MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0059777 1

LIBRARY
ECTION 307

[redacted]

ORNL-3491
C-44a – Nuclear Technology – Materials
M-3679 (30th ed.)

OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

JULY 1963

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this document, send in name with document and the library will arrange a loan.

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

Downgrade to Unclassified After August 6, 1964

[redacted]

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

[redacted]

ORNL-3491

Contract No. W-7405-eng-26

OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

JULY 1963

DATE ISSUED
AUG 8 1963

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0059777 1

[redacted]

[redacted]

CONTENTS

REACTOR DEVELOPMENT..... 1
GAS-COOLED REACTOR PROGRAM..... 1
EGCR Startup Program..... 1
EGCR Flux Scanners..... 1
EGCR Construction Support..... 2
GCR-ORR Loop No. 1..... 2
GCR-ORR Loop No. 2..... 2
Capsule Irradiations in the LITR..... 2
Capsule Irradiations in the ORR Poolside Facility..... 2
Postirradiation Examination of Fueled-Graphite Spheres.... 3
Pyrolytic-Carbon-Coating Fabrication Studies..... 3
Instantaneous Fission-Gas Release from UO_2..... 3
Furnace for Thermal Treatment of Graphite Bodies..... 3
STUDIES AND EVALUATIONS..... 4
Review of Nuclear Power Plant for Rooppur, East Pakistan..... 4
Value of Plutonium as Recycle Fuel in Large Heavy-Water-Moderated Reactors..... 4
Molten-Salt Reactor Studies..... 4
Spent-Fuel Shipping..... 4
Evaluation of Seed-Blanket Power Reactor..... 5
REACTOR FUELS AND MATERIALS..... 5
Nondestructive Test Development..... 5
Materials Compatibility Studies..... 5
Fuel Element Development..... 6
POWER REACTOR FUEL PROCESSING..... 6
Shear-Leach Process..... 6
Aqueous Process Development for Uranium Carbide Reactor Fuel..... 7
Corrosion..... 7
Fluoride Volatility Development: Aluminum Alloy Flowsheet Development..... 8
Fluoride Volatility Development: NaF Sorption Studies.... 9
Fluoride Volatility Development: Corrosion..... 9
Fluoride Volatility Pilot Plant..... 10
MOLTEN-SALT REACTOR PROGRAM..... 10
Molten-Salt Reactor Experiment..... 10
Metallurgy..... 11
Chemical Development..... 11
Preparation of MSRE Materials..... 11
Radiation Effects..... 12
MSR Processing..... 13
Analysis of Radioactive MSRE Fuels..... 13
HIGH FLUX ISOTOPE REACTOR DESIGN AND DEVELOPMENT..... 13
Metallurgy..... 13
Component Development..... 14
Design and Analysis..... 14
Reports..... 14

[redacted]

PHYSICAL RESEARCH..... 15
Research Operations..... 15
Waste Disposal..... 15
Hot-Cell Operations..... 15
PHYSICS AND MATHEMATICS..... 15
Neutron Diffraction..... 15
Theoretical Physics..... 16
Low-Energy Neutron Time-of-Flight Spectroscopy..... 16
Low-Temperature, Nuclear and Solid State Physics..... 16
High-Voltage Experimental Program: Low-Energy (p,n) Reaction $Mn^{55}(p,n)Fe^{55}$..... 16
High-Voltage Experimental Program: Resonant Neutron Capture Gamma-Ray Spectra in Titanium and Vanadium..... 17
Mathematics and Programming Research..... 17
CHEMISTRY..... 17
Effects of Radiation on Analytical Methods..... 17
Separations Chemistry Research..... 18
Separations Process Development..... 19
Volatility Studies..... 19
Radiolysis of Metal Fluorides..... 19
Mechanism of Aqueous and Radiation Corrosion of Zirconium Alloys..... 19
Electrochemical Kinetics and Its Application to Corrosion..... 20
Physical Chemistry of Molten Salts..... 20
High-Temperature Aqueous Solution Chemistry..... 20
Chemical Separation of Isotopes..... 21
METALLURGY AND MATERIALS..... 21
Physical Properties Studies..... 21
CONTROLLED THERMONUCLEAR RESEARCH..... 22
DCX-1 Facility..... 22
Beam-Plasma Interaction..... 22
Theory..... 23
Cross Sections..... 23

BIOLOGY AND MEDICINE..... 23
RADIATION EFFECTS..... 23
Statistical Services and Research..... 23
Pathology and Physiology..... 24
Recovery from Somatic Effects of Radiation..... 24
Physiology of Blood Platelets..... 25
Medium(Low)-Level Long-Term Effects of Radiation..... 25
COMBATING DETRIMENTAL EFFECTS OF RADIATION..... 25
Mammalian Recovery..... 25
MOLECULAR- AND CELLULAR-LEVEL STUDIES..... 26
Biophysics: Ultraviolet Studies with Bacteria..... 26
Biophysics: Decay of Long-Lived Free Radicals..... 27
Biophysics: Growth Curve of Salamanders..... 27

CIVILIAN APPLICATIONS OF NUCLEAR EXPLOSIVES..... 27
Chemical Applications of Nuclear Explosions..... 27

OPEN LITERATURE PUBLICATIONS..... 28

FOREIGN VISITORS..... 32

[redacted]

OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

JULY 1963

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

REACTOR DEVELOPMENT

GAS-COOLED REACTOR PROGRAM

EGCR Startup Program. — Prompt-neutron lifetimes and the approach to criticality for core I were analyzed, and accurate control-rod boundary conditions and rod worths were calculated. A substantial step was taken toward completion of the checkout of the pulser transient code, and a start was made in the programming of a code to extract decay constants from experimental neutron-pulser data. Test calculations were completed which checked the phase of the code that calculates the flux distribution as a function of time during a pulser-induced transient. In checking the flux distributions against those calculated by other means, it was found that good accuracy was obtained with 15 terms in the flux expansion, and, for some cases, tolerable accuracy was obtained with 10 terms. The presently specified locations for detectors were found to be satisfactory. No detector relocation will be necessary during the critical experiment unless the critical core is substantially larger than anticipated. Including an allowance for air poison, the present estimate indicates that the critical core will consist of 47.5 channels loaded with fuel and two small loop positions plugged with graphite.

EGCR Flux Scanners. — Calculations were made to evaluate some effects that would result from adoption of a proposal to insert an Inconel liner (0.50 in. OD, 0.26 in. ID) in each of the 18 flux-scanner tubes of the EGCR. It was found that the liners would increase the gamma-radiation heating of the scanner tubes by about 57%; in a typical EGCR operating situation, the maximum heating would be about 462 w per scanner tube. The liners would not significantly affect the fast-neutron flux distribution; they would, however, depress the thermal-neutron flux to about 87% of the value in the unlined tubes. The liners would decrease the effective multiplication factor of the reactor by $\Delta k/k = 0.72\%$; this corresponds to a decrease of about 9% of the lifetime for the first core.

[redacted]

EGCR Construction Support. — The two large pipe welds joining A212B carbon steel to type 304 stainless steel, which will be in the primary coolant system of the EGCR, were completed in the ORNL shops. These pipes are approximately 3 ft in diameter and have 1-in.-thick walls. The welds were made with Inconel 182 filler metal following procedures developed at ORNL. A 200 to 300°F preheat was imposed during welding, and a 1150°F postheat was employed after welding. Stringent inspection of the welds was maintained, including periodic examinations by an ASME code inspector. The welds were of excellent quality, and the pipes were shipped to the EGCR site for insertion in the reactor system.

GCR-ORR Loop No. 1. — A stainless-steel-clad UO_2 fuel element of the EGCR type that was made defective by drilling a 1/16-in.-diam hole through the cladding was tested in GCR-ORR loop No. 1 for one month. The hole in the cladding was positioned at the end-cap insulator to avoid line-of-sight release of recoil fission products from the fuel to the helium coolant. With the cladding surface temperature at 1500°F and central fuel temperatures of 2050 to 2150°F, apparent equilibrium was reached in approximately 12 hr with about 1 curie of xenon and krypton activity in the loop. This relatively high fission-gas release was expected for this fuel, which has a D' (release rate parameter) of approximately 10^{-11} sec^{-1}. No operational difficulties were experienced with the loop, and a new test is planned with a fuel that is expected to retain more of the fission gas.

GCR-ORR Loop No. 2. — Irradiation of the first capsule containing four 1.5-in.-diam graphite-matrix spheres fueled with coated particles was initiated with ORR cycle 48. After initial adjustment of several components in secondary systems, operation of the loop proceeded smoothly. The average heat generation for the four fuel spheres is approximately 30 w/cm^3, which is the design value, indicating that previous flux measurements were accurate. The gas temperature at the fuel assembly inlet is approximately 1060°F, and the central fuel temperatures vary between 1200 and 1600°F. Fission-gas release from the fuel has been very low, with estimated concentrations of krypton and xenon activity of less than 25 $\mu\mu c/cm^3$.

Capsule Irradiations in the LITR. — A new capsule containing pyrolytic-carbon-coated particles of UC_2 and $(U + Th)C_2$, manufactured by the National Carbon Company, was installed in the LITR for testing. Operation with the revised arrangement for the test facility in the LITR tank, which avoids interference with the capsules during refueling, has proved to be quite convenient.

Capsule Irradiations in the ORR Poolside Facility. — Irradiation of the set of capsules described previously is continuing in the ORR poolside facility. Included are three sweep capsules containing 1.5-in.-diam graphite matrix spheres fueled with pyrolytic-carbon-coated uranium carbide particles. The ratio of fission-gas release rate to birth rate for Kr^{88} for two of the capsules continues to be approximately 1×10^{-5}. The release rate ratio for the third capsule has increased to approximately 2×10^{-5}. The estimated burnup is about 3 at. % of the total uranium.

Postirradiation Examination of Fueled-Graphite Spheres. — Two irradiated capsules containing fueled-graphite spheres are being examined. One capsule contained four 1.5-in.-diam molded spheres in which the fuel particles were uniformly dispersed, and the other contained four 1.5-in.-diam machined graphite spheres in which a cylindrical fuel compact was held in place by a threaded graphite plug. Irradiation temperatures were about 1500 and 1100°F for the molded and machined spheres respectively. Fission-gas release, which was measured both during and after irradiation, was low in both capsules. No flaws were apparent by visual examination after irradiation. Dimensional changes indicated a maximum of about 1% shrinkage in the A direction (with the grain) for the molded spheres. Most of the spheres showed small weight losses, < 0.5%. Additional tests will include determinations of impact strength, compression strength, and abrasion resistance; and metallographic examinations will be made.

Pyrolytic-Carbon-Coating Fabrication Studies. — Nine coating runs were made at 1400°C in a low-temperature furnace to gain experience in rapidly applying laminar coatings (deposition rates > 25 μ/hr) at 1400°C and to study the effects of minor variations in coating conditions on deposition rate and properties. It was found that careful control of methane flow rate, methane partial pressure, and size of particle charge was required to duplicate the thickness of one of the rapidly deposited laminar coatings. All rapidly deposited coatings appeared to have the same microstructure — a general laminar structure with a very coarse texture. The surface appearance for different runs varied, however, from dull or mat through a greasy luster to very glossy.

The crushing load of the particle coatings was found to be roughly dependent on coating thickness. Within any given batch there was a considerable spread in crushing load, by as much as a factor of 3, but average values indicated that one way to obtain strong coated particles was to apply thick coatings.

Instantaneous Fission-Gas Release from UO_2. — In an initial experiment with single-crystal UO_2 specimens, it was observed that the fission-gas release decreased with burnup and that the fission-gas emission was independent of the production rate. A second set of specimens is being irradiated in an attempt to confirm these observations, and, as for the first set, the fission-gas release rate has decreased with burnup. It was thought that the decrease occurred because the surface of the UO_2 was being smoothed out by evaporation caused by fission spikes and redeposition. The first specimens were therefore examined with an electron microscope, and a very definite smoothing of the surface was observed.

The first specimens had an equilibrium emission of Kr^{88} that was independent of the amount of Kr^{88} contained in the specimen for flux levels from 1.1×10^{13} to 3.6×10^{13} neutrons cm^{-2} sec^{-1}. The second specimens have an equilibrium emission of Kr^{88} that is independent of flux from 1.1×10^{13} to 4.2×10^{13} neutrons cm^{-2} sec^{-1}.

Furnace for Thermal Treatment of Graphite Bodies. — A graphite resistor furnace was completed that is suitable for testing either three 6-cm-diam spheres or five 1.5-in.-diam spheres. It will be possible to quench the spheres with helium, if desired, to provide a severe thermal stress condition. Outgassing of the new 3-in.-diam heating element and associated

insulation has progressed, and the continuous operating temperature is now 1500°C. The ultimate temperature capability of this furnace will probably be about 2000°C.

STUDIES AND EVALUATIONS

Review of Nuclear Power Plant for Rooppur, East Pakistan. — The conceptual design of a 50-Mw (electrical) natural-circulation, single-cycle, boiling-water reactor nuclear plant was prepared by the Bechtel Corporation as a basis for establishing the economic feasibility of nuclear power in East Pakistan. Design details of the proposed reactor were not available for an analysis of the specific concept; however, calculations of the nuclear characteristics and fuel costs of similar reactors (Humbolt Bay and Big Rock Point) substantiate Bechtel's estimated nuclear power costs. The conclusions are that the proposed nuclear plant is technically feasible and economically competitive with a conventional oil-fired station of equal capacity.

Value of Plutonium as Recycle Fuel in Large Heavy-Water-Moderated Reactors. — Previously calculated fuel cycle costs for large-scale natural-uranium heavy-water reactors have been based on the assumption that the by-product plutonium can be sold for use in other types of reactors at a price of about $7.00 per gram. If such a market for plutonium does not exist, a reactor operator would have to choose between a plutonium throwaway cycle and the use of plutonium in his own reactor to enrich natural uranium or depleted uranium. Calculations of fuel cycle costs under conditions of a large developed fuel industry indicate that the first recycle of plutonium with natural uranium results in a fuel cost saving of only 0.08 mill/kwhr, as compared with a throwaway cycle. This is equivalent to sale of the plutonium for $2.83 per gram of fissile material. Subsequent recycles of the plutonium result in even lower savings, with the value of plutonium reaching zero at the third cycle.

Molten-Salt Reactor Studies. — A literature search was carried out to determine the chemical compatibility of certain construction materials (INOR-8, Ni, Mo, Nb, stainless steel, Inconel, Croloy, graphite, Ta, W, and V) and fused chlorides and fluorides. A hazard analysis of molten-salt reactors was initiated. Design studies of fast molten-salt reactors are in progress.

Spent-Fuel Shipping. — The report on a "Guide to the Design of Shipping Casks" is progressing satisfactorily. The sections on criticality, heat transfer, shielding, contamination, regulations, and accidents have been completed in first rough-draft form. The section on structural integrity is approximately 65% complete.

A report has also been completed on "Drop Tests Performed on the Franklin Institute's 1/4 Scale Model of a 55-ton Cask." The report describes the series of five impact drops which were carried out with the cask and includes a section in which an energy balance was written on the piston drops. The balance takes advantage of some of the information developed earlier in the drop-testing program.

Evaluation of Seed-Blanket Power Reactor. — The evaluation of a Bettis proposal for a 500-Mw (electrical) pressurized light-water seed-blanket reactor was initiated. Two representative designs will be considered. The first, designated as a thorium-converter burner reactor, utilizes an enriched U^{235} seed and a thorium blanket. This approach has the objective of achieving long fuel life (70,000 full-power hours) and low fuel cycle costs. The second design, designated as a thorium-converter recycle reactor, utilizes U^{233} as the seed. Preliminary calculations by the Knolls Atomic Power Laboratory indicate that this latter concept has the potential of providing a self-sustaining breeder cycle capable of full utilization of thorium.

REACTOR FUELS AND MATERIALS

Nondestructive Test Development. — Recent ultrasonic development work has included further study on the through-transmission technique for the detection of laminations or nonbond in thin sections such as sheet, fuel plates, etc. The program has included both the development of new scanning equipment and the application of the technique to test specimens.

The new scanning device, which consists of the search-tube adjustment and drive system, specimen holders, and a mechanical recording system, was fabricated as an adjunct to the existing tube-scanning facility. The continuous roller chain drive of the tubing scanner translates the specimens longitudinally past the ultrasonic transducers which are clamped into the search-tube drive system. At the end of each longitudinal scan, the transducers are indexed vertically (in the transverse direction) a fixed increment (variable from 0.0005 to 0.500 in.), and the specimens are then translated in a reverse parallel scan. The recorder table mounts longitudinally on the tank and is indexed in a horizontal transverse direction simultaneously with the search units. Parallel Slo-syn stepping motors accomplish the concurrent motion. The stylus which writes on the electrosensitive paper is suspended above the recorder table and is mechanically coupled to the longitudinal chain drive. This system allows one-to-one recording on all specimens up to approximately 48 in. long and approximately 6-1/2 in. wide.

Materials Compatibility Studies. — The compatibility of niobium with potassium and sodium as functions of temperature and oxygen concentration in the alkali metal are important considerations in temperature-gradient mass transfer and other corrosion mechanisms. A series of static tests has been completed in which relatively pure niobium was exposed at elevated temperatures for periods of at least 48 hr to potassium and to sodium containing from 25 to several thousand ppm of oxygen. Compatibility of the refractory metal with the alkali metal was assessed by determining the niobium concentration in the alkali metal before and after test. Exposure temperatures were 400 and 600°C for the Nb-O-K system and 400 and 800°C for the Nb-O-Na system. In both systems significant increases in the niobium concentration in the alkali metal were noted as functions of both the temperature and the oxygen concentration in the alkali metal. This is in qualitative agreement with observations of other workers who have studied the Nb-O-Na, V-O-Na, and refractory metal—N—Li systems.

However, important differences were noted in the current tests: oxygen seemed to be the principal catalyst for dissolution of the refractory metal in the Nb-O-K system, while temperature exerted the greater influence in the Nb-O-Na system.

Fuel Element Development. — Studies were conducted on the effects of hot-rolling temperature and cold reduction on the blistering tendency in high-strength aluminum-base plates and on the subsequent forming characteristics of the plates. To duplicate the conditions normally encountered in forming fuel plates, composite-type compacts of Alclad type 6061 aluminum were assembled and were fabricated in the temperature range 400 to 500°C with typical fuel-plate reduction schedules. The plates were subsequently cold reduced 7.4, 19.4, and 31.5% in thickness, followed by heat treating at 500°C, and furnace cooling prior to forming at a constant pressure of 1600 psi. It was shown that the formability of the plates could be improved by either decreasing the hot-rolling temperature or increasing the percentage of cold reduction. In general, the formability of type 6061 aluminum was found to be best at 450°C and at cold reductions greater than 7.4%.

Although the formability of type 6061 aluminum was shown to improve at the lower hot-rolling temperatures, the blistering tendency of the composites was observed to increase as the hot-rolling temperature decreased. A 30% blister rejection rate was observed in plates fabricated at 400°C, as compared with only 5% in plates roll clad at 500°C. The majority of blisters noted in these plates were associated with a lack of metallurgical bonding in the clad-frame interface. Metallurgical bonding was not achieved in plates fabricated at 400°C, as manifested by the discontinuous nature of the interfacial grain growth at the clad-frame boundaries. Continuous grain growth was noted in the plates fabricated at 500°C.

On the basis of these results, a fabrication technique using a 500°C temperature and incorporating a minimum of 20% cold work before the final anneal was recommended.

POWER REACTOR FUEL PROCESSING

Shear-Leach Process. — The engineering-scale development of the reactor-fuel shear and leach equipment, consisting of a 250-ton prototype shear, conveyor-feeder, and leacher, was continued.

Particle-size measurements were made on sheared sections of stainless-steel-clad UO_2, UO_2-ThO_2, and Zircaloy-2-clad UO_2. The sheared sections were 1, 1-1/2, and 2 in. long. The amount of core material dislodged from Zircaloy-2-clad UO_2 sheared into 2-in. lengths was 73%, a factor of 5.8 and 4.2 more than stainless-steel-clad UO_2 and UO_2-ThO_2 respectively.

Batch leaching of stainless-steel-clad oxide reactor fuels sheared to 1/2- to 2-in. lengths was also studied. In these tests the pieces were placed in a perforated basket which was then suspended in a batch dissolver containing recirculating acid for leaching the ThO_2-UO_2 or UO_2. Factors studied included sheared length, basket perforation size, and air sparge rates for the suspension of fines.

Batch leaching of 1-in. sheared lengths of stainless-steel-clad ThO_2-UO_2 contained in a slotted basket (0.015-in.-wide slots, 23% open area,

ratio of the diameter of the basket to the diameter of the tank = 0.81) and air sparged at less than 1.2 scfm/ft^2 resulted in the most rapid leaching observed to date. Thorium dissolution was 90% complete in 2.9 hr and 99% complete in 7.4 hr. A similar run, identical except for the omission of air sparging, required 5.7 hr for 90% dissolution and about 13 hr for 99% dissolution.

Packing-density measurements on sheared stainless-steel-clad ThO_2-UO_2 in 3- to 6-in.-diam cylinders were 4.4 to 5.1 g/cm^3 for 1/2-in. sheared lengths and 3.7 to 3.9 g/cm^3 for 1- and 1-1/2-in. lengths. The uncertainty in these values may be as high as ±10%.

With the stepped blade, a maximum force of about 156 tons was required to shear a bundle consisting of 49 solid type 304 stainless steel rods 5/16 in. in outside diameter.

Aqueous Process Development for Uranium Carbide Reactor Fuel. — The irradiation of impure uranium monocarbide (5.0% C) or high-purity uranium monocarbide (4.8% C) to 5000 to 7000 Mwd/ton had a significant effect on the chemical reactivity of this fuel material. In recent hot-cell studies, the irradiated specimens were almost nonreactive in water at 80 and 90°C, whereas unirradiated specimens of the same original composition were completely hydrolyzed to uranium dioxide in 4 to 6 hr under comparable conditions. Reactivity of the irradiated material in mineral acids, however, appears to be greatly accelerated. Dissolution of the water-soaked pellets in 6 M HCl at 80°C was completed in 5 min, compared with 6 hr for unirradiated specimens; gas evolution was too rapid for measurement. The reaction rate in 2 M HCl was about the same as that in 6 M HCl at the unirradiated or 500-Mwd/ton level. Dissolution in 15.8 M HNO_3 was completed in less than 30 min, compared with the 2 hr required for unirradiated material.

Since the hydrolysis-dissolution head-end flowsheet developed for this fuel cannot be applied unless passivity to hydrolysis can be overcome, an alternative head-end flowsheet is being developed in which unirradiated uranium monocarbide is dissolved in excess 15.8 M HNO_3 in 2 hr, yielding a dark-brown solids-free solution containing 100 g of uranium per liter and 12.8 M HNO_3. The partial destruction of organic acids is accomplished by a 16-hr reflux of the strong nitric acid solution and subsequent distillation of the excess acid. After distillation of the excess acid, the uranyl nitrate concentrate is diluted with water to yield a stable raw feed solution containing about 375 g of uranium per liter and 1 M HNO_3; the color is yellow-orange. The remaining organic impurities finally are destroyed by a 2-hr reflux with 0.05 M $Ce(NH_4)_2(NO_3)_6$. Feed solution thus prepared performed adequately in batch extraction and stripping tests under simulated Purex solvent-extraction conditions. Uranium recovery was quantitative.

Corrosion. — Nichrome V, "A" nickel, and Haynes alloy No. 25 corroded at rates of 1.4, 1.2, and 31.1 mils/month during exposure to 13, 14, and 4 cyclic oxidation-chlorination tests respectively. The cycle consisted in exposure of the alloy specimen, which was buried in graphite-UO_2 moistened with HNO_3-HF, to (1) oxygen at 800°C for 5 hr and (2) chlorine at 500°C for 5 hr. In a similar cycle in which the chlorine exposure was replaced by chlorination in refluxing hexachloropropene for 3 hr at 180°C, the Nichrome V and Haynes 25 showed slight weight gains over 12 and 3 cycles, respectively, while "A" nickel and Carpenter 20 showed maximum corrosion rates of 8.0 and 1.2 mils/month over 11 and 9 cycles respectively.

Hastelloy B exposed for 304 hr to boiling 3 M $ZrOCl_2$–3 M HCl under an atmosphere of HCl-H_2 corroded at nearly constant rates of 0.8 mil/month in the vapor and 1.0 mil/month in the solution. No intergranular attack was noted. A specimen from a different heat, which corroded at about twice these rates and showed intergranular attack, was found to be highly contaminated with foreign material.

Fluoride Volatility Development: Aluminum Alloy Flowsheet Development. – At 600°C, the apparent maximum practical temperature for processing aluminum fuel elements, preliminary phase equilibrium data (ORNL-3462, p 9) indicated that KF-ZrF_4 melts had sufficient AlF_3 solubility to allow their use as the solvent in a molten-salt volatility process for Al-U alloy fuels. Additional data have since been obtained, principally by a new visual method, which better defined the 600°C isotherm and confirmed the choice of an approximate composition path of the process. Purification of the components, KF, ZrF_4, and AlF_3, by volatilization was necessary to obtain melts that were sufficiently clear for visual study.

Mixtures of KF-LiF were also studied as potentially lower-priced Al-U alloy fuel solvents for the volatility process. Although the binary system has a low-melting eutectic, the liquidus temperature rose so steeply upon the addition of AlF_3 that only 3 mole % could be dissolved at 600°C. The minimum solidus temperature along the LiF-3KF·AlF_3 quasibinary section was found to be 720°C. There is a 490°C eutectic at the approximate KF-LiF-AlF_3 ternary composition (51-6-43 mole %), but melts in this region would have a capacity for at most about 6 mole % additional AlF_3 at 600°C.

Further laboratory studies of the KF-ZrF_4 salt system were made in order to determine aluminum dissolution rates and to establish more definitely the chemical reactions involved. Gas evolution tests showed that the dissolution of aluminum in molten KF-ZrF_4 at 600°C with hydrogen fluoride proceeds with the liberation of only 25 to 35% of the theoretical amount of hydrogen. A digestion period during which the melt receives a continued hydrofluorination treatment results in the evolution of the remainder of the hydrogen and the elimination of a black residue in the salt. These observations reaffirm that only part of the aluminum dissolves through an acid-metal reaction; the remainder, and perhaps a major part, dissolves through the reduction (by the aluminum) of ZrF_4 to form amorphous zirconium. Further use of the hydrogen evolution procedure is planned to establish the relative hydrogen fluoride and ZrF_4 dissolution effects at various salt concentrations.

A modified Al-U alloy process flowsheet was devised to increase the process capacity – the amount of fuel processed in a given amount of salt. According to the proposed flowsheet, the fuel alloy is dissolved in 63-37 mole % KF-ZrF_4 until the composition 53.5-31.5-15.0 mole % KF-ZrF_4-AlF_3 is attained, KF is added, and then more fuel is dissolved to attain the composition 54-20-26 mole % KF-ZrF_4-AlF_3. Laboratory tests of this process modification were successful.

On an engineering scale, sections of LITR prototype Al-U alloy elements were dissolved in 62-38 mole % KF-ZrF_4 by using anhydrous hydrogen fluoride between 550 and 600°C in a 3.5-in.-ID × 24-in. INOR-8 vessel. Two dissolutions (one partial, one complete) were made with no important difficulties. The second dissolution, in which a 2-in.-long, four-plate, quarter-cross-section LITR element was completely dissolved, was very smooth

and rapid, as was the subsequent salt transfer. The respective penetration rates for these dissolutions were 12 and 30 mils/hr. The rates were calculated on the basis of the external surface only, since the internal channels between plates were closed by sludge at the end of the partial-dissolution run.

Fluoride Volatility Development: NaF Sorption Studies. — The removal of UF_6 and N_2 by pelleted NaF was investigated by the use of differential beds of pellets. Data on the rate and extent of sorption were obtained in the temperature range 29 to 100°C and in the UF_6 concentration range 0.57 to 10.9 mole %.

The rate-controlling mechanisms were found to be transfer of the UF_6 across a stagnant gas film surrounding the pellet, diffusion of the gaseous UF_6 in the pore space of the pellet, and diffusion of the UF_6 through a layer of UF_6-NaF complex covering unreacted NaF in the interior of the pellet. The crystalline density of the complex $UF_6 \cdot 2NaF$ was determined to be 4.13 g/cm^3, indicating that incomplete reaction of the NaF will occur for pellets in which the initial-volume void fraction is less than 0.807.

A model was devised to represent the sorption of UF_6 by a single pellet of NaF, and differential equations based on the model were written. A general method of solution of the partial differential equation describing simultaneous diffusion and irreversible reaction with variable diffusivity and reaction rate constant was derived for systems in which a steady-state type of solution is valid. The experimental data were correlated on the basis of the model, with a root-mean-square error of 9.5% for all points. The resulting computer code and associated data may be used for design of sorber systems such as fixed or moving beds.

The effective capacity of 1/8-in. right-circular cylindrical pellets of NaF for UF_6 was found to decrease with increasing temperature: At 29°C a capacity of 1.13 g of UF_6 per gram of NaF was observed, whereas the capacity at 100°C was only 0.64 g of UF_6 per gram of NaF. A model-predicted result of a 35% decrease in capacity for pellets having an initial void fraction of 0.45 was observed experimentally as the surface area was increased from 0.86 to 1.1 m^2/g.

In another study, a gasometric apparatus for rapidly characterizing dissociation pressures, sorption equilibria and kinetics, chemical states, and decomposition conditions was built and tested. The method simply involves the measurement of pressure changes, which indicate quantities of gases reacting with, or evolving from, known quantities of solid.

With the new apparatus the dissociation pressures of HF and UF_6 over their respective complexes with NaF and the decomposition of the UF_6 complex to give F_2 were verified. Also, a test for the sorption of UF_6 on NaF was developed, the existence of the compound Na_2UF_8 was demonstrated, a more active form of NaF was made by an HF treatment, the stability of the pentavalent uranium-NaF complex was studied, data were obtained which indicated formation of a compound $(NaF)_2UF_6HF$, and the interaction of HF and UF_6 on NaF was studied.

Fluoride Volatility Development: Corrosion. — Laboratory-scale studies were made at Battelle Memorial Institute to study the corrosion occurring during the cyclic hydrofluorination of Zr-U alloy and fluorination of the resulting UF_4 in the same vessel, using the current zirconium flowsheet salt (initially 37.5-37.5-25 mole % NaF-LiF-ZrF_4). This work supplemented engineering-scale studies previously reported (ORNL-3436, p 12).

Specimens of L nickel, HyMu 80, INOR-8, Ni–5% Fe, and Ni–1% Al were exposed alternately to HF-salt and F_2-salt in an INOR-8 container. The study continued for ten exposure cycles, each consisting of 20 hr of HF treatment at 650°C, 2 hr of F_2 treatment at 500°C, and 2 hr of helium treatment (1 hr during each temperature transition period).

According to micrometer measurements, Ni–5% Fe, INOR-8, and HyMu 80 were the most satisfactory, in that order; the maximum corrosion rates for all alloys (excluding L nickel) were 5.2 to 9.0 mils/month. Container wall penetration rates were about 6 mils/month – rather inconclusive because of the variation in initial wall thickness. No intergranular attack was noted in specimens of HyMu 80, Ni–5% Fe, and Ni–1% Al. The L nickel showed its usual intergranular attack, and INOR-8 coupons, as contrasted with the container, showed grain-boundary modifications which were revealed only by etching. Bend tests caused separation of the L-nickel grains, but not for the INOR-8 specimens. Further details are reported in BMI-X-234.

Fluoride Volatility Pilot Plant. – Outstanding overall decontamination factors were obtained during run R-8, one of a series made to demonstrate the recovery in the pilot plant of uranium from highly irradiated Zr-U alloy fuel elements. The six-month decay time for the fuel used in this run was the minimum anticipated for the Zr-U alloy processing demonstration. This program is scheduled for completion in calendar year 1963.

Overall (including dissolution and product recovery) decontamination factors (DF's) ranged from more than 10^8 to more than 10^9 for volatile Sb^{125}, Te, and Ru^{106}, and from more than 10^9 to more than 10^{10} for non-volatile Zr^{95}, Sr^{90}, and Cs^{137}. A DF of nearly 10^{11} was obtained for Nb^{95}, possibly the highest DF ever achieved for a single-cycle radiochemical process. In general, dissolution DF's were small compared with the recovery DF's. Dissolution DF's for volatile fission products were Te, 7200; Sb^{125}, 5; Ru^{106}, 2800; and Nb^{95}, 50. Strontium-90 and Cs^{137} DF's were 2 and 1.5, respectively, and probably reflect the accuracy of the calculations rather than decontamination. Trace quantities of Ru^{106} and Zr-Nb^{95} were detected in the UF_6 product, but all other nuclides were below analytical limits of detection. The UF_6-product beta-gamma natural background is being evaluated to determine whether AEC specifications for returned UF_6 were met during the run.

Total cationic impurities in the R-8 product were about 712 ppm (AEC total cation maximum is 300 ppm, based on uranium), with sodium, at 327 ppm, being the major impurity. Molybdenum removal by selective desorption from the movable-bed absorber at 150°C was effective (the molybdenum level in the UF_6 product was 43 ppm, a fifth of the AEC maximum limit). The MgF_2 trap in the product recovery system removed Tc^{99} and Np^{237} to acceptable levels (4 and 48 ppm respectively).

MOLTEN-SALT REACTOR PROGRAM

Molten-Salt Reactor Experiment. – Progress was made in the installation of auxiliary piping, instrumentation, and electrical services in the reactor cell and the coolant cell. The second fuel drain tank and steam dome assembly and the coolant drain tank were delivered to the site. Machining was completed on the coolant pumps, and all welding was completed

on the fuel pump. The H. K. Ferguson Company started work on the electrical and auxiliary piping systems outside the three reactor-system cells. The overall project was 75.5% complete as of July 1, 1963.

Metallurgy. — Grade CGB graphite bars produced for the MSRE moderator were found to meet specifications except that all bars contain cracks and some bars have densities as low as 1.82 g/cc. Despite these conditions, the graphite was found to have good mechanical strength and low permeability by salt. Salt permeation of cracked grade CGB graphite was compared with that of other graphites at 150 psig and 1300°F. Grade CGB was found to have less than 0.1% of its bulk volume permeated. Rapid thermal cycling of this graphite between 390 and 1300°F did not damage the graphite or cause salt-impregnated cracks to propagate. Tensile strength of grade CGB was found to range from 5440 to 6500 psi when tested as a round bar or ring. Severely cracked test specimens were tested to as low as 1500 psi; however, the material did not demonstrate notch sensitivity. The specifications were modified on the basis of these tests to define the amount of cracking that could be accepted in bars for the MSRE.

Chemical purity of the graphite was established by testing for ash, boron, vanadium, and sulfur. These elements were well below the acceptable limits. Chemisorbed oxygen content was determined to be 6 cc of CO per 100 cc of graphite by measuring the gases evolved from the graphite at 1800°C after a room-temperature evacuation to 10^{-3} torr.

Chemical Development. — One of the controlling considerations in adjusting the BeF_2 content in MSRE-type fluoride melts is a favorable balance between the decrease in melting point and increase in viscosity associated with increasing proportions of the highly viscous BeF_2. Preliminary values of the viscosities of an MSRE fuel ($LiF-BeF_2-ZrF_4-UF_4$, 66.8-29.0-4.0-0.2 mole %) and coolant ($LiF-BeF_2$, 66-34 mole %) as estimated from previous measurements on similar mixtures were about 7.6 and 5.7 centipoises, respectively, at 650°C. Recent measurements on the above MSRE compositions (but with 0.8 rather than 0.2 mole % UF_4 in the fuel) with a rotating-cylinder viscometer (Brookfield) gave revised values of 7.5 and 6.3 centipoises for the fuel and coolant, respectively, at 650°C in accordance with the relations $\eta(\text{fuel}) = 0.0916 \exp (4098/T)$ and $\eta(\text{coolant}) = 0.116 \exp (3755/T)$, where η is the viscosity in centipoises and T is the absolute temperature. The higher viscosity of the fuel in comparison with that of the coolant can be viewed as indicative of a diminished effectiveness of LiF as a diluent for BeF_2 because of complexing by quadrivalent cations of fluoride nominally available from the LiF and also, as an added effect, as a contribution of larger units of liquid structure associated with the quadrivalent cations. The viscosity of the coolant changes from a value of 11 to 9 centipoises in the interval between the design temperature limits of 550 and 595°C for the MSRE coolant circuit.

Preparation of MSRE Materials. — Some lots of the 16,000 lb of Li^7F on hand for use in the preparation of fluoride mixtures for the MSRE were found to have an undesirably low bulk density and high moisture content. These characteristics would make it difficult to load and process the required weights of dry material in the premelting furnace of the fuel production facility. Consequently, an experimental program was undertaken to develop a technique for improving the properties of the material. The

experiments were performed in small-scale equipment which is similar to larger equipment available in the fluoride production facility.

The results of the experiments showed that powdered low-density LiF could be changed into a free-flowing crystalline material of much higher bulk density by a simple heat and dehydration treatment. The LiF was purged with a mixture of anhydrous HF and helium while being heated to 200°C to convert hydroxides to fluorides and to remove moisture. The system was then purged with helium while being heated to 650°C and while being cooled to room temperature. During the treatment period the material was continually agitated by a rotating-vane mechanism. The final product was satisfactory for use in the premelting operation.

Radiation Effects. — The history of the release of fluorine gas from two gas-swept capsules in the most recent in-pile irradiation of MSRE fuel (47-5) has been completed. The fluorine, which continued to be evolved at decreasing rates for five months following termination of the exposure, was produced only over a fairly narrow temperature range between −100 and +100°C, with a pronounced maximum, at least for the out-of-pile decay period, near 50°C. Estimated G values for the region near the maximum, in terms of molecules of F_2 per 100 ev of decay energy, decreased from 0.04 to 0.02 or lower, in part at least as a consequence of back-reaction with the buildup of chemically reduced species in the fuel. No evidence of F_2 at MSRE conditions was found, and the evolution from frozen fuel occurred usually only after an induction period.

During the several MTR shutdowns that interrupted the exposure, the capsules were near 35°C for periods of several days, and the ensuing losses of F_2 were equivalent to increments of chemical reduction of the fuel. The accumulated effects, shown in terms of the extent of expected reduction of UF_4 to UF_3 in the following table, caused the fuel, rather early in its history, to be reduced to the point that some disproportionation of UF_3 could have been expected; appreciable deposition of uranium, particularly in the capsule with higher power density, must have occurred before the exposure was terminated.

Further evolution of F_2 after termination of the exposure led to cumulative losses of about 190 and 410 std cc of fluorine or 1.9 and 4.1% of the total fluoride content of the fuel for the low-power and high-power capsules respectively (nominal experimental design powers were 35 and 65 w/cc).

Calculated Conversion of UF_4 to UF_3 Due to F_2 Loss Induced by Decay Energy During Pile Shutdowns While Irradiating MSRE Fuel (ORNL-MTR-47-5)

Shutdown Interval		0.34 mole % UF_4 in Fuel			0.66 mole % UF_4 in Fuel		
Date	Duration (hr)	Induction Period (hr)	Cumulative F_2 Loss: Std cc	Cumulative F_2 Loss: % UF_4 to UF_3	Induction Period (hr)	Cumulative F_2 Loss: Std cc	Cumulative F_2 Loss: % UF_4 to UF_3
10/29	98	36	7.8	32	8	21.4	46
11/13	53	30	10.5	43	10?	32.7	71
11/19	64	> 44	No yield		6	55.5	120
12/1	47	20?	12.0	49.5	0	75.5	163
12/21	47.5	> 47.5	No yield		> 47.5	No yield	
1/4	85	30?	17.5	72	20?	98.8	214
1/21	8	0?	18.2	75	0	107.3	232

MSR Processing. — The MSRE fuel processing system was reviewed by the Radiochemical Plants Committee. Of most concern was the possible ground contamination from activity released during processing. The permissible releases to prevent excessive ground contamination are a factor of 10^2 to 10^4 lower than the permissible releases for air contamination. Off-gas samples from the Volatility Pilot Plant runs under conditions similar to those in MSRE processing contain no detectable activity except tellurium, and the amount detected corresponds roughly to the permissible release at the MSRE. An activated-charcoal trap will be added to the system, and it should provide a margin of safety for iodine and tellurium. This will be verified by tests at the MSRE following equipment installation.

Analysis of Radioactive MSRE Fuels. — The statistical evaluation of the spectrophotometric determination of nickel in sulfuric acid solutions of the MSRE fuel has been completed in the mockup. The dimethylglyoxime (persulfate oxidation) method was used. The absorbancy of the solutions was measured on the remotely operated filter-photometer (ORNL-LR-DWG 13584A series) fitted with a 450-mμ filter. The relative standard deviation was 2.8%.

A variable-electrode cell system for amperometric, coulometric, and polarographic determinations for hot-cell use was designed, and fabrication is 80% complete.

The statistical evaluation of the newly developed chromium amperometric method is currently in progress on sulfuric acid solutions of MSRE fuel by use of the variable-electrode cell system.

Other phases of the work necessary for handling and analyzing the MSRE fuel sample in the hot cell are in progress.

The evaluation of the amperometric titration method for the determination of chromium in sulfuric acid solutions of MSRE fuel samples was completed. When the method was carried out in the Analytical Chemistry Division mockup cell to simulate the hot-cell facility, a relative standard deviation of 1.6% was obtained for unirradiated MSRE salt solutions. This titration method was carried out without any prior separations. When the titration is performed remotely, the results indicate a positive bias of approximately 1%.

HIGH FLUX ISOTOPE REACTOR DESIGN AND DEVELOPMENT

Metallurgy. — A problem expected in the production of the HFIR fuel elements will be the determination of the quality of the welds where the fuel plates are joined to the side plates. None of the standard inspection techniques will provide such information; therefore, quality-control procedures must be used. It has been shown that with proper joint design the most critical variable is the distance the plate penetrates into the weld groove. Conventional techniques for measuring this dimension for 540 plates in several weld grooves are slow and expensive. A technique has been developed by which a room-temperature vulcanizing rubber is used to make an impression of an entire weld groove. After setting, the rubber form can be placed on a shadowgraph, and the plate penetrations can be measured quickly and accurately.

A through-transmission x-ray attenuation technique was developed for the measurement of fuel concentration variations in the HFIR fuel plate. A tightly collimated beam of 50-kvp x rays is transmitted through a 5/64-in.-diam area of the plate before being intercepted by an NaI(Tl) crystal photomultiplier detector which converts the radiation beam into an electrical signal. As the fuel concentration varies, there will be an associated change in the transmitted x-ray intensity and the subsequent electrical signal. Calibration with reference standards containing known fuel concentrations allows interpretation of the signal in terms of fuel within the plate. Instrumentation was designed and constructed to allow direct comparison between the attenuation values of the calibration standards and those of the plate being inspected. This allows immediate recognition of out-of-tolerance conditions. The mechanical scanning system translates the plate to be inspected longitudinally through the x-ray beam. At the end of each longitudinal scan, there is a transverse index before the return parallel scan; thus there is complete X-Y scanning of the plate. Such techniques have been used to inspect the HFIR fuel plates to the required ±30% uranium homogeneity standard for each 5/64-in.-diam spot.

Component Development. — The corrosion test program has been expanded to include impregnated Teflon, Delrin, and Celcon plastics. These materials have been tentatively selected for use in seal housings for the HFIR control-rod drive rods and the ball-latch-mechanism push rod. These rods reciprocate through Buna or Palmetto seals at slow cyclic rates. Plastic was chosen for these housings in order to eliminate seal failures caused by rods being scored while reciprocating through a metallic packing gland. Delrin was initially chosen for this service and was found to be mechanically acceptable in extensive tests. Delrin failed rapidly (< 1000 hr) in corrosion tests when subjected to pH 5 water at 100°C. These tests will be repeated at 50°C, which is closer to the actual service temperature.

Tests are continuing on the various bearings prepared for use in the HFIR. Two Marlin-Rockwell Corporation 106KSW10 bearings with an outside diameter of 2.1654 in. have been operated approximately 1,350,000 revolutions under a load of 100 lb per bearing. The coefficient of friction measured at the beginning of the test was 0.0132, and that at the end of the test was 0.0209. The increase in radial clearance was approximately 0.0006 in. for each bearing. Journal-type bearings with Graphitar 14 inserts and a Stellite sleeve-type bearing are currently being tested. Measurements indicate that the coefficient of friction for the bearings with the Graphitar inserts is about 0.13 to 0.14 after 16,500 cycles (8-in. reciprocating stroke) in pH 5 demineralized water at 195°F.

A prototype assembly of an outer control-rod drive rod has been designed and fabricated, and tests are now under way.

Design and Analysis. — Design effort for the HFIR core components has been concentrated on the preparation of certified-for-construction drawings for the reactor internal structure. Since the last reporting date, certified-for-construction drawings have been issued for the reactor beam tubes and the supporting structure for the fuel and reflector assemblies. Work is continuing on the design of the control-rod track and bearing assembly.

Reports. — Most of the material for the HFIR hazards report has been submitted. The second draft is approximately 50% complete, with about 75% of the illustrations finished. The first draft of the operating manual is about 5% complete, and the first draft of the design report is about 50% complete.

PHYSICAL RESEARCH

Reactor Operations. — For the period January 1, 1963, through July 21, 1963, the ORR operated 75.8% of the time, the LITR operated 86.1% of the time, and the ORNL Graphite Reactor operated 93.6% of the time.

An ORR fuel-element rupture occurred on July 1, but no contamination of equipment or building occurred, nor was there any overexposure of personnel. Only 150 mc of fission product iodine escaped through the off-gas cleaning system to the environment. Alterations to the LITR reactor tank were completed for side access to the experiment positions in the core.

Waste Disposal. — The continuous-monitoring equipment at the 3039 stack was found to be very sensitive in detecting the gaseous activity released from the ORR fuel-element rupture on July 1. Although the readings on the off-gas line and stack tape monitors were very high, the total release, according to analyses of the inventory samples, was no more than 150 mc, mainly fission product iodine.

The Ru^{106} discharge from the waste-pit area to White Oak Creek, during the month of June, dropped to 63 curies, the lowest monthly release experienced in the last several years.

Hot-Cell Operations. — Operations in the hot cells were normal. Nine fueled capsules from the ORR and the LITR were disassembled and examined; fuels included UO_2, UC_2 particles with pyrolytic carbon coating, BeO-UO_2, and pyrolytic-carbon-coated UC_2 embedded in graphite. Examination of experiment ORNL 41-9, containing about 180 stainless-steel-encapsulated BeO pellets irradiated at the ETR, was completed; and examination of ORNL 41-10, a similar BeO experiment, was begun. The first ORR-GCR loop No. 2 experiment, a calibration test, was cut up in the disassembly cells. Specimens were recovered from 16 ORR experiments in the ORR cells. The study of the rate of gas evolution from molten-salt experiment MTR 47-5 under various conditions was completed, and disassembly was started.

At the High-Radiation-Level Examination Laboratory, installation of in-cell and out-of-cell equipment continued.

PHYSICS AND MATHEMATICS

Neutron Diffraction. — Bulk magnetization and neutron scattering measurements were made on alloys of the type $Pd_{0.96}Fe_{0.03}RE_{0.01}$ (RE = La, Ce, Pr, Nd, Gd, Tb, Dy, Ho, Er, Tm, Yb) to determine the existence and type of coupling of the rare-earth moments with the ferromagnetic Pd-Fe matrix. The saturation moment was increased by the addition of Pr and Nd and decreased by the addition of the heavy rare earths. Thus it appears that those rare earths to the left of Gd ($J = L - S$) have their moments aligned parallel and those to the right of Gd ($J = L + S$) have them antiparallel to the ferromagnetic Pd-Fe lattice. This is in accord with a negative ionic-spin-conduction-electron interaction. The neutron

scattering data indicate that there is only partial alignment of the rare-earth moments and that part of the change in average moment is associated with an alteration of the Pd moments on addition of the rare earths.

Theoretical Physics. — A theory has been developed which takes into account the possibility of inelastic scattering before and after a rearrangement collision in nuclear reactions. These effects modify the selection rules operating in the reaction, so that transitions may occur which would otherwise appear anomalous. These phenomena are expected to arise in, for example, deuteron stripping on deformed nuclei, and some such cases have been observed. A computer code is being prepared for numerical studies, in which the inelastic scattering is generated by a nonspherical optical-model potential.

Low-Energy Neutron Time-of-Flight Spectroscopy. — The gamma-ray spectra resulting from the capture of thermal neutrons in Zr^{90}, Zr^{91}, Zr^{92}, Zr^{94}, and Zr^{96} have been studied with a large (9 × 12 in.) NaI crystal. Gamma-ray spectra from the capture of neutrons in Zr^{91} agree with previous measurements made with natural zirconium, since ~60% of the thermal capture in natural zirconium arises from the Zr^{91} isotope. Many of the observed gamma rays from neutron capture in these five isotopes can be correlated with known decay schemes. For example, neutron capture in Zr^{92} gives gamma rays at 4.2 and 5.2 Mev which correspond to transitions to the excited states in Zr^{93} at 2.43 and 1.42 Mev. Measurement will also be made of the gamma-ray spectra from neutron capture in individual resonances of zirconium.

Low-Temperature, Nuclear and Solid State Physics. — The internal magnetic field H_e for the Mössbauer nucleus Ni^{61} in metallic nickel has been determined by application of an external magnetic field which ranged from 2.8 up to 24.0 kilogauss. The hyperfine splitting of the Ni^{61} Mössbauer radiation shrinks, indicating a negative effective field. Comparing the observed changes in the absorption spectra with computer-calculated absorption curves (taking into account absorber thickness, etc.) yields $H_e = -(90 \pm 20)$ kilogauss. This result is in contradiction with the older nuclear magnetic resonance results, but it agrees with the new nuclear magnetic resonance results published recently by Streever *et al.* The previous value obtained at ORNL for the ratio of the nuclear moments is, of course, still valid; it is $\mu_e/\mu_g = -0.47 \pm 0.08$. With the new value $\mu_g = 0.70 \pm 0.04$, it follows that $\mu_e = -0.33 \pm 0.06$. The magnetic moments for Ni^{61} in the ground and first excited states are therefore about 2.3 times the values originally reported.

High-Voltage Experimental Program: Low-Energy (p,n) Reaction $Mn^{55}(p,n)Fe^{55}$. — The 3-Mv pulsed Van de Graaff accelerator and associated time-of-flight equipment have been used to study the reaction $Mn^{55}(p,n)Fe^{55}$ in the bombarding energy range 2.360 to 2.445 Mev. Strong fluctuations of the kind discussed by Ericson [Phys. Rev. Letters *5*, 430 (1960)] were observed. The excitation functions of the neutron groups feeding the 413-kev, the 933-kev, and the ground state of Fe^{55} fluctuate with a width Γ of 10 to 15 kev, and the fluctuations of different neutron groups show strong correlations. In addition to the 413- and 933-kev states, two previously

unreported states of Fe^{55*} with excitation energies of 510 ± 10 and 680 ± 10 kev were observed. These levels were observed both in the neutron spectrum and in the de-excitation gamma-ray spectrum.

High-Voltage Experimental Program: Resonant Neutron Capture Gamma-Ray Spectra in Titanium and Vanadium. — The theories of radiative capture predict a minimum in the potential or direct s-wave capture process as the low-lying p states become filled [Progr. Theoret. Phys. 23, 161 (1960); Nucl. Phys. 17, 563 (1960); C. Shakin (private communication)]. Such an effect should be at least qualitatively observable in the general region of the s-wave strength function maximum. Since in this region of A, the p states are near ground, it would follow that in those cases in which thermal capture is dominated by the direct process, the high-energy lines should strongly dominate but should diminish in relative intensity in the resonance region. Such an effect has already been reported [Phys. Letters 1, 262 (1962)]. It is of interest to continue to study resonance capture in this region of A. Preliminary results have been obtained on a number of nuclei in the region of the s-wave giant resonance. The energy-averaged spectrum of vanadium shows only moderate strengthening of the low-energy transitions. Both vanadium and titanium have large resonances, and the gamma-ray spectra show substantial changes from resonance to resonance.

Mathematics and Programing Research. — Facilities have been added to the Oak Ridge ALGOL compiler for the CDC 1604 computer to provide for the use of FORTRAN subprograms in an ALGOL program. Any FORTRAN subprogram, whether compiled under the FORTRAN 62 or the FORTRAN 63 compiler, may be referenced from an ALGOL program through one of four ALGOL standard procedures (available without declaration): FORTRAN (for FORTRAN 62 subroutines), FORTRANF (for FORTRAN 62 functions), FTN (for FORTRAN 63 subroutines), and FTNF (for FORTRAN 63 functions). Each of these names acts as a signal to the compiler to generate the appropriate FORTRAN calling sequence. These facilities may also be used for referencing CODAP-1 (assembly language) subprograms.

CHEMISTRY

Effects of Radiation on Analytical Methods. — The study of the effect of gamma radiation on the dimethylglyoxime method for determining nickel colorimetrically has been continued. It has been found that the colored nickel-dimethylglyoxime complex is extremely stable, with no apparent degradation being caused by gamma doses of $\sim 10^6$ r. Dimethylglyoxime itself is much more sensitive to gamma radiation than the complex; appreciable radiation damage has been noted at about 10^5 r. There is some evidence of a postirradiation recombination of the radiolysis products of dimethylglyoxime. This phenomenon is being studied, together with the effects of radiation on the other reagents involved in the procedure.

A study has been initiated to determine the effects of gamma radiation on arsenazo III (1,8-dihydroxynaphthalene-3,6-disulfonic acid-2,7-bis [(azo-2)-phenylarsonic acid]), a chromogenic agent for the

determination of members of the actinide and lanthanide series. Arsenazo III has been found to be quite sensitive to radiation. The effects of reagent concentration, acidity, dose rate, etc., on the radiolytic decomposition of arsenazo III are being examined. The sensitivity of the reagent to gamma radiation and the linearity and reproducibility of the results suggest that the reagent might find usage as a dosimeter for absorbed doses as low as 100 r. This possibility is being explored.

The effect of gamma radiation on some procedures for the separation of transuranium elements is being studied. Hydrochloric acid in the 10 M lithium chloride solution that is used in these procedures is decomposed by ionizing radiation to give free chlorine, hydrogen ion being consumed. The G value (number of molecules per 100 ev) for the formation of free chlorine brought about by Co^{60} gamma radiation increases from 3.9 at 0.01 M HCl to 7.8 at 0.25 M HCl.

Separations Chemistry Research. — Single-stage separation factors greater than 100 between the lanthanides cerium and europium and the transplutonium element americium were obtained by extraction with di(2-ethylhexyl)phosphoric acid (HDEHP) in hydrocarbon diluents from very dilute solutions of diethylenetriaminepentaacetic acid (H_5DTPA) containing sodium nitrate. Europium was extracted much more slowly than cerium and americium. Equally large separation factors between the two groups of elements, but without an observable time effect, were obtained in extractions by dialkylphosphoric acids and alkyl hydrogen alkylphosphonates from mixtures of carboxylic acids and sodium salts of DTPA. Complete separation of americium from cerium was accomplished by a reversed-phase chromatographic procedure in which a tracer-level mixture of the two elements in a solution 1 M in glycine nitrate and 0.1 M in pentasodium diethylenetriaminepentaacetate was filtered through a 20-cm-high column containing 5 ml of 0.3 M HDEHP in diisopropylbenzene absorbed in 5 g of microporous polyethylene. Residual americium was washed from the column with only about two column volumes of a similar unspiked aqueous solution.

From the inception of the Amex extraction of uranyl sulfate, there has been a question as to whether the actual mechanism of extraction is transfer of a neutral complex,

$$x(R_3NH)_2SO_{4(org)} + UO_2SO_4 \rightleftharpoons UO_2(R_3NH)_{2x}(SO_4)_{x+1(org)}\,, \qquad (1)$$

or exchange of anions,

$$x(R_3NH)_2SO_{4(org)} + UO_2(SO_4)_2^{2-} \rightleftharpoons UO_2(R_3NH)_{2x}(SO_4)_{x+1(org)} + SO_4^{2-}. \qquad (2)$$

This question cannot be answered by any equilibrium measurement, since both mechanisms are thermodynamically equivalent. Kinetic measurements of the transfer of S^{35}-tagged sulfate between amine sulfate organic solution and sodium sulfate aqueous solution, with uranium absent, present and being extracted, or already at equilibrium distribution, showed that both mechanisms contribute to the total uranium transfer. Mechanism (1)

predominates in the extraction from low-sulfate solutions, where little of the uranyl ion is complexed (e.g., >50% as uncomplexed UO_2^{2+} at < 0.01 M Na_2SO_4). Mechanism (2) becomes important at higher sulfate concentrations, where most of the uranium exists in anionic complexes [e.g., 75% as $UO_2(SO_4)_2^{2-}$ at 0.5 M Na_2SO_4].

Separations Process Development. – In a continuous run in mixer-settler equipment, more than 98% of the cesium was recovered from an alkaline pollucite ore leach liquor (pH about 13) by extraction with 1 M 4-sec-butyl-2-(α-methylbenzyl)phenol (BAMBP) in kerosene and stripping with hydrochloric acid. The strip solution contained 375 g of cesium per liter. Decontamination factors for cesium (from feed liquor to strip solution product) were 180 from Rb, 700 from K, > 10,000 from Na, > 700 from Li, and > 10,000 from Si. The cesium was also readily stripped from the extract with water and carbon dioxide in a slightly pressurized contacting vessel to give a cesium carbonate product.

Volatility Studies. – Increasing the fluorine pressure used in tests on the volatilization of PuF_6 from molten 31-24-45 mole % $LiF-NaF-ZrF_4$ at 600°C resulted in a faster volatilization rate. In two tests at about 40 psig of fluorine, half-time values of 1.3 and 1.7 hr were obtained. These are markedly less than the normal value of about 4 hr. This pressure effect indicated that the slow volatilization rate is basically due to unfavorable chemical kinetics.

No changes in PuF_6 volatilization rates were observed in other tests where 2 wt % PbF_2 was added to the molten salt to act as a fluorine carrier, or where 50-50 mole % $LiF-ZrF_4$ salt was used to avoid the possibly adverse effect due to the presence of NaF as a complexing agent.

Radiolysis of Metal Fluorides. – Several experiments to determine fluorine evolution rates from solid MSRE-type fused salt under fast-electron bombardment have been conducted with equipment and techniques developed for experiments of this type. About 0.3 g of salt in the form of 30- to 50-mil-diam particles was exposed to 1.72-Mev Van de Graaff electrons at a current of 0.97 μa. The calculated dose rate was 1.7×10^{13} Mev sec^{-1} g^{-1}. Estimated temperatures in the salt were 30°C at the maximum and 25°C average.

Completed experiments yield values of G_{F_2} as a function of dose up to a total of about 6×10^{17} Mev per gram of salt. The observed G_{F_2} increased with increasing dose to about 3.5×10^{17} Mev/g and then remained approximately constant at 0.015 to 0.016. During the initial dose of 1.2×10^{17} Mev/g, the average G_{F_2} was 0.005.

For comparison, some G_{F_2} values in MSRE in-pile capsule tests reported by others are 0.02 and 0.04 during comparable low- and high-dose periods. Exploration of effects of dose rates and other possible explanations of these differences in values is continuing.

Mechanism of Aqueous and Radiation Corrosion of Zirconium Alloys. – A program is under way to study the mechanism of radiation corrosion of Zircaloy-2 by means of ac film impedance measurements. Measurements have been made on specimens irradiated by fast neutrons (5 to 8×10^{17} nv > 1 Mev) while in a helium atmosphere at 100 or 300°C.

Changes in the capacitance part of the impedance of irradiated corrosion film were similar to those which have been shown by others to result from porosity and to be related to decreased corrosion protection. Postirradiation exposure of the specimens to 300°C steam plus oxygen caused the film capacitance to recover in 7 to 15 min. No measurable enhancement of corrosion by weight-gain measurements ($\pm 0.3\ \mu g/cm^2$) was observed. It has not yet been determined whether the oxidizing environment is required for the recovery of the film impedance.

Electrochemical Kinetics and Its Application to Corrosion. — The dissolution of zirconium in solutions containing HF involves the continuous formation and dissolution of a film of ZrO_2. In order to determine the true rate of the surface reaction between HF and the zirconium ions of the surface of the film, the effects of mass transfer (diffusion and convection) must be eliminated. A rotating-disk electrode system was therefore designed and put into operation. With this system the effects of the concentration gradient set up by mass transfer are eliminated by measuring the current as a function of rotational velocity. Data were obtained from which the appropriate rate constants and the diffusion coefficient of HF can be calculated. Although preliminary experiments indicated that the reaction is first order with respect to HF, more refined experiments showed that the reaction is most probably second order with respect to HF.

Physical Chemistry of Molten Salts. — Freezing-point depressions in NaF caused by the addition of up to 0.15 mole fraction of AlF_3, ScF_3, InF_3, YF_3, LaF_3, and eight rare-earth trifluorides were measured as part of a program of investigating how the thermodynamic behavior of fluoride melts is related to structural parameters of the components. (Previous measurements with the rare-earth trifluorides alone were reported in ORNL-3279, p 21.) The excess partial molal free energies of solution of NaF, $(\overline{F} - F^\circ)^E_{NaF}$, evaluated from the measurements, are all negative. For all the solutes except AlF_3 and InF_3, $(\overline{F} - F^\circ)^E_{NaF}$ was found to be inversely proportional to the interionic distance of the solute. The different solution behavior of AlF_3 and InF_3 is attributed to steric and polarization effects. The values of $(\overline{F} - F^\circ)^E_{NaF}$ with trivalent-fluoride solutes are generally more negative than corresponding values with tetravalent solutes but less negative than the values with divalent solutes.

High-Temperature Aqueous Solution Chemistry. — Measurements of thorium(IV) hydrolysis in 1 M sodium perchlorate solution at 94°C, described previously (ORNL-3307), have been completed. The resulting variation of hydroxyl number $\overline{n}$ (the average number of bound OH^- ions per Th^{4+} ion in solution) with pH and with the thorium concentration has been compared with the behavior expected for various assumed hydrolysis species $Th_x(OH)_y^{(4x-y)+}$ by the use of a nonlinear least-squares computer program. It appears from this analysis, not yet complete, that at least four species must be assumed to account for the experimental results. Initially, two mononuclear hydrolysis products are formed, $ThOH^{3+}$ ($\log Q_{1,1} \approx -2.2$) and $Th(OH)_2^{2+}$ ($\log Q_{1,2} \approx -4.5$), Q_{xy} being the formation quotient of $Th_x(OH)_y$,

$C_{Th_x(OH)_y}\ C_H^y/C_{Th}^x$. It appears that two polynuclear products are formed subsequently, either $(Th)_2(OH)_2^{6+}$ ($\log Q_{2,2} \approx -2.5$) and $(Th)_5(OH)_{12}^{8+}$ ($\log Q_{5,12} \approx -16.4$), or $(Th)_2(OH)_3^{5+}$ ($\log Q_{2,3} \approx -4.7$) and $(Th)_4(OH)_{10}^{6+}$ ($\log Q_{4,10} \approx 14.6$). Either scheme (x:y = 1:1, 1:2, 2:2, 5:12 or x:y = 1:1, 1:2, 2:3, 4:10) produces agreement between the calculated and observed values of $\bar{n}$ with a mean deviation less than 0.02. Comparison of these schemes with available observed hydrolysis data at 25° shows a similar consistency.

Chemical Separation of Isotopes. — Two disturbances to the water distillation cascade were experienced. On June 10, process water was lost from column 4 as a result of a leak at a soldered joint in a feed line. On June 22, a partial flooding of column 6 occurred when the jacket water became cooled after an electrical outage which affected both jacket water heating circuits simultaneously. It is estimated that these disturbances will increase the time to achieve isotopic equilibrium by approximately four weeks. The water distillation cascade is currently performing well: the present concentrations of O^{17} and O^{18} are 1.17% and 66.0% respectively.

METALLURGY AND MATERIALS

Physical Properties Studies. — Thermal conductivity data on 93.4%-dense UO_2 that were previously obtained in the radial heat flow apparatus indicated that below 200°C the thermal resistivity deviates from the linear relation observed between 200 and 1050°C. A limited study of the temperature region 100 to −67°C was made by modifying the high-temperature radial heat flow apparatus. The thermal resistivity showed a definite upward trend with decreasing temperature in the temperature range below 0°C. Between 200 and 18°C the thermal resistivity decreases with decreasing temperature; hence the thermal resistivity of UO_2 passes through a minimum near 0°C, or in other words, the thermal conductivity reaches a maximum value near 0°C.

The thermal comparator apparatus for rapidly measuring the thermal conductivity of small samples was calibrated satisfactorily at 125°C and is currently being calibrated at 400°C, which is the limit of operation of this apparatus.

The total hemispherical emittance apparatus is now capable of continuous operation at 1 to 4×10^{-7} torr. Precise measurements up to 1200°C have been realized with a dc power supply which has better than 0.1% stability. A FORTRAN computer program was written to expedite the numerous routine calculations involved in obtaining emittance and electrical resistivity values. Measurements on strips and rods of INOR-8 yielded emittance data which are related to the electrical resistivity data. The electrical resistivity of INOR-8 is quite high and has a maximum indicative of short-range order. The resistivity can be altered 5 to

10% by rapid cooling in the apparatus and is reduced nearly 25% by cold-working. It appears that these data can be used to study the effects of order-disorder on thermophysical properties.

CONTROLLED THERMONUCLEAR RESEARCH

DCX-1 Facility. – Observations of the plasma volume, density, rf radiation, and total number of trapped protons have continued on plasmas formed by Lorentz dissociation. Injected H_2^+ beams (obtained from H_3^+ dissociation) with currents from 10 to 300 μa have been used to create the plasmas, which were contained for times from 0.1 to 20 sec at each injected current. The containment times were varied by controlling the operating pressure. For short confinement periods (0.1–1.0 sec) the plasma density and the total number of trapped particles vary linearly with the beam currents and containment times as predicted; however, for longer periods (1.0–20 sec) the plasma spreads from a volume of 2 liters to 30 liters and reaches a density limit close to 10^8 protons/cm^3. The total number of trapped protons still continues to increase nearly linearly.

For the same containment times, the gross properties of plasmas established by Lorentz-force trapping are qualitatively the same as those of plasmas with an equivalent number of trapped protons established by gas dissociation, even though the H_2^+ beam is a factor of 100 lower for Lorentz than for gas trapping. This indicates that there is no strong H_2^+-beam–proton-plasma interaction in the system. The basic problem is then that of understanding and quenching the plasma spread by some stabilization technique.

Beam-Plasma Interaction. – Observations of a beam-plasma interaction have been made with an intense dc electron beam of 1/2 to 1 amp at a voltage between 20 and 30 kv. The distance from accelerating electrode to beam catcher is about 20 in. Coaxial to the beam and 4 in. in front of the beam catcher is a 9-in.-long, 7-1/2-in.-diam copper cylinder in which a localized high-pressure region can be obtained. The entire apparatus is located in a uniform magnetic field of 3700 gauss maximum.

At least two different modes of interaction have been observed; both modes are effective x-ray producers. The first is characterized by an x-ray energy maximum between 30 and 40 kev and an apparent self-excited pulsing of the electron beam which can be varied from about 50 to 120 kc by careful adjustment of the electron gun parameters.

The second mode is characterized by an x-ray intensity 50 to 100 times that of the first mode and by an x-ray energy maximum between 175 and 200 kev. There is no beam pulsing in the kilocycle range associated with this mode, and the x-ray intensity falls sharply below 2000 gauss or above 2500 gauss. In addition the position of a longitudinally movable electrode between the accelerating electrode and the interaction region has exhibited marked effects upon the x-ray production. On many occasions, the x-ray intensity has been observed to have two maxima as a function of the movable electrode position. Qualitatively, these peaks can be interpreted as arising from electron bunching of the beam. The

beam velocity being known, the bunching frequency is calculated to be equivalent to the electron cyclotron frequency.

Theory. – Exact upper bounds on instability growth rates in realistic mirror-machine configurations have been obtained from the rate of change of free energy, a method reported previously. Complications included magnetic mirror field curvature, large density gradients, azimuthal streaming of ions through electrons (diamagnetic current), and ion temperature anisotropy. The bounds, at most of the order of the ion plasma frequency, correspond to the fastest growth of the Harris electrostatic streaming and anisotropy instabilities in infinite plasmas in a uniform magnetic field. Thus, one concludes that no faster modes are introduced by the density gradients and field curvature. Also, the result emphasizes dependence of Harris modes on R/a, the ratio of plasma radius and Larmor radius, which might account for differences in ion cyclotron activity in the DCX machines, for which R/a is small, and the neutral-injection machines Phoenix (Aldermaston) and ALICE (LRL). The growth rate for the azimuthal streaming mode goes down as R/a increases, corresponding to a reduction in diamagnetic current; R/a goes up with magnetic field. A weakening of the streaming mode might account for the observed change of character of ion cyclotron oscillations in Phoenix and ALICE as the magnetic field is increased.

Cross Sections. – A 127° electron velocity selector was used to produce electrons whose energies were between 15.67 and 15.95 v. Collisions of these electrons with hydrogen molecules produced H_2^+ ions in the ground vibrational state. Measurements were made of the dissociation cross section of H_2^+ in gases to determine the sensitivity of the dissociation cross section to the vibrational level of the molecular ion. The resolution of the velocity analyzer was sufficient to detect ions in the first three vibrational levels. The attenuation of the H_2^+ beam by the gas-cell entrance aperture reduced the small beam (200 ions/min) to currents of less than 1 ion/min. Geometric changes are being made in the analyzer to obtain larger H_2^+ currents.

Passage of H_3^+ ions through a water vapor cell was used to form H_2^+ in highly excited vibrational levels by a single dissociative collision. The number of H_2^+ ions formed per incident H_3^+ was 0.14 at 60 kev and decreased to 0.11 at 400 kev. Measurements of the H_2^+ spatial distribution indicated that less than 1 v of internal potential energy was converted to kinetic energy during the time of the collision and that the measured half angle at half maximum amplitude was less than 5 milliradians for a 60-kev H_3^+ beam.

BIOLOGY AND MEDICINE

RADIATION EFFECTS

Statistical Services and Research. – Mean platelet size and size distribution in blood can be determined from plots produced by a 25-channel Coulter counter. Electronic noise and particles in the diluent

cause error in counting platelets of small size, and the limit of 25 channels causes truncation of the upper end of the distribution. An unbiased statistical procedure for estimating the mean and the variance of the size distribution has been applied. A method of estimating the number of counts due to the noise and the diluent, separately, has been proposed for future experiments.

A computer program for the CDC 1604 has been written for processing Coulter counter data. Programming for the CDC 1604 and conversion of IBM 7090 programs to CDC 1604 programs are continuing.

Pathology and Physiology. — To explore the relation between shortened survival and late effects of ionizing radiation on specific age-dependent processes, the aging of collagen fibers from tail tendons of irradiated and unirradiated mice was investigated. Virgin male and female RF/Up mice, caged separately by sex in groups of 8 to 10, received a whole-body exposure of 450 r at 2 to 3 months of age, or in the case of a few animals, a tail exposure of 2000 r. At intervals through the remainder of the life span, the irradiated animals and controls were killed, and the temperature of maximum contraction (TMC) was determined for single tail-tendon fibers. In fibers from both irradiated and unirradiated animals the mean TMC increased smoothly with age, with no significant difference in slope between groups, except in fibers from mice that were members of actively breeding or formerly breeding pairs. The results indicate that the thermal response of collagen fibers shows an age-dependent relation to temperature which is not appreciably influenced by whole-body x radiation in life-shortening doses or by larger doses of x rays administered to the tail. The results with breeders imply the influence of other factors on the age-dependent changes in collagen (e.g., sexual, nutritional, or stress variables), the role of which remains to be established.

Recovery from Somatic Effects of Radiation. — Assessment of the proliferative capacity of bone marrow cells of (BALB/c × A/He)F_1 mice was obtained by determining the ability of these cells to repopulate the spleen on transplantation into x-irradiated (700 r) syngeneic recipients, the repopulation being measured by analysis of the uptake of labeled iododeoxyuridine (I^{131}UdR), a specific deoxyribonucleic acid (DNA) precursor, in the spleen. The relation between the I^{131}UdR uptake in the repopulated spleen and the number of marrow cells transplanted five days earlier was linear over a range from 0.5×10^5 to 16×10^5 normal cells. Curves identical in slope were obtained with marrow cells exposed in vitro to 50, 100, 200, and 400 r of 300-kvp x rays. From these data, an x-ray-dose—survival curve was obtained, which differs from the curves obtained by other methods in that it is of the one-hit type. The reason for this difference is, however, yet to be disclosed. The advantages of the present method for studying the proliferation of marrow cells, as influenced by irradiation or other factors, are as follows: (1) the recipient mouse is the natural medium for growth of transplanted marrow cells and need be maintained for only five days after inoculation, (2) I^{131}UdR labeling is specific for DNA of cells in S phase and, therefore, measures marrow cell proliferation directly, (3) five observations (i.e., five recipient mice) are adequate for reproducible assessment of the proliferative capacity of a given number of irradiated marrow cells, and (4) the method appears more sensitive to radiation than other techniques available heretofore.

Physiology of Blood Platelets. — Previous investigations suggested that young platelets are larger than the average size of platelets in a normal population and that they decrease in size as they age. Confirmation was sought by making rats platelet-deficient with platelet-specific antiserum and then measuring the volume of the newly formed platelets at intervals by use of a Coulter counter and size distribution plotter. The mean size of platelets collected two days after injection of platelet-specific antiserum was greater than that of a normal population; the size distribution was observed to return toward normal during a four-day period. Thus the suggestion was confirmed that young platelets produced under these circumstances are larger than the mean size and decrease in size with age.

Medium(Low)-Level Long-Term Effects of Radiation. — The labeled thymidine analogue iododeoxyuridine (I^{131}UdR), which is a specific DNA precursor, was used to assay cellular proliferation in vivo by scintillation counting of the I^{131} gamma rays emitted from newly synthesized DNA. Cellular multiplication and turnover were measured by injecting known amounts of I^{131}UdR into an animal and analyzing whole organs for radioactivity at various intervals after injection. Such determinations were made in young adult gnotobiotic (germ-free) and conventionally reared ND-2 (Lobund) random-bred mice to study cellular renewal in these animals and the dynamics of the lymphoid hypoplasia in the germ-free state. The preliminary data on germ-free mice indicate a significantly reduced proliferative activity in lymph nodes, as measured by DNA precursor incorporation, and to a lesser extent in the liver and bone marrow. In the spleen and thymus of the germ-free mice, I^{131}UdR incorporation was comparable with that occurring in conventionally reared mice. Judged by ability to repopulate the spleen on transplantation into lethally irradiated recipient mice, the marrow of germ-free donors possessed the same proliferative potential as the marrow from conventional donors. These data point to the importance of bacterial antigens and resulting immunological reactions in the physiology of normal lymphatic organs.

COMBATING DETRIMENTAL EFFECTS OF RADIATION

Mammalian Recovery. — There is evidence that all immune responses involve the induction of specific primitive cells with subsequent proliferation and differentiation. A most important problem is the origin and life history of these cells. This is true either with the clonal selection model, in which the primitive cells are previously committed, or with other existing models in which the cells are multipotent and uncommitted until induced by the antigen.

Histologic studies of lymphatic tissue of antigenically stimulated animals have indicated a relation between large, primitive lymphocytes proliferating in germinal centers and the primitive antibody-forming cells developing in the lymphatic nodule and medullary cords. These observations have more specifically demonstrated that the germinal centers are dissociated during the first 24 hr after injection of an antigen, and

that the cells of the dissociated germinal centers are rapidly proliferating and differentiating into recognizable members of the plasma cell series. Since the plasma cell is known to have the capacity to produce a specific antibody, the correlation has been made between the germinal center cells and the primitive antibody-forming cells associated with all immune responses.

By systematically following the H^3-thymidine-labeled germinal center cells at close intervals, evidence has been obtained regarding the activity and migration pattern of these cells in normal and antigenically stimulated animals. Data from autoradiographic studies demonstrated no significant difference between the primitive stem cells of the germinal centers and the morphologically identical cells in the lymphatic nodules of antigen-stimulated or control animals. The results indicate that the germinal center stem cells have a generation time of 5 to 7 hr, whereas the cells in the lymphatic nodule divide in about 9 hr.

A study of the percentage of labeled germinal center cells over a series of 2-hr intervals demonstrated a significant difference in the flux of cells in antigen-stimulated and control animals. It was also evident that another effect of the antigen is a stimulation for more mitotic activity in the germinal center and an increased migration of cells into the lymphatic nodule.

According to the autoradiographic investigations, the observed dissociation of germinal centers in the first 24 hr of the immune response can now be postulated as a direct or indirect disruption by the antigen of a steady-state compartment of primitive lymphoid stem cells. These cells then become localized throughout the spleen and undergo intense proliferation. On a morphologic and functional basis, there is no reason to doubt the existing correlation between the germinal center cells and the primitive, potential antibody-forming cells, which are a constant feature of the histology of the immune response.

MOLECULAR- AND CELLULAR-LEVEL STUDIES

Biophysics: Ultraviolet Studies with Bacteria. – If *Escherichia coli* B is exposed to near-ultraviolet radiation before exposure to far-ultraviolet radiation, it shows less sensitivity to the far ultraviolet. This is called photoprotection (because the near ultraviolet is given first), and it presumably involves induction of a growth and division delay. Recovery can also be obtained by giving the near ultraviolet after the far ultraviolet (photoreactivation), but this is primarily a photoenzymatic repair of far-ultraviolet damage. There is no obvious reason why the growth and division delay involved in photoprotection should not also be involved in photoreactivation. With a mutant (phr^-) isolated by W. Harm, photoreactivation has been found at 3341 A, but not at 4047 A. Knowledge of the action spectra for the two processes permits the conclusion that the photoreactivation observed with this mutant is of the growth and division delay type and not of the photoenzymatic-repair type. It is suggested that any cell that shows photoprotection will have a growth and division delay component in its photoreactivation.

Biophysics: Decay of Long-Lived Free Radicals. – Measurements of the rates of decay at different temperatures of the long-lived free radicals produced by x irradiation of glycine, alanine, glutamic acid, and glycylglycine are in progress. For glycine and alanine the data fit second-order kinetics better than first-order. This implies direct radical-radical recombination. For glutamic acid and glycylglycine the data to date fit first- or second-order kinetics about equally well. Measurements in the absence of oxygen indicate that the decay is not oxygen-dependent. Second-order kinetics can also be used to explain previously observed free-radical decay data in seeds and the seemingly more rapid decay in heavily irradiated amino acids, as compared with the same acids lightly irradiated.

Biophysics: Growth Curve of Salamanders. – Inspection of a recently published growth curve [Copeia 1, 119–30 (1963)] for the cave salamander, *Gyrinophilus palleucus*, reveals that the growth under optimal growth conditions without metamorphic changes can be accurately described by an equation of the form $L(t) = L_{max}(1 - e^{-Kt})$, where L is the length of the animal, t the age, and L_{max} and K empirically determined constants. A preliminary literature search has been begun to find whether this formulation has been given previously and whether this form is relatively common. Such a simple expression of growth should be amenable to a biophysical, mechanistic explanation.

CIVILIAN APPLICATIONS OF NUCLEAR EXPLOSIVES

Chemical Applications of Nuclear Explosions. – Leaching of the water-insoluble residue from a composite Gnome sample with hydrochloric acid gave almost the same solubility and percentage of activity leached that was found in previous leaching experiments with nitric acid. With 30 ml of acid per gram, 80% of the plutonium and total-rare-earth betas were leached, and 75% of the solid dissolved at hydrochloric acid concentrations of 1 to 6 N. By using only 6 ml of acid per gram, 60% of the plutonium and total rare earths were leached, and 50% of the original sample dissolved. Analyses for calcium and magnesium showed that nearly all the magnesium dissolved when 6 ml of acid was added for each gram of residue. However, the concentration of dissolved calcium showed a threefold increase when the acid-to-sample ratio was increased from 6 to 30 ml/g. Acid consumption was 15 meq/g. Glycolic acid was about 80% as effective as the equivalent concentration of hydrochloric or nitric acid for the leaching of plutonium and total-rare-earth beta activities.

OPEN LITERATURE PUBLICATIONS

Akimoto, Kazou, and W. A. Sibley, "Hardening of Potassium Chloride Single Crystals by Quenching and Irradiation," J. Appl. Phys. 34, 1767 (1963).

Anderson, N. G., "On the Origin of Life," p 1 in Lectures in Biological Sciences (ed. by J. I. Townsend), University of Tennessee Press, Knoxville, 1963.

Barnett, W. E., and F. J. de Serres, "Fixed Genetic Instability in Neurospora crassa," Genetics 48, 717 (1963).

Begun, G. M., and A. A. Palko, "Raman and Infrared Spectra of BF_3 Complexes with Diethyl Ether and Tetrahydrofuran, and the Isotopic Exchange of These Complexes with BF_3," J. Chem. Phys. 38, 2112 (1963).

Bollum, F. J., "'Primer' in DNA Polymerase Reactions," p 1 in Progress in Nucleic Acid Research, vol I (ed. by J. N. Davidson and W. E. Cohn), Academic Press, New York, 1963.

Bollum, F. J., and R. B. Setlow, "Ultraviolet Inactivation of Deoxyribonucleic Acid Primer Activity. I. Effects of Different Wavelengths and Doses," Biochim. et Biophys. Acta 68, 599 (1963).

Boom, R. W., L. D. Roberts, and R. S. Livingston, "Developments in Superconductor Solenoids," Nucl. Instr. Methods 20, 495 (1963).

Boyce, Richard, and R. B. Setlow, "The Action Spectra for Ultraviolet-Light Inactivation of Systems Containing 5-Bromouracil-Substituted Deoxyribonucleic Acid. I. Escherichia coli 15 $T^-A^-U^-$," Biochim. et Biophys. Acta 68, 446 (1963).

Carlson, T. A., "Electron Shake-off Following the Beta Decay of Ne^{23}," Phys. Rev. 130, 2361 (1963).

Cartledge, G. H., and D. H. Spahrbier, "Ion-Exchange Properties of the Film on Passive Iron and Steel," J. Electrochem. Soc. 110, 644 (1963).

Chu, E. H. Y., "Dose Relations in the Induction of Human Chromosome Aberrations," p 217 in Radiation-Induced Chromosome Aberrations (ed. by Sheldon Wolff), Columbia University Press, New York, 1963.

Congdon, C. C, and A. L. Kretchmar, "Increased Liver Weight in Bone Marrow Chimeras," Exptl. Mol. Pathol. 2, 277 (1963).

Conklin, J. W., A. C. Upton, K. W. Christenberry, and T. P. McDonald, "Comparative Late Somatic Effects of Some Radiomimetic Agents and X Rays," Radiation Res. 19, 156 (1963).

Crawford, J. H., Jr., "Investigations of Color Centers in Alkali Halides at Oak Ridge National Laboratory: Structure Sensitivity of Color Center Production in γ-Irradiated KCl," J. Phys. Soc. Japan 18 (suppl III), 329 (1963).

Deering, R. A., and R. B. Setlow, "Effects of Ultraviolet Light on Thymidine Dinucleotide and Polynucleotide," Biochim. et Biophys. Acta 68, 526 (1963).

Dent, J. N., and J. S. Kirby-Smith, "Metamorphic Physiology and Morphology of the Cave Salamander, Gyrinophilus palleucus," Copeia 1, 119 (1963).

Doherty, D. G., and Raymond Shapira, "Synthesis of D- and L-2-Aminobutylisothiourea Dihydrobromide Isomers and Their Conversion to Guanidothiols, Disulfides, and Thiazolines," J. Org. Chem. 28, 1339 (1963).

Federer, J. I., and T. S. Lundy, "Diffusion of Zr^{95} and Cb^{95} in Bcc Zirconium," Trans. AIME 227, 592 (1963).

Fisher, W. D., and G. B. Cline, "A Density Gradient for the Isolation of Metabolically Active Thymus Nuclei," Biochim. et Biophys. Acta 68, 640 (1963).

Gilbert, R. A., "Molar Enthalpies of Mixing in the Molten Lithium Fluoride—Potassium Fluoride System, J. Phys. Chem. 67, 1143 (1963).

Gill, J. S., and W. L. Marshall, "Glass-to-Metal Tube Connector for Visual Observation of the Effect of Pressure on Phase Equilibria," Rev. Sci. Instr. 34, 442 (1963).

Halperin, J., F. J. Johnston, R. W. Stoughton, J. H. Oliver, E. L. Blevins, R. E. Druschel, A. L. Harkness, and B. A. Swarz, "The Average Capture/Fission Ratio of U^{233} for Epithermal Neutrons," Nucl. Sci. Eng. 16, 245 (1963).

Harvey, J. A., and D. J. Hughes, "Neutrons," chap. 8H, pp 8—114 in American Institute of Physics Handbook, 2d ed., McGraw-Hill, New York, 1963.

Hodgson, G. S., "Radiosensitivity of Marrow Cells Responsible for Reestablishing Erythropoiesis in Lethally Irradiated Mice," Acta Physiol. Lat. Amer. 12, 365 (1962).

Hollaender, Alexander, "Acceptance Speech at University of Leeds (On Occasion of Conferment of Honorary Degrees, Doctor of Science honoris causa, to Louis Harold Gray, Alexander Hollaender, Alexander Mikhajlovich Kuzin, and Raymond Latarjet)," p vii in Radiation Effects in Physics, Chemistry, and Biology, Proceedings of the Second International Congress of Radiation Research, Harrogate, England, August 5—10, 1962 (ed. by Michael Ebert and Alma Howard), North-Holland Publishing Company, Amsterdam, 1963.

Jacobson, K. B., and S. Nishimura, "Paper Chromatography of Transfer Ribonucleic Acid on Diethylaminoethyl-Cellulose," Biochim. et Biophys. Acta 68, 490 (1963).

Kenney, F. T., "Immunochemical Analysis of the Induction of Tyrosine-α-ketoglutarate Transaminase in Rat Liver," Ann. N.Y. Acad. Sci. 103, 1083 (1963).

Khym, J. X., "The Use of Amines in Liquid-Liquid Extractions of Nucleic Acids and Related Compounds," Biochemistry 2, 401 (1963).

Kirby-Smith, J. S., "Effects of Combined UV and X Radiations on Chromosome Breakage in Tradescantia Pollen," p 203 in Radiation-Induced Chromosome Aberrations (ed. by Sheldon Wolff), Columbia University Press, New York, 1963.

Lietzke, M. H., "Generalized Least Squares and the Inversion of Symmetric Positive Definite Matrices," p 1 in Applications of Computers to Nuclear and Radiochemistry, NAS-NS 3107, National Academy of Sciences — National Research Council, Washington, D.C., 1963.

Lietzke, M. H., R. W. Stoughton, and Marjorie P. Lietzke, "A Mathematical Model for the Solvent Extraction of Uranyl Nitrate and Nitric Acid," Nucl. Sci. Eng. 16, 25 (1963).

Lindenbaum, S., and G. E. Boyd, "Spectrophotometric Investigation of the Extraction of Transition Metal Halo-complex Ions by Amine Extractants," J. Phys. Chem. 67, 1238 (1963).

Lindsley, D. L., "General Survey of Genetic Effects of Chromosomal Aberrations," p 273 in Radiation-Induced Chromosome Aberrations (ed. by Sheldon Wolff), Columbia University Press, New York, 1963.

Löbbecke, E. A., "Nitrogen Mustard Induced Mutation in Extracellular Bacteriophage," Genetics 48, 691 (1963).

Macklin, R. L., J. H. Gibbons, and T. Inada, "Neutron Capture Cross Sections near 30 kev Using a Moxon-Rae Detector," Nucl. Phys. 43, 353 (1963).

Marshall, W. L., Ruth Slusher, and F. J. Smith, "Aqueous Systems at High Temperature. IX. Investigations on the System Li_2SO_4-H_2SO_4-H_2O and Its D_2O Analogue, 200–470°C: Solubilities and Critical Phenomena," J. Inorg. Nucl. Chem. 25, 559 (1963).

Mason, E. A., R. B. Evans III, and G. M. Watson, "Gaseous Diffusion in Porous Media. III. Thermal Transpiration," J. Chem. Phys. 38, 1808 (1963).

McNally, J. R., and M. R. Skidmore, "Spectroscopic Line-Profile Studies of Long Magnetically Confined High-Current, Steady-State Vacuum Arcs," Appl. Opt. 2, 699 (1963).

Oakberg, E. F., "The Influence of Germ Cell Stage on Reproductive and Genetic Effects of Radiation in Mammals," Diseases Nervous System 24 (monograph suppl), 1 (1963).

Pawel, R. E., J. V. Cathcart, and J. J. Campbell, "Stress Generation in Tantalum During Oxidation," J. Electrochem. Soc. 110, 551 (1963).

Popp, R. A., "Hemoglobin Loci: Mice Classified for Their Hb and Sol Alleles," Science 140, 893 (1963).

Russell, Liane B., "Mammalian X-Chromosome Action: Inactivation Limited in Spread and in Region of Origin," Science 140, 976 (1963).

Rutenberg, A. C., "Xenon Fluorides: Fluorine-19 Nuclear Magnetic Resonance Spectra," Science 140, 993 (1963).

Schindler, A. I., and R. H. Kernohan, "The Interaction Between Irradiation-Induced Defects and Magnetic Structure," J. Phys. Soc. Japan 18 (suppl III), 314 (1963).

Setlow, R. B., and Richard Boyce, "The Action Spectra for Ultraviolet-Light Inactivation of Systems Containing 5-Bromouracil-Substituted Deoxyribonucleic Acid. II. Bacteriophage T4," Biochim. et Biophys. Acta 68, 455 (1963).

Silverman, M. D., B. O. Heston, and P. S. Rudolph, "Radiation Damage to Freon-11, CCl_3F," Nucl. Sci. Eng. 15, 217 (1963).

Snider, P. J., "Genetic Evidence for Nuclear Migration in Basidiomycetes," Genetics 48, 47 (1963).

Suu, Vu Thi, C. C Congdon, and A. L. Kretchmar, "Increase in Lysozyme Activity in Kidneys of Irradiation Chimeras," Proc. Soc. Exptl. Biol. Med. 113, 481 (1963).

Thompson, D. O., "Evidence for Vacancy Clustering in Dislocations in Copper as Measured by Internal Friction Techniques," J. Phys. Soc. Japan 18 (suppl I), 104 (1963).

Toth, K. S., and E. Newman, "Excitation Functions for Single-Nucleon Transfer Reactions Close to the Barrier," Phys. Rev. 130, 536 (1963).

Trammell, G. T., "Symmetry Function of the Cube," J. Math. Phys. 4, 431 (1963).

Troutner, D. E., R. L. Ferguson, and G. D. O'Kelley, "Yields and Half-Lives in the Mass-99 Fission Product Chain," Phys. Rev. 130, 1466 (1963).

Urso, Paul, and Takashi Makinodan, "The Roles of Cellular Division and Maturation in the Formation of Precipitating Antibody," J. Immunol. 90, 897 (1963).

Volkin, Elliot, and Drew Schwartz, "Nucleic Acid Metabolism of Germinating Corn Seedlings," Bull. Res. Council Israel (S. Hestrin Memorial Issue) 11, 387 (1963).

Walton, Derek, "Comment on 'Formation Conditions of Thin Epitaxial Germanium Films on Single Crystal Substrates' by Billy W. Sloope and Calvin O. Tiller," J. Appl. Phys. 34, 1827 (1963).

Walton, Derek, T. N. Rhodin, and R. W. Rollins, "Nucleation of Silver on Sodium Chloride," J. Chem. Phys. 38, 2698 (1963).

Wechsler, M. S., J. M. Williams, and H. M. Otte, "Atomic Rearrangements in Deformed Cu-Si and Cu-Si-Mn Alloys," J. Phys. Soc. Japan 18 (suppl II), 123 (1963).

Williams, Anna M., and F. J. Bollum, "Inhibition of Enzymatic DNA Synthesis by Certain Pathological Human Sera," Proc. Soc. Exptl. Biol. Med. 112, 701 (1963).

Wolff, Sheldon, "Extended Comments to Paper by H. J. Evans: Chromosome Aberrations and Target Theory," p 8 in Radiation-Induced Chromosome Aberrations (ed. by Sheldon Wolff), Columbia University Press, New York, 1963.

Wust, C. J., "Interference with Antibody Neutralization by Coenzyme and Reducing Agents," Ann. N.Y. Acad. Sci. 103, 849 (1963).

Wust, C. J., and G. D. Novelli, "Ribonucleoprotein-Bound Antibody to the Enzyme Triose Phosphate Dehydrogenase," J. Immunol. 90, 734 (1963).

Young, F. W., Jr., "Etch Pit Studies of Dislocations in Copper Crystals Deformed by Bending: I. Annealed Crystals; II. Irradiated Crystals," J. Phys. Soc. Japan 18 (suppl I), 1 (1963).

Zucker, A., and A. H. Snell, "Meson Factories," Phys. Today 16, 19 (1963).

FOREIGN VISITORS

Name	Affiliation	Citizen of
Allen, D. C.	University of Sydney	Australia
Baetsle, L. H.	Belgian Nuclear Center	Belgium
Bisset, I. J.	Australian Embassy	Australia
Cartwright, H.	United Kingdom Atomic Energy Authority	United Kingdom
Casanovas, J.	Dominican Government	Dominican Republic
Chavy, P. P.	Control Data Corporation	France
Daguerre, A.	Goverment of Senegal	Senegal
Demildt, A. C.	Belgian Atomic Energy Commission	Belgium
Espinal, J. A.	Dominican Government	Dominican Republic
Franck, E. U.	Institut fur Physikalische Chemie und Elektrochemie	Germany
Frisby, H. J.	French C. E. A.	France
Grisolia, C.	Dominican Government	Dominican Republic
Gross, B.	International Atomic Energy Agency	Brazil
Hamelin, R. A.	Embassy of France	France
Hansford, R. N.	United Kingdom Atomic Energy Authority	United Kingdom
Hellwege, A. M.	Lendold-Bolnvernstien Institute	Germany
Isihara, A.	Polytechnic Institute of Brooklyn	Japan
Kawai, M.	University of Pittsburgh	Japan
Kley, W.	EURATOM	Germany
Kloots, J.	Florida State University	Netherlands
Kothari, L. S.	Brookhaven National Laboratory	India
Larsson, B.	University of Uppsala	Sweden
Liu, C. F.	University of Michigan	China
Miles, G. L.	Australian Embassy	Australia
Moore, A. J.	University of Melbourne	Australia
Peirson, D. E. H.	United Kingdom Atomic Energy Authority	United Kingdom

Name	Affiliation	Citizen of
Ramirez, M. A.	Dominican Government	Dominican Republic
Roberts, M.	Conseiller Technique du Service National de la Protection Civile	France
Ruffilli, D.	University of Rome, Italy	Italy
Sanders, P.	ORTEC	Great Britain
Steinmann, W.	University of Southern California	Germany
Stephenson, J.	British Embassy	Great Britain
Williams, T.	University of Tennessee	United Kingdom

Reports issued in this series during the past year:

July 1962	ORNL-3331
August 1962	ORNL-3351
September 1962	ORNL-3368
October 1962	ORNL-3377
November 1962	ORNL-3388
December 1962	ORNL-3402
January 1963	ORNL-3410
February 1963	ORNL-3426
March 1963	ORNL-3436
April 1963	ORNL-3451
May 1963	ORNL-3462
June 1963	ORNL-3477

ORNL-3491
C-44a — Nuclear Technology — Materials
M-3679 (30th ed.)

INTERNAL DISTRIBUTION

1. I. Alexeff
2. C. F. Baes
3. E. A. Bagley
4. P. S. Baker
5. C. R. Baldock
6. L. H. Barker
7. S. E. Beall
8. E. E. Beauchamp
9. P. R. Bell
10. D. S. Billington
11. C. A. Blake
12. R. E. Blanco
13. F. F. Blankenship
14. E. P. Blizard
15. J. O. Blomeke
16. A. L. Boch
17. E. G. Bohlmann
18. C. J. Borkowski
19. G. E. Boyd
20. M. A. Bredig
21. J. C. Bresee
22. R. B. Briggs
23. R. E. Brooksbank
24. K. B. Brown
25. F. R. Bruce
26. W. D. Burch
27. T. H. J. Burnett
28. A. D. Callihan
29. A. E. Cameron
30. T. E. Cole
31. C. F. Coleman
32. E. L. Compere
33. D. D. Cowen
34. J. A. Cox
35. F. L. Culler
36. J. E. Cunningham
37. R. A. Dandl
38. J. S. Drury
39. J. L. Dunlap
40. A. C. England
41. M. F. Fair
42. D. E. Ferguson
43-46. J. L. Fowler
47. J. H. Frye, Jr.
48. J. L. Gabbard (K-25)
49. W. F. Gauster
50. J. H. Gillette
51. W. Y. Gissel
52. H. E. Goeller
53. C. D. Goodman
54. A. T. Gresky
55. J. C. Griess
56. W. R. Grimes
57. P. A. Haas
58. C. S. Harrill
59. J. C. Hart
60. M. R. Hill
61. C. J. Hochanadel
62. A. Hollaender
63. L. B. Holland
64. R. W. Horton
65. F. T. Howard
66. A. S. Householder
67. H. H. Hubbell
68. G. S. Hurst
69. G. H. Jenks
70. R. W. Johnson
71. R. J. Jones
72. W. H. Jordan
73. P. R. Kasten
74. G. W. Keilholtz
75. G. G. Kelley
76. M. T. Kelley
77. E. M. King
78. K. A. Kraus
79. Laboratory Shift Supervisor
80. J. A. Lane
81. D. M. Lang (K-25)
82. C. E. Larson
83. C. F. Leitten, Jr.
84. R. E. Leuze
85. T. A. Lincoln
86. S. C. Lind
87. R. B. Lindauer
88. R. S. Livingston
89. J. T. Long
90. L. O. Love
91. R. N. Lyon
92. H. G. MacPherson
93. F. C. Maienschein
94. W. D. Manly
95. J. A. Martin

96. H. F. McDuffie
97. J. R. McNally
98. R. A. McNees
99. A. J. Miller
100. E. C. Miller
101. K. Z. Morgan
102. W. L. Morgan
103. E. J. Murphy
104. J. P. Murray (K-25)
105. R. V. Neidigh
106. M. L. Nelson
107. G. W. Parker
108. R. B. Parker
109. P. Patriarca
110. J. J. Pinajian
111. M. E. Ramsey
112. A. W. Riikola
113. L. P. Riordan
114. A. F. Rupp
115. A. D. Ryon
116. H. C. Savage
117. H. W. Savage
118. A. W. Savolainen
119. H. E. Seagren
120. C. H. Secoy
121. E. D. Shipley
122. O. Sisman
123. J. R. Sites
124. M. J. Skinner
125. A. H. Snell
126. W. S. Snyder
127. W. L. Stirling
128. R. W. Stoughton
129. H. Stringfield
130. E. G. Struxness
131. J. C. Suddath
132. W. H Sullivan
133. C. D. Susano
134. J. A. Swartout
135. E. H. Taylor
136. R. E. Thoma
137. C. D. Watson
138. B. S. Weaver
139. M. S. Wechsler
140. A. M. Weinberg
141. M. E. Whatley
142. J. C. White
143. E. O. Wollan
144. R. W. Worsham
145. R. G. Wymer
146. Gale Young
147. W. Zobel
148. A. Zucker
149-150. Central Research Library
151-152. ORNL - Y-12 Technical Library Document Reference Section
153. Reactor Division Library
154. Biology Library
155-345. Laboratory Records Department
346. Laboratory Records, ORNL R.C.

EXTERNAL DISTRIBUTION

347. Division of Reactor Development, AEC, Washington (J. M. Simmons)
348-356. Research and Development Division, AEC, ORO
357. Aeroprojects, Inc. (W. B. Tarpley)
358. Allis-Chalmers Manufacturing Co. (W. F. Banks)
359-361. Ames Laboratory, Iowa State College (F. H. Spedding)
362-364. Argonne National Laboratory (A. V. Crewe)
365. Atomics International (H. Pearlman)
366. Babcock and Wilcox Co. (Atomic Energy Division)
367-368. Battelle Memorial Institute (H. W. Russell)
369-371. Brookhaven National Laboratory (M. Goldhaber)
372. Bureau of Mines, Salt Lake City (J. B. Clemmer)
373-380. General Atomic (General Dynamics Corp.) (Manager)
381-382. General Nuclear Engineering Corp. (J. West)
383. Grand Junction Operations Office (W. C. Hutchinson, Jr.)
384-385. Idaho Chemical Processing Plant (R. L. Doan)
386. Kaiser Engineers (P. D. Bush)
387-388. Knolls Atomic Power Laboratory (K. R. Van Tassell)
389-390. Lawrence Radiation Laboratory (H. Fidler)

391-392. Los Alamos Scientific Laboratory (N. E. Bradbury)
393-394. National Bureau of Standards (L. S. Taylor)
395. National Lead Company (C. K. McArthur)
396. Nuclear Metals, Inc. (A. R. Kaufmann)
397-398. Philadelphia Electric Co. (L. R. Gaty)
399. Sanderson and Porter (Atomic Energy Division)
400. Union Carbide Corporation (R. W. McNamee)
401. USAEC, Assistant General Manager (S. G. English)
402. USAEC, Division of Biology and Medicine (C. L. Dunham)
403-405. USAEC, Division of Isotope Development (P. C. Aebersold)
406. USAEC, Division of Production (F. P. Baranowski)
407. USAEC, Division of Raw Materials (J. C. Johnson)
408-422. USAEC, Division of Reactor Development (F. K. Pittman)
423-428. USAEC, Division of Research (P. W. McDaniel)
429. USAEC, Division of Technical Information (Technical Reports Library)
430-431. USAEC, Chicago Operations Office
432. USAEC, Lockland Aircraft Reactors Operations Office (H. H. Gorman)
433-434. USAEC, San Francisco Operations Office (R. Hughey)
435-436. USAEC, Savannah River Operations Office (H. Rahner)
437. Westinghouse Electric Corp. (A. Squire)
438-694. Given distribution as shown in M-3679 (30th ed.) category C-44a and those addresses shown in C-44b, C-44c, and C-44d, which do not receive copies under C-44a