleic Acid Synthesis by Mammalian Enzymes: Some Observations on Primers," p 60 in The Cell Nucleus, ed., J. S. Mitchell, Butterworths, London, 1960.

Clayton, R. K., and Carolmarie Smith, "Rhodopseudomonas spheroides: High Catalase and Blue-Green Double Mutants," Biochem. Biophys. Research Communs. 3, 143 (1960).

Dabbs, J. W. T., S. H. Hanauer, L. D. Roberts, F. J. Walter, and G. W. Parker, "Alpha-Particle Emission from Oriented Np^{237}," p 936 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Dazai, T., "An Analysis of the $F^{19}(d,p)F^{20}$ Reaction," p 936 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Felsner, G., and M. E. Rose, "Electron Polarization in Allowed Beta-Transitions with Coulomb Corrections," Z. Physik 159, 505 (1960).

Fowler, J. L., E. G. Corman, and E. C. Campbell, "Neutron Scattering from Closed Shell Nuclei," p 474 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Gaulden, M. E., "The Nucleolus and Mitotic Activity," p 15 in The Cell Nucleus, ed., J. S. Mitchell, Butterworths, London, 1960.

Harvey, J. A., "Donald J. Hughes (1915–1960)," Nuclear Phys. 20, 1 (1960).

Harvey, J. A., "Slow Neutron Resonances," p 659 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Jacobson, K. B., "Inhibition of Acetyl Transfer by Amethopterin," J. Biol. Chem. 235, 2713 (1960).

Kastenbaum, M. A., "A Note on the Additive Partitioning of Chi-Square in Contigency Tables," Biometrics 16, 416 (1960).

Kennedy, C. R., and D. A. Douglas, "Relaxation Characteristics of Inconel at Elevated Temperatures," Proc. Am. Soc. Testing Materials 60 (1960).

Kennedy, C. R., W. O. Harms, and D. A. Douglas, "Multiaxial Creep Studies on Inconel at 1500°F," J. Basic Eng. 81, 599 (1959).

Kimball, R. F., L. Vogt-Köhne, and T. O. Caspersson, "Quantitative Cytochemical Studies on Paramecium aurelia. III. Dry Weight and Ultraviolet Absorption of Isolated Macronuclei During Various Stages of the Interdivision," Exptl. Cell Research 20, 368 (1960).

Macklin, R. L., G. deSaussure, J. D. Kington, and W. S. Lyon, "Manganese Bath Measurements of η of U^{233} and U^{235}," Nuclear Sci. and Eng. 8, 210 (1960).

Maisin, Jean, G. D. Novelli, D. G. Doherty, and C. C. Congdon, "Chemical Protection of the Alimentary Tract of Whole-Body X-Irradiated Mice. I. Changes in Weight, Histology, and Cell Division in Relation to Nucleic Acid and Protein Synthesis," Intern. J. Radiation Biol. 2, 281 (1960).

Maisin, J. R., and R. A. Popp, "Effect of AET on Sodium, Potassium, and Esterases of the Alimentary Tract of Irradiated Mice," Am. J. Physiol. 199, 251 (1960).

McGowan, F. K., and P. H. Stelson, "Coulomb Excitation of Vibrational States in Th^{232} and U^{238}," p 957 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

McHargue, C. J., and C. G. Dunn, "On a Complex Recrystallization Texture in 3% Silicon Iron," J. Appl. Phys. 31, 1767 (1960).

McHargue, C. J., and H. L. Yakel, Jr., "Phase Transformations in Cerium," Acta Met. 8, 637 (1960).

Meyer, R. E., "Cathodic Processes on Passive Zirconium," J. Electrochem. Soc. 107, 847 (1960).

Miller, P. D., J. H. Gibbons, J. H. Neiler, W. M. Good, and R. L. Macklin, "Statistical Parameters of Medium Weight Nuclei from kev Neutron Total and Capture Cross Sections," p 959 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Moak, C. D., "Space-Charge Effects in Cylindrical Beams with Uniform Acceleration," Nuclear Instr. & Methods 8, 19 (1960).

Pattenden, N. J., and J. A. Harvey, "The Resonance Energy Cross Section of U^{233}," p 882 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Pearlstein, L. D., Y. C. Tang, and K. Wildermuth, "Energy Levels of He^5 and Li^5," p 962 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Peck, H. D., Jr., "Adenosine 5′-Phosphosulfate as an Intermediate in the Oxidation of Thiosulfate by Thiobacillus thioparus," Proc. Natl. Acad. Sci. U.S. 46, 1053 (1960).

Peck, H. D., Jr., "Evidence for Oxidative Phosphorylation During the Reduction of Sulfate with Hydrogen by Desulfovibrio desulfuricans," J. Biol. Chem. 235, 2734 (1960).

Phan The Tran and M. A. Bender, "Factors Affecting the Survival of Mouse Bone Marrow Cells During Freezing and Thawing in Glycerol," J. Appl. Physiol. 15, 939 (1960).

Popp, R. A., "Erythrocyte Repopulation in X-Irradiated Recipients of Nucleated, Peripheral Blood Cells of Normal Mice," Proc. Soc. Exptl. Biol. Med. 104, 722 (1960).

Popp, R. A., and W. St. Amand, "Studies on the Mouse Hemoglobin Locus. I. Identification of Hemoglobin Types and Linkage of Hemoglobin with Albinism," J. Heredity 51, 141 (1960).

Roberts, L. D., F. J. Walter, J. W. T. Dabbs, G. W. Parker, and J. O. Thomson, "Fission Fragments from Oriented U^{233} and U^{235}," p 884 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Schwartz, Drew, "Analysis of a Highly Mutable Gene in Maize. A Molecular Model for Gene Instability," Genetics 45, 1141 (1960).

Schwartz, Drew, "Deoxyribonucleic Acid and Chromosome Structure," p 227 in The Cell Nucleus, ed., J. S. Mitchell, Butterworths, London, 1960.

Schwartz, Drew, "Genetic Studies on Mutant Enzymes in Maize: Synthesis of Hybrid Enzymes by Heterozygotes," Proc. Natl. Acad. Sci. U.S. 46, 1210 (1960).

Shekarchi, I. C., and Takashi Makinodan, "Electrophoretic Analyses of Sera from Mice Protected from Lethal X Radiation," Intern. J. Radiation Biol. 2, 353 (1960).

Sicard, M. A., and D. Schwartz, "Dépendance du mode de conservation après irradiation et des radiolésions produites dans les graines d'orge sêches," Compt. rend. 251, 897 (1960).

Stelson, P. H., "Vibrations in Spherical and Nearly Spherical Nuclei," p 787 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Stelson, P. H., and F. K. McGowan, "Coulomb Excitation with Ne^{20} Ions," p 47 in Reactions Between Complex Nuclei. Proceedings of the Second Conference on Reactions Between Complex Nuclei, May 2-4, 1960, Gatlinburg, Tennessee, Wiley, New York, 1960.

Stiegler, J. O., and T. S. Noggle, "Direct Replica Technique for Copper," J. Appl. Phys. 31, 1827 (1960).

Upton, A. C., A. W. Kimball, Jacob Furth, K. W. Christenberry, and W. H. Benedict, "Some Delayed Effects of Atom-Bomb Radiations in Mice," Cancer Research 20, No. 8 (Part 2), 1 (1960).

Upton, A. C., T. T. Odell, Jr., and E. P. Sniffen, "Influence of Age at Time of Irradiation on Induction of Leukemia in RF Mice," Proc. Soc. Exptl. Biol. Med. 104, 769 (1960).

Volkin, Elliot, "The Function of RNA in T2-Infected Bacteria," Proc. Natl. Acad. Sci. U.S. 46, 1336 (1960).

Wegener, H. H. F., "Schroedinger Equation in Multiply Connected Spaces and Phase Optics," Z. Physik 159, 243 (1960).

Wells, Carolyn, "The Response of Tetrahymena pyriformis to Ionizing Radiation: Strain Specific Radiosensitivities," J. Cellular Comp. Physiol. 55, 207 (1960).

Wildermuth, K., and H. Faissner, "Asymmetric Fission from the Viewpoint of the Cluster Model," p 972 in Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, University of Toronto Press, 1960.

Wolf, F. T., "Pteridine Pigments in Microorganisms and Higher Plants," p 53 in Comparative Biochemistry of Photoreactive Systems, ed., Mary Belle Allen, Academic Press, New York, 1960.

Zukas, J. C., and R. G. Berggren, "Flux Measurements and Irradiation Assemblies Used in the LITR, MTR, and ORR Reactors," p 36 in USAEC Conference on the Status of Radiation Effects Research on Structural Materials and the Implications to Reactor Design, Held at Chicago, Ill., Oct. 15-16, 1959, TID-7588 (1960).

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November 1959	ORNL-2874
December 1959	ORNL-2895
January 1960	ORNL-2906
February 1960	ORNL-2922
March 1960	ORNL-2932
April 1960	ORNL-2945
May 1960	ORNL-2960
June 1960	ORNL-2980
July 1960	ORNL-2991
August 1960	ORNL-3009
September 1960	ORNL-3024
October 1960	ORNL-3038

OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

November 1960

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