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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

JANUARY 1963

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OAK RIDGE NATIONAL LABORATORY

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Oak Ridge, Tennessee
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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

JANUARY 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 PROGRAM

GAS-COOLED REACTOR PROGRAM

Evaluation of Material for Primary Nozzles of Pneumatic Temperature-Measurement Devices for the EGCR. — Four samples of type 304 stainless steel to be used for the primary nozzles of the pneumatic temperature-measurement devices at the EGCR gas outlets were nitrided, and the prepared surfaces were cut back by centerless grinding to expose varying depths of nitride coating. After the samples had been exposed to impure helium for 1000 hr at 1050°F, it was observed that nitriding had decreased the oxidation resistance of the type 304 stainless steel in direct relation to the thickness of the nitride layer.

UO_2 Fission-Gas Release Studies. — EGCR fuel bushings fabricated from virgin UO_2 to bulk densities of 10.4 to 10.44 g/cm^3 were irradiated for a study of fission-gas retention. The bushings had very fine-grained structures and essentially no open porosity. After irradiation the samples were heated for 24 hr at 1400°C in vacuum, and the amount of Xe^{133} released was monitored continuously. The low xenon release values obtained may be interpreted to mean that the rates of fission-gas release in the EGCR fuel rods will be approximately 1/50 as high as those assumed for design calculations.

GCR-ORR Loop No. 1. — The fuel element with a roughened surface that was installed in GCR-ORR loop No. 1 last month has operated satisfactorily for one complete reactor cycle. Data from this element, together with data from two previously tested elements, one of which had a roughened surface and the other a smooth surface, indicate that the roughened surface definitely improves heat transfer under loop conditions. Additional tests are being planned to provide a better basis for extrapolation of performance data for roughened-surface elements to reactor operating conditions by increasing the heat generation rate from present test values of 40,000 to 45,000 Btu/hr per foot of length to 60,000 to 70,000.

GCR-ORR Loop No. 2. — Preparations were made for in-pile installation of GCR-ORR loop No. 2, and startup and emergency operating procedures were

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prepared. Procedures for the decontamination and maintenance of the regenerative compressors are being prepared. Design of the complete fuel holder assembly, including the fission product deposition equipment, was completed. The fabrication schedule is being paced to meet the test requirements of the loop.

LITR Capsule Irradiations. — The third capsule in the LITR high-temperature UO_2 irradiation test series was irradiated for a scheduled period of 19 hr. The initial operating temperature was beyond the calibration range for the thermocouples but is estimated to have been between 4200 and 4500°F. After 3 hr of irradiation, the temperature had decreased to approximately 4000°F, and it then remained constant for the remainder of the test. A fourth high-temperature irradiation capsule was inserted, after removal of the short-term capsule; it is to be irradiated for three months to a burnup of 7000 Mwd per metric ton of UO_2. The two capsules tested previously were irradiated for one week and one month; all capsules have been irradiated at approximately the same temperatures.

ORR Capsule Irradiations. — The capsules installed in the ORR last month have been irradiated for one ORR cycle. The fueled-graphite balls with cylindrical coated-particle uranium carbide inserts have had low fission-gas release rates throughout the cycle. The fuel temperatures have been increased progressively from 1000 to 1400°F by moving the capsule to positions of higher flux and increasing the power. The present ratio of release rate to birth rate is $\sim 10^{-5}$ at the high-power position. Vendor-made EGCR fuel elements have operated satisfactorily with no apparent fission-gas leakage.

Instantaneous Fission-Gas Release from Coated Particles. — Capsule B9-9, containing pyrolytic-carbon-coated uranium carbide particles, was irradiated to 18.6 at. % uranium burnup. The capsule was irradiated at 800, 1200, 1600, and 1740°F. The fission-gas release rates showed a definite temperature dependence at 1600 and 1740°F but did not increase with uranium burnup at any operating temperature. At 1600°F, small bursts of activity were released at irregular intervals. These bursts are believed to indicate the rupture of the coating of a single particle. The maximum fission-gas release rates were produced at 1740°F. The average fractional fission-gas release rates at 1740°F were: Kr^{85m}, 1.7×10^{-4}; Kr^{87}, 8.3×10^{-5}; Kr^{88}, 1.1×10^{-4}; Xe^{133}, 3.7×10^{-4}; and Xe^{135}, 9.0×10^{-5}. These release rates represent an increase by a factor of 5 to 13 over the release rates at 800°F.

Fabrication of Pyrolytic-Carbon-Coated Particles. — Glossy, unagglomerated, pyrolytic-carbon-coated particles were successfully fabricated by use of a fluidized-bed technique. Angular 200- to 300-μ particles were coated at 1400°C, using undiluted methane at 200 mm Hg. Microscopic examination revealed a smooth glossy coating with from 1 to 5% agglomerates. Microradiography indicated that the coatings were quite uniform and averaged 115 μ in thickness. Metallography revealed the coating structure to be both laminar and columnar, with the apparent columnar structure decreasing from the inner surface to the outer surface.

Chlorination of Coated Particles. — Equipment was assembled to permit surface treatment of coated particles with mixtures of chlorine and argon

at temperatures up to 1000°C. Coated particles with fuel contamination assumed to be on the coating surface were swept with a 25 to 40 vol % chlorine-argon mixture for 3 hr at 800°C. Radiographic examination revealed that the high-density contamination was completely removed without deleterious side effects.

Fission Product Poisoning. — A study was made to determine the dependence of higher-order fission product poisoning (i.e., neutron capture in nuclides themselves produced by neutron capture in other fission products) on such variables as fractional fuel burnup, fuel specific power, and the spectrum of neutrons producing fission. Attention was concentrated on 16 nuclides in the mass range from Nd^{145} to Eu^{155}. It was found that secondary captures may be nearly as important as captures in primary fission products, in the mass range indicated, under conditions of interest in many reactors (e.g., 1 to 1.5 fissions per initial fissile atom, 0.5 to 2 Mw per kg of fissile material, 30% epithermal fissions). Captures in Sm^{149} produced from Nd^{147} may nearly equal those from Sm^{149} produced by decay of primary Pm^{149}. Primary captures for Nd^{147} (in nuclide Pm^{147}) are very important, and for long fuel life may be almost identical with the total captures in Sm^{149}. The majority of captures in nuclides from Sm^{151} through Eu^{155} are secondary. These results confirm the necessity for including the effects of higher-order poisoning in fuel-cycle calculations and identify the most important nuclides.

Fuel Loadings for AVR Reactor. — In view of the possibility that the AEC may supply coated-particle fuel elements for the AVR (German pebble-bed reactor), calculations were made to examine the several possible fuel-loading schedules being considered. In every instance, it was assumed that thorium, as well as enriched uranium, would be incorporated in the initial fuel balls and that the combined weight of thorium and uranium would be 5% of the weight of the balls. Two main approaches to the fueling program were considered: (1) loading a fraction of the core (e.g., one-third) with fueled balls and the remainder with nonfueled balls; (2) loading a fraction of the core with fueled balls, as in case (1), and then adjusting the thorium-to-uranium ratio so that there would be no excess reactivity. In the first program, the thorium-to-uranium ratio would be chosen to provide sufficient excess reactivity for some specified period of operation. The excess reactivity would be offset by poison balls included among the nonfueled balls, and these would be removed from the core at a rate required to maintain criticality. In the second program, criticality would be maintained by replacement of nonfueled balls with additional fueled balls. For this case, it was assumed that the replacement balls would have the same amount of uranium as the initial fuel balls, but various amounts of thorium were considered.

STUDIES AND EVALUATIONS

Reactor Evaluation Studies. — A study was made of the amounts of Np^{237} and Pu^{238} which would be produced in Dresden- and Yankee-type reactors. It was found that only small amounts of Pu^{238} would be formed

during initial exposure of the fuel; the fuel-cycle credit associated with the Pu^{238} valued at $500/g was less than 0.05 mill/kwhr (electrical) for typical conditions and fuel exposures. In addition, such Pu^{238} would constitute less than 2% of the plutonium formed in low-enrichment systems. At the same time, the amount of Np^{237} formed would be more than five times the quantity of Pu^{238}. The value of Np^{237} can be appreciable, since it is an excellent source material for Pu^{238}. Assumption of a credit of $150/g for the Np^{237} produced in present-generation reactors would reduce fuel costs by 0.3 to 0.4 mill/kwhr (electrical), and would increase the fuel enrichment associated with minimum fuel costs, relative to that associated with zero credit for the Np^{237}.

The potential uranium utilization in natural-uranium, heavy-water reactors was studied in a CANDU-type system, considering countercurrent fueling and recycle of bred plutonium. If plutonium produced in a given cycle of a CANDU reactor were utilized with natural uranium in the subsequent cycle, the equilibrium reactivity lifetime would be about 16,000 Mwd (thermal) per ton of natural uranium, if recycle plutonium were kept separate from bred plutonium. On the same bases, but removing fission products after every exposure of 4000 Mwd/ton, the equilibrium fuel exposure would be about 20,000 Mwd (thermal) per ton of natural uranium.

REACTOR FUELS AND MATERIALS DEVELOPMENT

Nondestructive Test Development. — Development has continued on the new phase-sensitive eddy-current instrument. The system was originally designed to perform phase-shift measurements on an electromagnetic wave passing through a conductor. Such through-transmission measurements have been made on stainless steel as thick as 1/2 in. The phase change is linear with thickness variation and there is relatively little phase change associated with differences in coil-to-specimen spacing.

For many tests, a large thickness range and excellent linearity are not necessary; in addition, only one side of the conductor may be accessible. For these reasons, a technique has been developed to measure the phase shift of the reflected wave. The coil system consists of a large driving coil to generate the field and two small pickup coils. The pickup coils are positioned coaxially with and at either end of the drive coil. Precision positional adjustment is made so that the voltage difference of the small identical coils is zero with the coils in air, and equal to the reflected field with the driving coil on a conductor. The phase shift is a nonlinear function of thickness, and the range is considerably less than that for through transmission. However, measurements may still be performed with relative insensitivity to liftoff.

Single-sided phase measurements have been performed on stainless steel and Zircaloy tubing, on graphite rods, and on Al-U_3O_8 fuel plates. Through-transmission measurements have been performed on the Fermi core B fuel element, on stainless steel tapered tubing, and on finned beryllium tubing. These phase measurements have proven to be accurate and may be rapidly performed.

Mechanical Properties. — The compatibility of stainless steel with gaseous environments has been investigated at ORNL and several other laboratories during the past few years. This work has revealed that some stainless steels, type 304 in particular, are carburized when exposed at elevated temperatures to CO_2. However, iron is decarburized when similarly exposed, and not all stainless steels exposed to CO_2 are carburized. In investigations to determine what alloying constituents or combination of alloying constituents are necessary to cause carburization of iron-base alloys, preliminary studies indicated that chromium content was related to carburization. Iron alloys containing 1 to 10 wt % Cr were carburized in CO_2, and the degree of carburization increased with increasing chromium. These studies have been expanded to include a wider range of chromium content. Laboratory heats of Fe—9% Ni—Cr alloys were prepared containing chromium in the range 7 to 28%.

Experiments with these alloys reveal several significant facts:

1. The Fe—9% Ni—28% Cr alloy exposed in CO_2 at 815°C for 1000 hr did not carburize.

2. A 1000-hr exposure of the Fe—9% Ni—20% Cr alloy in CO_2 at 815°C resulted in carburization, but the alloy was not carburized after 1000 hr at 775°C.

3. Alloys containing less than 20 wt % Cr carburized at all temperature levels between 600 and 815°C for the 1000-hr treatment.

4. The magnitude of the carburization increases with increasing chromium up to a maximum at 11% Cr. Increases in chromium content above the 11% level decrease the magnitude of the carburization for a given temperature and exposure time.

In general, the amount of carburization increased as the degree of oxidation increased for these Fe-Cr-Ni alloys. It is postulated that increasing the chromium content of the alloy increases the carburization potential of the material but that the kinetics of the carburization reaction are related to the oxidation process. Since the oxidation kinetics are decreased by increasing the chromium content, longer times or higher temperatures are required to carburize the alloys containing chromium contents greater than 20 wt %. One can postulate further that minor constituents in a given heat of material that decrease the rate of oxidation may also result in decreased carburization.

Solid Reaction Studies. — The radioisotope V^{48}, produced by proton bombardment of a scandium target in the ORNL 86-Inch Cyclotron, was used to determine self-diffusion coefficients in single crystals of vanadium over the range 1000 to 1890°C. These coefficients were found to vary from 2.9×10^{-13} to 3.6×10^{-8} cm^2/sec for the temperatures studied. Their temperature dependence could not be described in terms of the Arrhenius-type equation with constant frequency factor and activation energy.

Materials Compatibility Studies. — Further studies on the equilibrium distribution of oxygen between niobium and potassium have been hampered by lack of confidence in the accuracy of the mercury amalgamation method for determining the oxygen concentration of potassium. An indirect procedure was developed to determine oxygen in potassium which involves the double gettering of potassium at 815°C with separate zirconium foils and analyzing for oxygen in zirconium by vacuum fusion analyses. It is assumed that the distribution coefficient for oxygen in the K-O-Zr system

is constant at 815°C. Since relatively large amounts of oxygen are usually added to the potassium before equilibrating the niobium specimen with potassium, the pretest oxygen concentration of the potassium can be calculated accurately.

This procedure was used to determine the initial oxygen concentration in potassium, and the following values of the distribution coefficient were obtained in six individual experiments after equilibration with niobium samples for 100 hr at 815°C: 0.1, 0.005, 0.025, 0.13, 0.21, and 0.25. Initial oxygen concentrations in the niobium specimens varied from 360 to 1300 ppm; the oxygen concentrations in the potassium varied from 125 to 1225 ppm.

Fuel Element Development. — Fabrication development was initiated to incorporate large, UO_2-ThO_2 fuel particles in high-density BeO matrices. Efforts were directed primarily toward producing a high-density, solid-solution, spheroidal fuel particle with shrinkage characteristics compatible with BeO matrices.

A UO_2-ThO_2 sol-gel product prepared by the Chemical Technology Division was selected as the most promising starting material, based on a comparative evaluation of UO_2-ThO_2 mechanical mixtures of sinterable powders and UO_2-ThO_2 powders from coprecipitation processes. The sol-gel product becomes essentially a homogeneous $(U,Th)O_2$ solid solution and attains a density of 98 to 99% of theoretical on heating to 1100°C in air. It has a linear shrinkage of approximately 25%, which is compatible with the shrinkage of BeO matrices. Because of its hard, brittle nature, however, the sol-gel material could not be spheroidized by the air-tumbling process (ORNL-3307, p 3) developed for spheroidizing powder granules.

A method was developed for spheroidizing the sol-gel product, based on its characteristic solubility in water in the as-dried condition. The method consists of drying the gel at 80°C, crushing the cake formed to yield granules of a given sieve-size fraction, moistening the granules with an alcohol-water mixture, then tumbling in a closed cylindrical container for approximately 16 hr. Spheroidizing is achieved by the tumbling action of the granules during a controlled dissolving action of the alcohol-water mixture on the granules.

Fuel loadings up to 30 vol % of 150-μ $(U,Th)O_2$ solid-solution spheroidal particles were successfully incorporated in BeO matrices by cold pressing and sintering at 1750°C in hydrogen. Bulk densities of 94% of theoretical for the composite bodies were obtained.

POWER REACTOR FUEL PROCESSING

Mechanical Processing of Fuels. — Work on the chop-leach process for metal-clad oxide and alloy fuels is continuing. The 250-ton shear was out of service during the report period in order that a single-rod shear attachment for shearing sodium- or NaK-bonded fuel could be installed.

Bench-scale leaching tests were made on stainless-steel-clad pieces of ThO_2-UO_2 fuel sheared to 1/2-in. lengths. Contacting of the fuel in a recirculating batch of 12 M HNO_3–0.04 M NaF–0.10 M $Al(NO_3)_3$ dissolver solution resulted in dissolution of only 35% of the ThO_2-UO_2 in 7 hr. The

large amount of ThO_2-UO_2 powder dislodged during shearing (about 90% of the total ThO_2-UO_2) was wet by the acid only at the bed surface. Therefore, the percentage of the oxide surface area available for reaction at any time was very small. Means of improving the contact between ThO_2-UO_2 powder and the dissolvent are being investigated.

Hydrolysis of Uranium Carbides. — Hydrolysis tests were made on samples of uranium sesquicarbide having a composition of $UC_{1.48}$. The samples, which were heat-treated at 1600°C, were nearly single phase according to x-ray analysis but showed a fair amount of secondary phases under the microscope. On hydrolysis between 40 and 99°C, this material yielded 61 ml (STP) of gas per gram of carbide. The gas consisted of 58% hydrogen, 2% methane, 26% ethane, 5% C_3 to C_8 alkanes, 7% alkenes, 0.5% alkynes, and 1% unidentified species. Of the carbon in the sample, 50% was found in the gas and 11% in a water-insoluble wax. The reaction was not affected by temperature.

Protactinium Adsorption. — Tests were continued on the adsorption of protactinium on inorganic adsorbing media. A column of unfired Vycor glass 1 cm in diameter and 8.64 cm long adsorbed 5 mg of Pa^{231} per gram of glass from a solution that was 0.5 M in thorium, 11.1 N in HNO_3, 0.074 M in aluminum, about 0.03 M in F, and had a Pa^{231} concentration of 54 mg/liter. The solution was passed through the column at 0.22 ml cm^{-2} min^{-1} until the protactinium concentration in the emerging raffinate rose from 4 to about 10% of the concentration in the feed. Ninety-five percent of the protactinium was adsorbed on the column.

Chloride Volatility Process. — The chloride volatility process involves the chlorination of various reactor fuels at 300 to 600°C to produce uranium and fuel-diluent chlorides. With many fuels the chlorides of the diluent metal volatilized more readily than the uranium chlorides, and a partial separation of the two was achieved.

A calculation was made in order to determine the maximum internal temperature in an MTR fuel element at steady state during hydrochlorination. The calculation was made on the IBM 7090 computer with the GHTR code. The calculated temperature was 1120°C. Heat transfer by both radiation and conduction in a fuel element of infinite length was considered. A uniform surface reaction rate of 1.2 mg cm^{-2} min^{-1} (12 mils/hr) was assumed; this rate would lead to complete reaction of the fuel plates in 5 hr and of the side plates in 15 hr. Although the simplifying assumptions cast some doubt on the results, a temperature of 1120°C, which is about 500°C above the melting point of the fuel, leaves little doubt that the inside of the fuel would melt. This calculation will be repeated, and a reaction rate of 0.6 mg cm^{-2} min^{-1}, half the rate used in the first problem, will be assumed.

Two experiments were run to determine whether CO reduces the higher-valence uranium chlorides to a lower valence state. The experiments indicated that CO effectively reduces uranium chlorides at 300°C and that the reduction occurs either in the gas phase or during the recondensation.

The starting material was prepared by treating moderately pure UCl_4 with 15% CCl_4—Cl_2 vapor at 450°C and collecting the volatile product, which was assumed to be pure UCl_6, at 25°C. Specifically, the experiments were performed in order to compare the valence of the uranium chloride

volatilized by treating UCl_6 at 300°C in a stream of argon and in a stream of CO. The products were collected at the cool exit of the tube, which was at approximately 25°C. The respective Cl/U ratios in the residues after argon or CO was used were 4.07 and 4.08; in the recondensed product the respective ratios were 6.54 and 2.69. Accordingly, the uranium chloride that volatilized in argon was UCl_6, with some adsorbed chloride, while the uranium chloride that volatilized in CO had been reduced below the trivalent state. The argon volatilized about 1% of the uranium in the UCl_6 sample, while the CO volatilized about 2%. There was no indication that the CO reduced the uranium chloride that remained in the residue, since with both CO and argon the UCl_6 disproportionated to form UCl_4.

Solvent Extraction. — Development of the solvent extraction process for the BNL Kilorod Program was continued. The complexing ratio of di-sec-butylphenyl phosphonate (DSBPP) to uranyl nitrate was found to be 2:1; therefore, extraction is similar to that with tributyl phosphate. The maximum concentration of uranium in 2.5 vol % DSBPP in diethylbenzene is about 12 g/liter.

Fluoride Volatility Processing: $2KF-ZrF_4$. — Dissolution-hydrofluorination rates for aluminum in a second fused-salt system, $2LiF-BeF_2$, were determined for comparison with similar rates in the $2KF-ZrF_4$ system (ORNL-3388, p 24) as the basis for reprocessing Al-U alloy fuel. Penetration rates of 15.5, 13.9, 10.4, and 5.7 mils/hr were obtained at 625°C at AlF_3 concentrations of 0, 6, 12, and 18 mole % respectively. This system closely resembles the $2KF-ZrF_4$ system, in that the increasing concentration of "acidic" fluorides, AlF_3 plus either ZrF_4 or BeF_2, leads to decreasing reaction rates. When this concentration is about 20 to 25 mole % in either of the two systems, the penetration rates appear to decrease to the minimum practicable rate of 3 to 5 mils/hr for single coupons.

As a further check on the suitability of the $2KF-ZrF_4$ system for dissolving aluminum with HF, Battelle Memorial Institute found that INOR-8 and alloy 79-4 (Ni-Mo-Fe, 79-4-16 wt %) were corroded only very slightly at 600°C. At AlF_3 concentrations between 4.8 and 15 mole %, maximum corrosion rates were 0.16 and 0.77 mil/month for INOR-8 and alloy 79-4 respectively. The salt-phase rate for TD nickel (2% ThO_2 dispersed in nickel) was 0.57 mil/month, compared with 0.02 mil/month for INOR-8. Type 1100 aluminum was dissolved at 3.6 mils/hr at an AlF_3 concentration of 4.8 mole %, dropping to 0.3 mil/hr at 15 mole %. (These rates are lower than previously reported rates for single coupons. Multiple coupons react inefficiently, due to the stacking and consequent covering of surfaces.) Results are summarized in memorandum BMI-X-215.

Fluoride Volatility Processing: Retention of TeF_6. — Work was done to determine whether TeF_6 generated in the fused-salt—volatility process would be adequately absorbed, in the fluorine disposal system, to prevent release to the atmosphere. Preliminary results indicate that some absorption occurs in the 10% KOH solution used for fluorine disposal, particularly if a warm solution is used. However, the accuracy in this work was low, due to use of low concentrations of TeF_6, and there was some doubt as to the valence state of the tellurium transferred to the absorption system in the fluorine stream.

Fluoride Volatility Processing: Phase Equilibrium Studies. — An investigation of liquid-solid equilibria in the system $LiF-KF-AlF_3$ was initiated in search of suitable solvents for use in the dissolution of aluminum-based spent fuel elements by HF. Selection of LiF-KF as a solvent for AlF_3 was made on the basis that rates of dissolution of aluminum by HF are expected to be more rapid than those obtained using mixtures of $LiF-BeF_2$ or $KF-ZrF_4$ (ORNL-3388, p 24). Liquidus values of compositions along the section $KF \cdot AlF_3-LiF$, determined by visual polythermal analysis, rise from 518 to 629° through the entire LiF concentration range, 10 to 60 mole %, indicating that liquidus temperatures in the ternary system $LiF-KF-AlF_3$ are sufficiently low that LiF-KF mixtures have potential use as economical solvents for dissolution of aluminum-based fuel elements.

Fluoride Volatility Processing: Corrosion. — Memorandum BMI-X-213 (Dec. 5, 1962) presents the results of two experiments to determine the corrosion resistance of INOR-8, alloy 79-4, and several experimental nickel-base alloys in $NaF-LiF-BeF_2$ (50.5-37.0-12.5 mole %) and in $NaF-LiF-ZrF_4$ (37.5-37.5-25 mole %) in the presence of HF at 650°C, with no metal dissolution (ORNL-3368, p 11, and ORNL-3388, p 12).

Fluoride Volatility Pilot Plant. — The section of the dissolver that had leaked (ORNL-3388, p 12) was examined metallographically. The major cracks were thought to have been of external origin and related to metal preparation and attachment of the two thermocouple beads. Regularly spaced internal horizontal cracks as much as 40 mils deep were found at several locations in the lower section. No such cracks were observed in a ring of metal between the upper girth weld in the section removed and the cut severing the removed section. This ring of metal should be typical of the remaining lower section of the dissolver. Chemical analyses are being made in an attempt to determine whether the section of the vessel that failed had been made from a known substandard heat of INOR-8.

The two 4-in.-diam disks removed from the fluorinator were examined by Battelle Memorial Institute personnel. The customary L-nickel intergranular attack was noted in the base metal but was not present in the INCO-61 welds. In an attempt to account for the weld attack in the fluorinator, aqueous decontamination conditions were simulated as far as possible in a laboratory study at BMI. The L-nickel specimens corroded in 0.1 M $Al(NO_3)_3$—0.01 M HNO_3 (AN-N) at boiling temperature, with rates ranging downward from 250 to 20 mils/month. Solutions of 5-2-2 wt % NaOH—sodium tartrate—H_2O_2 (CTP) at room temperature gave rates for L-nickel ranging from 1.6 to 8 mils/month. The INCO-61 weld-rod specimens corroded at rates less than half those of L-nickel, but the INCO-61 weld in L-nickel specimens cut from the Volatility Pilot Plant fluorinator showed a definitely higher rate of attack than the adjoining L-nickel. Coupons welded with INCO-61 also showed a region of accelerated attack at the junction of the weld and the base metal. Specimens of INOR-8, the alloy from which the dissolver is made, were attacked only very slightly by AN-N and CTP. A three-step, 68-hr decontamination of the ORNL bench-scale INOR-8 dissolver with AN-N at about 90°C resulted in an average corrosion penetration of 3 mils (about 0.3 mil/month). Thus, AN-N appears to be a satisfactory decontamination reagent for INOR-8, but not satisfactory for the L-nickel and INCO-61 welds under the conditions used.

Modifications and repairs in the main processing equipment are almost complete, with the only major items remaining to be repaired being auxiliaries, such as a caustic sampler. The system was dried and pressure-tested and is being leak-tested with fluorine.

Dissolution of PuO_2. — Studies on the dissolution of PuO_2 pellets, a relatively new reactor fuel material, were continued. The maximum dissolution rate of high-density pellets (about 93% of theoretical density) thus far obtained is about 2 mg cm^{-2} min^{-1} in 14 M HNO_3 containing 0.1 M HF. When 0.3 M $Al(NO_3)_3$ was added to the solution to decrease corrosion, the rate decreased to 0.02 mg cm^{-2} min^{-1}. Oxidizing agents increase the dissolution rate in less than about 10 M HNO_3 but did not have an appreciable effect above this acid concentration.

THORIUM UTILIZATION PROGRAM

Planning and Evaluation Studies. — Evaluation of the Babcock and Wilcox Spectral Shift Control Reactor was completed. The reactor used UO_2-ThO_2 pellet fuel, Zircaloy-2 cladding, H_2O-D_2O as moderator-coolant, and operated at 450 Mw (electrical). Its fuel cost and breeding potential were obtained with the two-group, two-dimensional diffusion-theory Equipoise-Burnout program, and the multigroup, one-dimensional equilibrium reactor code MERC-2. Conversion ratios and fuel-cycle costs were determined as a function of the fuel lifetime, using estimated fabrication-and-processing costs of about $80 per kg of Th. The maximum conversion ratio obtained for the reactor system was 0.86 at a fuel-cycle cost of 2.39 mills/kwhr (electrical); the minimum cost was 1.30 mills/kwhr (electrical) at a ratio of 0.80.

Preliminary nuclear and fuel-cost calculations were performed for the General Atomic High Temperature Graphite Reactor. The fuel was pyrolytic-carbon-coated particles of thorium and uranium carbide dispersed in a graphite matrix and clad in a graphite sheath. Utilizing recycle uranium, a conversion ratio of about 0.85 was attainable, but not at minimum fuel-cycle costs. Fuel fabrication and reprocessing costs were estimated to be between $350 and $450 per kg of Th for system C/Th ratios between 200 and 300 respectively. The fuel-cycle costs had a minimum value of about 1.0 mill/kwhr (electrical) at a system conversion ratio of 0.75, and rose above 2 mills/kwhr (electrical) at ratios near 0.85.

Testing of Thoria-Pellet and -Suspension Fuels. — Assembly and testing of a third in-pile slurry loop, 0-1-29S, were completed. Satisfactory circulation of the thoria suspension to be irradiated was demonstrated by operation of the loop at 280°C for 100 hr in the out-of-pile performance test program. The loop was ready for shipment to the reactor site for installation in beam hole HN-1 of the ORR during the January shutdown. However, as a result of a reduction in the budget funds for this program, in-pile operation of the loop was canceled and the loop package placed in standby.

Engineering of Thorium Reactor Systems. — A series of seven forced-convection boiling burnout heat-flux measurements, using 6 × 1/2 × 0.005 in. stainless steel strips mounted axially in 1-1/2-in. pipe, was carried

out in a high-pressure slurry loop with thoria slurry and water at pressures between 215 and 1035 psia. The mean pipeline velocity was held constant at 15 fps, and the subcooling ($T_{sat} - T_{bulk}$) was maintained in the range 122 to 131°F for the slurry and 95 to 117°F for water. The slurry concentration was in the range 910 to 977 g of ThO_2 per liter.

At the lowest pressures, the burnout heat fluxes in water and in slurry were both 2.6×10^6 Btu hr^{-1} ft^{-2}. As the pressure increased, the burnout heat flux in water increased to 3.0×10^6 (in agreement with existing data), while that in slurry decreased to 1.9×10^6 at the highest pressure.

The reduction in the burnout heat flux in slurry is probably the result of the sharp decrease in the recirculation rate of bulk fluid past a boiling surface at burnout as the pressure on the boiling fluid is increased. This would, in the case of a suspension or solution, cause an increase in concentration adjacent to the boiling surface as the pressure is increased.

MOLTEN-SALT REACTOR PROGRAM

Molten-Salt Reactor Experiment. — The 165 U-tubes in the primary heat exchanger were assembled and semiautomatically welded to the tube sheet. A vendor, Wall Colmonoy, successfully back-brazed the tubes to the tube sheet with a gold-nickel alloy.

Fabrication of the steam domes for the two fuel drain tanks was completed. Fabrication is continuing on the tanks.

Fabrication of the ten radiator-tube banks was completed and these tube banks are being assembled on the main headers. Heating equipment is being installed in the radiator enclosure. Fabrication is continuing on the reactor vessel.

The contractor completed the building modifications and removed his forces from Building 7503.

The design has reached a state so near completion that the rate of minor alterations and additions will remain constant for an indefinite period — probably several months. As positively as can be determined, the design is complete except for these miscellaneous items.

Metallurgy. — Sections from MSRE moderator graphite (grade CGB) were tested to evaluate the effects of a cracked condition observed throughout the material. The cracks, oriented primarily in an axial direction, ranged in widths from 5 mils to less than 1 mil, the majority having widths less than 2 mils. All of the specimens tested had a bulk density of 1.87 g/cc.

Mechanical properties of the graphite were determined by using tensile tests and brittle-ring tests. Sixteen axial tensile specimens were broken, and results indicated that nine of these were not appreciably affected by the prior cracking, having yielded at a strength of 5440 psi. The specimens that demonstrated a definite effect of cracking yielded at a minimum strength of 1510 psi, still within the specified minimum. The latter specimens failed with stair-step-type fractures and showed no tendency to propagate fractures along the crack.

Specimens used in the brittle-ring test were oriented so that in some tests the maximum stress was in the direction of extrusion, while in others it was normal to the direction of extrusion. Failure stresses of the rings ranged from 4900 to 7100 psi. No significant trend was observed due to the presence of cracks.

Specimens of this graphite were also tested by thermal cycling after the graphite was impregnated with salt. The average bulk volume of the specimens permeated by the salt at 1300°F in 100 hr was 0.08% at 50 psig and 0.13% at 150 psig. The salt was observed only in the cracks. No physical changes were detected in the graphite or the cracks after the specimens were subjected to 100 rapid thermal cycles between 390 and 1300°F.

Chemical Development. — The presence of CF_4 in the cover gas over irradiated MSRE fuel in graphite boats led to numerous out-of-pile experiments on the rate of reaction of CF_4 with the fuel. According to experiments described under "Radiation Effects," the CF_4 apparently originates from free F_2, liberated from the solid fuel by decay-energy-induced radiolysis after shutdown. According to free-energy calculations, the CF_4 should react with molten fuel, but the reaction was generally slow.

The data for the rate of reaction with a large excess of fuel, as correlated, roughly at least, by a first-order equation, were characterized by a temperature dependence between 700 and 850°C, conforming to an energy of activation of about 32 kcal per mole of CF_4. This is less than one-third the C-F bond energy. Much faster reaction rates (e.g., 16 cc/hr) were encountered when CF_4 was introduced to the melt through the walls of a submerged graphite crucible at a flow rate of 30 cc/hr. Reduced fuel was used in all the tests, in the sense that the fuel as prepared contained most of the dissolved uranium as UF_3 rather than UF_4.

Radiation Effects. — Evidence that the evolution of F_2 or CF_4 from irradiation of MSRE fuel in contact with graphite is a consequence of radiolysis of the frozen fuel has continued to accumulate in the form of analyses by mass spectrometry made on the first 45 gas samples taken during in-pile irradiation. Of the samples collected following pressure rises noted during reactor shutdown periods, which were expected to contain F_2 and possibly CF_4, no CF_4 was noted and only one showed F_2 (5.8%) at a level above the detection limits, which ranged from a few ppm to 200 ppm. Rechecks with improved detection limits have been initiated. The absence of F_2 is probably attributable to its reaction with metal walls prior to analysis. Neither CF_4 nor F_2 was found in 23 samples collected over the molten fuel, and although small amounts of F_2 could obviously have escaped detection, the absence of CF_4 is presumptive evidence that F_2 was not being evolved by the fuel under operating conditions.

Irradiation Tests. — The ORNL-MTR-47-5 MSRE capsule irradiation experiment was terminated after completion of five MTR irradiation cycles. A total of 59 gas samples were collected from two capsules, of which 34 were accumulated over molten salt, 9 during reactor shutdown, 4 just after

reactor shutdown (salt freeze), 4 just after reactor startup (salt melting), and 8 over frozen salt with the reactor at low power (5 to 20 Mw). Temperatures during sample accumulation over molten salt ranged from 1050 to 1510°F for capsule 4, and specific capsule power was estimated to be from 1/4 to 1-1/4 times design power (65 and 35 w/cc for capsules 4 and 3 respectively). Pressure in isolated capsules was monitored during each long-term reactor shutdown period. In each case, a pressure rise was noted in capsule 4 (0.7 mole % UF_4) which began from 2 to 8 hr after shutdown and for which the rate of pressure rise was a function of the capsule power before shutdown. The pressure in capsule 3 (0.35 mole % UF_4) was observed to rise only during the shutdowns after the first and fourth reactor cycles, and, in each case, the rate of increase was less than that for capsule 4. Qualitative spectral analysis of gamma rays penetrating the nickel sample bottles was completed at the MTR for one set of samples, which included those taken during the first scheduled shutdown. Results indicate a major peak of Te^{132} and I^{132} with a minor of Xe^{133} for the shutdown samples and a major of Xe^{133} with no minor for samples accumulated over molten salt.

MSR Processing. — Design of the fuel processing system was completed except for checking and minor changes. Sixty piping, structural, electrical, and instrumentation drawings were prepared. A detailed cost estimate is being made.

Several changes were made to the flowsheet. Cooling of the fuel processing tank for short-decay fuel will be by air instead of water. The processing tank will be provided with a salt sampler to assist the UF_6 and HF analyzers in following the processing.

A preliminary draft of the hazards evaluation section of the design and operating report was issued for comment.

Analysis of Radioactive MSRE Fuels. — Additional modifications to the amperometric titration cell and the polarographic cell were completed and satisfactorily checked out. Determinations of zirconium, in the amperometric cell, and uranium, in the polarographic cell, were satisfactorily completed, as described below. The amperometric cell was transferred, installed, and tested satisfactorily in the High-Radiation-Level Analytical Facility. A coulometric cell for the determination of uranium (a primary method) was fabricated, checked, and installed in the mockup. Testing of the method and equipment on the MSRE fuel salt is in progress. A compact setup for the determination of F^- in the MSRE fuel salt by pyrolysis (a primary method) was designed, fabricated, and preliminarily tested.

Evaluation of the amperometric titration method for the determination of zirconium (a primary method) in the radioactive MSRE salt was completed. In the Analytical Chemistry mockup cell, simulating the hot-cell facility, a relative standard deviation of 1.4% was obtained on nonirradiated MSRE salt solutions.

Evaluation of the polarographic method for the determination of uranium (a secondary method) in sulfuric acid solutions of MSRE salt was completed. With simulated hot-cell operation, a relative standard deviation of 2% was obtained for the standard addition method and 2.5% for the direct comparison method. No separations are necessary in this procedure.

An irradiated MSRE salt was dissolved in the H_3BO_3-HNO_3-H_2SO_4 mixture commonly used for the nonradioactive salt, to produce a 1 M H_2SO_4 solution of the salt. The dissolution of a 2-g sample required about 3 hr, approximately the time needed to dissolve a similar quantity of the simulated fuel.

ADVANCED REACTOR DEVELOPMENT

Advanced Test Reactor Corrosion Program

Duplicate tests were conducted to simulate the decrease in heat flux across the aluminum fuel element cladding that will occur during an Advanced Test Reactor cycle. The pH of the coolant was 5.0 (HNO_3), its flow rate was 45 fps, and during the test the heat flux was gradually decreased from an initial value of 1.44×10^6 Btu hr^{-1} ft^{-2} to a final value of 1.24×10^6. The temperature of the coolant was such that the aluminum-water interface at the axial midpoint of the specimen was 340°F at the start of the test (no oxide present). During the 17-day test the coolant temperature was gradually lowered by 26°F. At the end of the test the average temperature at the aluminum—aluminum oxide interface was 396°F. In previously reported tests run in the same manner except that starting temperatures were 360 and 387°F, corresponding temperatures at the end of the test were 460 and 518°F respectively.

For structural reasons, fuel element temperatures should not exceed 400°F. Thus these results indicate that starting fuel element surface temperatures should not exceed 340°F, to ensure adequate fuel element stability throughout the reactor cycle.

High Flux Isotope Reactor Design and Development

Fuel Element Development. — Two full-size HFIR fuel elements were tested to determine the thermal stability after assembly. One element contained cored plates which had been forced into the correct shape by the use of spacers during assembly. This element had been assembled by using the bent-lip technique, with circular welds in grooves cut into the lips. The second element contained aluminum plates and was assembled by using the sliding-plate technique, with circumferential welds through the side plates. Both elements were held for 100 hr at 200, 300, and 400°F, the last of these temperatures being above the plate operating temperature. They were removed from the furnace and carefully measured after each test. In neither element were the locked-in stresses sufficient to cause significant changes in the dimensions. Minor and random changes in plate spacings and diameters were found but were in the direction of reducing the deviations from tolerances; no rotation was found.

Engineering Development. — The HFIR mockup has been reassembled and has been operated briefly at a flow rate of 17,000 gpm. This flow represents approximately 125% of the mockup design flow of 13,800 gpm. Operation

of the mockup will continue into February in order to verify all previous hydraulic readings. Strain gages are not being monitored during this series of tests, since only nominal strains were recorded on previous tests.

The control-plate tests are continuing and should be completed by the end of February. At that time, sufficient data will have been accumulated to permit establishment of criteria for deflections of outer plates and load on skid pads. In connection with this work, several suitable combinations of skid-pad and track material will be evaluated to determine coefficients of friction and wearing properties. Materials contemplated for use in the HFIR are being subjected to corrosion tests in aqueous solution at a pH of 5 at 100°C. The principal materials being tested are types 1100-0 and 6061 T-6 aluminum; types 303, 304, 410, and 17-4 PH stainless steel; and beryllium. In addition, "electrolyzed" 6061 aluminum, type 304 stainless steel, and type 304 stainless steel hot-dipped in aluminum are being evaluated for their ability to retard corrosion in stainless-to-aluminum structural joints. Each of the materials is being evaluated separately and also electrolytically coupled to the other materials.

Fabrication was completed of a prototype pneumatic actuator for the outer control rods and a prototype fission-chamber drive. Both units will be subjected to operational testing to determine where additional development is required.

Analysis. — Since January 1962, considerable effort has been concentrated on improving methods for calculating the nuclear behavior of the HFIR core and on determining and improving the nuclear characteristics of the control rods. Critical-experiment and analog-control-system simulation results were used as criteria from which improvements were judged necessary.

Calculation methods have been improved through the use of newly developed reactor codes, including a multigroup fuel-cycle analysis (only one nonthermal group had been used previously), calculation of spectrum-averaged nonthermal constants, and calculation of space-dependent spectrum-averaged thermal cross sections. Preliminary use of the multigroup fuel-cycle calculation for the HFIR core containing 9.4 kg of U^{235}, and boron and cadmium as burnable poisons, resulted in a satisfactory core life, but indicated a 10% higher peak power density than achieved in the 8.0-kg core, using the two-group analysis. At the time these calculations were made, the power distribution in the 8.0-kg critical experiment could be reproduced adequately with the multigroup code; however, the calculated value of neutron multiplication was about 4% high, making it difficult to interpret the power distribution and fuel-cycle time accurately. Recent use of the new spectrum-averaged cross sections in the multigroup diffusion calculation has improved the calculation of neutron multiplication sufficiently to permit further fuel-cycle calculations. These results will be used to determine the radial fuel distribution for the final critical experiment and for the first few production cores. The critical experiment is scheduled to begin on September 1, 1963.

Results from the 8.0-kg critical experiments and from the analog-control-system simulation studies indicated that the Al-Ni-Ag control rods

did not have sufficient sensitivity ($\Delta k/k$/in.) for all rod positions to satisfy the tentative stringent control-system criteria. This situation, which had not been predicted with calculations, was attributed to a combination of two factors: the high scattering cross section of nickel, and the occasional overlapping of the nickel regions of the two concentric control rods. These conditions have been corrected by specifying the use of the originally proposed aluminum control rod containing dispersions of europium oxide and tantalum in the black and gray regions respectively. Also, the length of the gray region has been reduced from 20 in. to about 5 in., so that during normal symmetrical operation of the rods the gray regions will not overlap with the reactor critical. The decrease in gray-region length will result in a shorter control-rod life and a small increase in the peak power density. However, in addition to improving the rod sensitivity, the decreased length also facilitates the solution of some otherwise very difficult mechanical and hydraulic problems associated with the control rods.

Instrumentation. — An analog computer analysis of loss-of-pressure accidents has been initiated; however, additional data will be obtained before the analysis is complete.

With the system operating at steady state at design-point conditions for a 100-Mw power level and no corrective action taken, the effects of various loss-of-pressure accidents in the primary coolant system were examined to determine whether core burnout occurred at the hot spots. The results were as follows:

1. A failure of the pressure controller or the valve in the letdown lines would cause no serious difficulty.

2. For any break having an equivalent hole diameter equal to or greater than 3/8 in., the pressurizer-pump suction tank would eventually be emptied. For a break equal to a 3-in. globe valve fully opened, the tank would be emptied in approximately 4 min.

3. The largest break that can be tolerated from the standpoint of hot-spot burnout damage within a very short time is one approximately equivalent to a 3-in. globe valve fully opened; however, with a hole this size, core damage could occur after approximately 4 min as a result of the inadequacy of the makeup system supplying water to the pressurizer-pump suction tank.

PHYSICAL RESEARCH PROGRAM

Reactor Operations. – During 1962 the ORR operated 83%, the LITR 90%, and the ORNL Graphite Reactor 92% of the time. For the last five weeks of 1962, the ORR had no unscheduled shutdowns.

The Reactor Operations Review Committee completed the examination of the operation of the three reactors.

The safety programs now require a large portion of the time of the technical staff in analyzing hazards, developing hazards reports, making tests, writing operating limits, and rewriting procedures. Some of these jobs are: hazards analysis of the waste-disposal facilities, hazards analysis of the HFIR, test of radioiodine removal in the ORR containment system, development of a hazards report for the LITR, and writing operating limits for the ORR and the LITR.

Waste Disposal. – Improved waste-disposal practices and intensive monitoring of waste streams have resulted in a significant reduction of activity released into the environment during 1962. The release of active strontium (90% Sr^{90}) into White Oak Creek in 1962 was 8.8 curies, as compared with 21.6 curies in 1961. The release of Ru^{106}, the other of the two important isotopes, was 5520 curies, compared with 7440 curies in 1961.

Hot-Cell Operations. – Operations in the hot cells were routine. Several ORR and LITR capsules, and two capsules from the MTR and the ETR, containing UO_2, ThO_2-UO_2, and UC_2 fuels were examined. One UO_2 meltdown experiment was disassembled. Several tube-burst specimens were examined, and a section of a volatility pilot plant dissolver was examined metallographically. Installation of a tensile test machine was completed in the 3025 hot cells, and the testing of nickel specimens was begun. A Jezabel assembly was broken and canned for processing in other cells. Specimens were recovered from 17 ORR experiments in the ORR cells. Several molten-salt capsules were sampled for gas, sectioned, and sampled for various analyses and metallographic study. Autoradiographs were made of four of the molten-salt capsules. A number of gas samples taken during and after irradiation of a molten-salt experiment in the MTR were received; aliquots of the samples were removed for analyses. A thorium slurry loop was segmented and stored, and two thoria autoclaves were examined.

PHYSICS AND MATHEMATICS RESEARCH

Charge Spectrometry. – Calculations have been made of the probabilities for single and multiple electron removal following a K vacancy in neon. As a requisite for this calculation, the transition probabilities for the different Auger processes leading to the filling of the K vacancy were computed on the IBM 7090. An additional correction was made for Coulombic shaking with the use of empirical data. If one assumes that a Coster-Kronig transition between the 2s and 2p orbitals is energetically possible, the calculated spectrum of ions in percent abundance is as

follows: Ne^{+}, 0.5; Ne^{2+}, 67.3; Ne^{3+}, 25.8; Ne^{4+}, 5.7; Ne^{5+}, 0.7. These results are in excellent agreement with some unpublished experimental data.

Neutron Diffraction. – Neutron diffraction measurements were made on the nickel hydride–nickel system in order to determine the structure of the hydride. The hydrogen atoms were found to occupy the octahedral sites of the expanded face-centered cubic lattice. A hydrogen-to-nickel atom ratio of 0.6 ± 0.1 was determined. In this respect the hydrogen uptake properties of nickel are similar to those of palladium. It is found, however, that the nickel-hydrogen system is unstable at room temperature, and it cannot be produced from the gas phase at hydrogen pressures up to 1200 psi. Palladium, on the other hand, absorbs hydrogen at room temperature and atmospheric pressure.

Theoretical Physics: Collective Effects and Elastic Scattering from Odd Nuclei. – It is suggested that a difference could be observed between the elastic scattering from even and that from odd nuclei whenever the nuclei are nonspherical. To second order in the "deformation," the difference is shown to be mainly due to an additional diagonal matrix element which occurs for odd nuclei with spin > 1/2. Numerical evaluation of this matrix element, using the distorted-waves Born approximation, is used to give an estimate of the size and qualitative behavior of this effect in a number of typical cases. It is found that, while not large, the effect need not be negligible and may be important for understanding the variations in optical potential parameters from nucleus to nucleus.

Theoretical Physics: Scattering from Oriented, Deformed Nuclei. – The elastic scattering of particles from oriented, deformed, odd nuclei was studied by using the collective model of the nucleus. Numerical results were obtained by using the distorted-waves Born approximation for the following typical cases: neutrons of 2, 5, and 14 Mev, protons of 5 and 14 Mev, and alphas of 43 Mev, incident on Mn^{55} and Ho^{165} target nuclei. It is found that the differential cross section shows large azimuthal asymmetries when the target is oriented perpendicular to the incident beam. The experimental observation of this effect would be valuable; for rotational nuclei it could measure the sign and magnitude of the deformation, while for vibrational nuclei it could yield important information about the coupling of the odd nucleon to the core.

Fast-Chopper Time-of-Flight Spectrometer. – About 100 resonances have been assigned to the ten tin isotopes in the energy range 0.2 to 10,000 ev from the ORNL fast-chopper measurements [Bull. Am. Phys. Soc. 7, 289 (1962); 7, 552 (1962)]. The average level spacing in each isotope depends clearly on whether the mass number is even or odd; that is, the spacings are large for the even target isotopes and small for the odd ones. The spacings for the even target isotopes increase with mass number, indicating the effect of the neutron binding energy. The s-wave strength function for the even target isotopes shows a steep decrease from Sn^{118} to Sn^{120}. This dependence of the strength function on mass number agrees well with the calculations by Shakin in computing the three quasi-particle model states based on the nuclear shell model and the optical model.

High-Voltage Experimental Program: 30-kev Neutron Capture in the Samarium Isotopes. — Recent theories concerning the formation of the elements are based on neutron capture in red giant stars and supernovas. The isotopic capture cross sections of the samarium isotopes are particularly significant because two of them, Sm^{148} and Sm^{150}, cannot be formed by neutron capture in supernovas. The red giant process predicts the cross-section ratio (from the observed isotopic abundance N) for these two cases.

Measurements near 30 kev (comparable to thermal energies in a star) confirm the predicted cross-section ratio very closely. A value of 1.02 (±6%) was found for the ratio $N\sigma_c(Sm^{150})/N\sigma_c(Sm^{149})$, where theory predicts a value close to 0.98. From the measured cross sections of the other isotopes, one can derive some information on the supernova process. The high capture cross section of Sm^{149} below a few electron volts of neutron energy does not seem to have resulted in any appreciable shift in the expected values. This places some restriction on theories accounting for deuterium formation by neutron capture in solid or liquid planetesimal bodies.

High-Voltage Experimental Program: Fission Cross Section and Fragment Angular Distribution for Fast-Neutron-Induced Fission of Th^{232}. — The angular distribution of fission fragments from the fast-neutron-induced fission of Th^{232} has been measured near threshold. The results are shown below:

E_n (kev)	σ_f (0/90)°
1188 ± 41	1.53 ± 0.15
1390 ± 41	0.75 ± 0.11
1594 ± 41	0.49 ± 0.04

These results plus those from earlier Los Alamos measurements [Phys. Rev. 103, 1292 (1956)] have been analyzed according to methods previously reported [Nucl. Phys. 38, 561 (1962)]. They are consistent with an assignment of a K-band sequence in order of increasing energy of $1/2^+$, $3/2^-$, $1/2^-$ to the compound nucleus Th^{233} near the saddle-point deformation.

The results at 1594 kev are inconsistent with a Los Alamos measurement at 1607 ± 67 kev of 0.12 ± 0.04 for σ_f (0/90)°. The inadequate beam from the 5-Mv Van de Graaff precluded more detailed measurements, so the source of the discrepancy remains unresolved. The fragment angular distribution is changing rapidly with energy in this region, so it could be due to an error in measurement of energy. The assignment of K-band sequence would be expected to be the same in either case.

Several Np^{237} foils have been standardized by alpha and fission counting and by comparison of these counts with masses obtained by other means. The thermal column of the ORNL Graphite Reactor was used as a means of producing a neutron flux homogeneous over the foil dimensions. Fast neutrons were obtained by use of a converter plate on the floor of the column. Counts were taken in fast and also in thermal flux in order to determine the extent of contamination of the neptunium with fissionable impurities. It turns out that these foils contain uranium, usually less

than 1%. It was introduced accidentally during the plating process at ORGDP. The counting techniques mentioned above permit quantitative evaluations without damage to the foils.

Mathematics and Programming Research: ALGOL Translation. — A joint effort was undertaken in September 1961 with Control Data Corporation to design and construct an ALGOL compiler for their CDC 1604 computer. The development consisted of: (1) extensions of the theory of ALGOL translation documented in ORNL-3054, (2) adaptation of the machine-independent plans to characteristics of the CDC 1604, and (3) the coding, which was contributed by Control Data Corporation personnel. The important theoretical aspects were considered in a machine-independent context; a report on algorithmic language translation will include such aspects as declarations, procedure linkage, and storage allocation.

Compilation consists of two passes on the source program, with error checking in the first pass and translation in the second. The compiler will operate as a part of the CO-OP Monitor Programming System. It will produce either a symbolic-language or a machine-language target program. Symbolic language is desirable for such things as mixing with other source languages and compiling procedures to a relocatable format. When compiling to machine language, speeds of the order of 10,000 instructions/min have been obtained.

Target-program efficiency has been emphasized: unnecessary use of temporary storage is avoided, and certain loops are optimized (but without use of index registers). A few features of the language are not handled: recursive procedures, dynamic own-arrays, and call of arrays by value. Certain restrictions on arithmetic type also improve target program speed: the type of an actual parameter must match that of the corresponding formal parameter, the simple arithmetic expressions occurring as constituents of conditional arithmetic expressions must have the same type, and the type of exponentiation expressions is redefined to prevent the type from depending upon the value of the exponent.

The compiler has undergone testing and is now ready for field test. A few additional features and streamlining modifications remain to be implemented.

Mathematics and Programming Research: Computer Program for Data Scaling and Plotting. — A computer program has been written for plotting data with the Calcomp 570 digital plotter. The program is a FORTRAN subroutine, and one of its principal features is the ability to automatically scale floating-point data if desired. Scaling and plotting may be done on blank paper, permitting maximum-sensitivity scaling with a complete grid drawn by the plotter. If printed graph paper is used, major intervals must be spaced 1 in. or 1/2 in. apart. Titles and labels for graphs may be specified. ORNL-3394 gives a complete description of this routine and instructions for its use.

Mathematics and Programming Research: Special Functions. — A new method, based on difference equations and continued fractions, has been developed to calculate Bessel functions of the first kind and of arbitrary real order. Subroutines in ALGOL have been written for the computation of $J_{a\pm n}(x)$, $I_{a\pm n}(x)$, where $\theta \leq a < 1$, $x > 0$, $n = 0, 1, 2, \ldots$. They are being tested on the IBM 7090.

Mathematics and Programming Research: Partial-Differential Equations. — In formulating an elliptic partial-differential problem for solution on a digital computer, one major difficulty is the handling of the interfaces and boundaries if these are curved or are not parallel to the lines of the finite-difference mesh. A theory has been developed which removes this difficulty by two simple steps. Each interface and boundary is replaced by an approximating surface, and then each associated differential condition imposed across the surface is suitably modified. The approximating surface can be chosen so that the modified condition is easily applied by using only mesh points at regular locations. Numerical experiments are being planned to test the method.

CHEMISTRY RESEARCH

Effects of Radiation on Analytical Methods. — A study was completed of the effects of gamma radiation on various thiocyanate complexes commonly used in analytical chemistry, namely, those of molybdenum, uranium, and iron. Stannous chloride was found to be a fairly good agent for protecting these complexes from the degradation effect of gamma radiation.

Tests were also made of the use of acetone as a scavenger or protective agent. Since cyanide and sulfur, products in the degradation of thiocyanate complexes by gamma radiation, recombine to form thiocyanate in the presence of acetone, it was anticipated that the degradation of the complexes would be reduced by utilizing an acetone-water medium. This did not, however, prove to be the case. Although the cyanide, sulfide, and sulfur degradation products did not appear as quickly as in an aqueous medium, the change in chromophoric absorption as a consequence of gamma radiation was greater in the acetone-water medium than in water alone.

A study is being continued on the effects of gamma radiation on electrode systems commonly used in analytical chemistry. The apparatus was made completely mobile, and further modifications were made on the salt bridge, which is necessary for carrying out remote measurements.

Solvent Extraction Research. — Gamma decontamination, with actual but aged samples of Purex process 1BP solution, was shown (ORNL-3256) to be unsatisfactory in hot-cell testing of the proposed fuel-cycle plutonium purification by tertiary amine—nitrate extraction. Aged 1BP solutions were shown (ORNL-3368) to contain considerable amounts of gamma activity readily extractable by the hydrocarbon diluents used with the amine and other extractants. Subsequent tests with fresh 1BP solution, completed within 70 hr after it was withdrawn from the plant process stream, showed little or no such diluent-extractable gamma activity and confirmed the expected high decontamination in amine extraction. Separation factors were $\geq 10^4$ for plutonium over gross gamma in single extractions, and the decontamination factor was 2×10^4 for plutonium over zirconium-niobium in a batch cascade extraction-scrub-strip test.

In further studies on the extraction of metal ions from 0.5 to 10 M HCl and from LiCl—0.2 M HCl solutions (0.5 to 10 M total Cl^-), maximum extraction coefficients obtained with 0.1 M solutions of representative primary, secondary, tertiary, and quaternary amines in diethylbenzene

were about 70 for Ge(IV), 70 for Se(IV), 9×10^{-4} for Rb, 4×10^{-3} for Sr, 3×10^{-2} for Y, 200 for Nb, 2000 for Mo(VI), 70 for Ru(III), and 120 for Ru(IV). In general, extraction coefficients increased with increasing chloride concentration and were higher with Aliquat 336 (quaternary) than with the other amines.

Amides of high-molecular-weight fatty acids are being tested in continuation of the program of systematic evaluation of potential solvent extraction reagents. As with tributyl phosphate, uranium(VI) and thorium extractions from nitric acid solutions reach maxima at 4 to 7 M HNO_3. With equal reagent concentrations, uranium extraction coefficients with TBP were always greater than those with amides, but thorium coefficients with the amides were greater than those with TBP above 4 M HNO_3, and increased rapidly with increasing nitric acid concentration. The amide prepared from octanoic acid extracted thorium better than uranium when the nitric acid concentration was less than 6 M. This is in contrast to TBP extractions, where uranium coefficients are greater than those for thorium at all concentrations of nitric acid.

The efficiency of a pulsed solvent extraction column was determined at a high aqueous-to-solvent flow ratio (100:1) for possible application in processes for the recovery and concentration of tracer concentrations of valuable materials. The height equivalent to a theoretical stage in a standard sieve-plate column (0.125-in. holes, 23% free area, 2-in. plate spacing, aqueous phase continuous) decreased from 20 ft to 3.9 ft as the pulse frequency was increased from 35 to 90 cpm for the extraction of uranyl nitrate by 30% TBP from 4 M $NaNO_3$ solution. The HETS at 90 cpm is only about twice as large as the HETS at the more conventional flow ratio of 1:1.

Volatility Studies. — The volatilization of PuF_6 from fused salt by direct fluorination was about the same at an initial plutonium concentration of 960 ppm as in previous work where only 2 ppm was used. The data appear to follow the usual first-order concentration rule, with a half-value period of about 3 hr. A total of 89.3% of the plutonium was volatilized in 10 hr by using LiF-NaF-ZrF_4 (31-24-45 mole %) at 600°C. The overall material balance was 97.8%, with 84.8% being trapped on consecutive CaF_2 and NaF beds at 100°C. Only 0.5% was retained on the wall of the nickel fluorinator vessel.

Mechanisms of Separations Processes. — As one phase of a study of the thermodynamics of the solvent extraction of uranyl nitrate from aqueous nitric acid solutions, activity coefficients of nitric acid, uranyl nitrate, and water in this three-component system are being determined. Experimentally, partial vapor pressures of nitric acid and water are measured, and the water vapor pressures are then compared with corresponding pressures over the two two-component solutions nitric acid—water and uranyl nitrate—water. It was found that the water vapor pressure over the three-component solution, over the two two-component solutions, and over pure water obeys a "product of the means equals the product of the extremes" rule; that is, the product of the water vapor pressures over the two two-component systems equals the product of the vapor pressure of pure water and the vapor pressure of water over the three-component solution when the molal concentration scale is used. The experimental

finding is being used to determine the effect of nitric acid on uranyl nitrate activity coefficients from the data on the effect of uranyl nitrate on nitric acid activity coefficients. Preliminary data may be summarized by the following equations, wherein the subscript 2 refers to nitric acid, 3 to uranyl nitrate, and 0 to the absence of uranyl nitrate from nitric acid solution or of nitric acid from uranyl nitrate solution:

$$\ln \gamma_2 = \ln \gamma_{2(0)} + 0.23\, \underline{m}_3 ,$$

$$\ln \gamma_3 = \ln \gamma_{3(0)} - 0.14\, \underline{m}_2 .$$

Nuclear Methods of Chemical Analysis: Cross Section of Reaction $Ti^{46}(n,p)Sc^{46m}$. – The cross section for the reaction $Ti^{46}(n,p)Sc^{46m}$ ($t_{1/2}$, 20 sec) has been studied by use of a 14-Mev neutron generator (Texas Nuclear Corporation, model 9501). The value found is 5.3 ± 0.9 mb. It is hoped that this reaction can be used in a method for the determination of titanium. Attempts to measure the average cross section of this reaction in the ORR have been hindered by the interference of impurities in the sample; this interference was accentuated by the presence of thermal neutrons.

Nuclear Methods of Chemical Analysis: Use of Activation Analysis to Explore Underground Passages. – The application of neutron activation analysis, utilizing stable tracers, has been proposed in an attempt to determine whether there are underground connections between geysers in Yellowstone National Park. The proposed method involves the addition of a cesium salt or an iodide to one pool and, after the elapse of a suitable interval of time, the determination of cesium or iodine, as the case may be, in the waters of other geysers.

Preliminary studies were completed on waters from two geysers – the Bonita Pool and the Daisy. Cesium was determined by flame spectrophotometry and by neutron activation analysis, while iodine was determined only by activation analysis. The cesium concentration was established by measuring the activity of Cs^{134m} ($t_{1/2}$, 3.0 hr) produced by irradiating a sample for a short time in the pneumatic tube of the ORR and also by measuring the activity of Cs^{134} ($t_{1/2}$, 2.07 yr) produced by irradiation for a week in the ORNL Graphite Reactor. Iodine was determined by measuring the activity of I^{128} ($t_{1/2}$, 25 min) produced by irradiating a sample for a short time in the pneumatic tube of the ORR. The results of the analyses of the two water samples were as follows:

Geyser	Activation Analysis		Cs (ppm), Flame Spectrophotometry
	Cs (ppm)	I (ppm)	
Daisy	0.154	0.10	0.18
Bonita Pool	0.127	0.096	0.13

Nuclear Chemistry: Neutron Cross Sections. — For the determination of the neutron capture cross section of Rh^{105}, in accordance with the reaction scheme

$$\begin{array}{ccccccc} Ru^{104} & \xrightarrow{(n,\gamma)} & Ru^{105} & \xrightarrow[4.5\ hr]{\beta^-} & Rh^{105} & \xrightarrow[36\ hr]{\beta^-} & Pd^{105} \\ & & & & \downarrow (n,\gamma) & & \\ & & & & Rh^{106} & \xrightarrow[30\ sec]{\beta^-} & Pd^{106} \end{array} ,$$

a total of 56 mg of high-purity enriched Ru^{104} (98.2%) metal was irradiated to a dose of 5.3×10^{20} neutrons/cm^2. By means of the double-focusing mass spectrometer it is possible to determine the ratio of the stable Pd^{105} and Pd^{106} after their separation from the ruthenium. Separation with a ruthenium decontamination factor of 10^7 was accomplished in a two-step operation. First, ruthenium was distilled as the tetroxide from a perchloric acid solution, with the palladium and nonvolatile trace impurities remaining in the distillate. Second, the palladium in the distillate was converted to the anion chloride complex for adsorption on a Dowex 2 resin column, from which it was removed with 0.25 M NH_4OH. Preliminary results indicate a (n,γ) cross section for Rh^{105} of $\overline{2}.1 \times 10^4$ barns.

Nuclear Chemistry: Fission Studies and Characterization of Low-Energy Properties of Nuclei. — The angular distribution of the 613-319-kev gamma-ray cascade in V^{51} was measured by using sources of 5.80-min Ti^{51} prepared in the ORNL Graphite Reactor. After correcting for the finite angular resolution of the detectors, the data were fitted to the function $W(\theta) = 1 + (0.013 \pm 0.030)P_2(\cos\theta) - (0.04 \pm 0.05)P_4(\cos\theta)$. The mixing ratio of the 319-kev transition, δ_{319}, where $\delta^2 = (Q/D)$, has been previously established as 0.52 by Ritter et al. With this ratio, the correlation coefficients are compatible with $\delta_{613} = -0.41$ or $+6.3$ for the spin sequence 3/2, 5/2, 7/2, and with $\delta_{613} = +0.18$ or -9.3 for the spin sequence 5/2, 5/2, 7/2. The intensities determined for the 613- and 934-kev gamma rays from the second level at 933 kev are (1.7 ± 0.2)% and (5.8 ± 0.06)% of the 319-kev gamma-ray intensity.

Chemical Physics: Microwave and Radio-Frequency Spectroscopy. — The electron spin resonance spectra of gamma-irradiated single crystals of dimethylglyoxime are being studied. In addition to a spectrum corresponding to an electron spin of 1/2 known from other work, there is present a spectrum corresponding to a spin of 1. The spin assignment was confirmed by observation of the relatively weak transition with a ΔM_S of 2. Hyperfine structure is present which is believed to arise from two equally or nearly equally coupled nitrogen nuclei. The spin-1 species is indefinitely stable at 77°K, but disappears slowly at room temperature.

Studies are continuing on paramagnetic species produced in H_2O_2 single crystals on irradiation with ultraviolet light. A species existing in the

triplet state (S = 1) has been seen. This species is indefinitely stable at 77°K. It is produced by ultraviolet with very low yield compared with a species discussed previously. Preliminary measurements indicate a D term (zero field splitting) in the Hamiltonian of about 0.05 cm^{-1}. The spectral lines have some structure but not enough to indicate large hyperfine effects with protons in the environment.

Physical Chemistry of Molten Salts. — Xenon tetrafluoride was prepared by reacting the elements at about 400°C; it was identified and its purity was verified by infrared analysis. The compound was sublimed in vacuum into specially dried quartz capillary tubes and sealed off. Single crystals of two phases were grown in these tubes and were characterized by x-ray diffraction. They are as follows:

Phase I	Phase II
Monoclinic	Monoclinic
a = 5.05, b = 5.92, c = 5.77 A	a = 6.64, b = 7.33, c = 6.40 A
β = 99.6°	β = 92.6°
$P2_1/n$	$P2_1/c$
2 molecules/unit cell	4 molecules/unit cell
Calculated density = 4.04 g/cm^3	Calculated density = 4.42 g/cm^3
Xe in body-centered positions	Xe in face-centered positions

A large single crystal (~40 mg) of phase I was grown and is being studied by neutron diffraction. The second phase is being further investigated by x-ray diffraction.

Chemical Separation of Isotopes. — The exchange of BF_3 between $(CH_3)_2O \cdot BF_3$ and $(C_2H_5)_2O \cdot BF_3$ was studied as a function of temperature and composition. The rate of exchange decreased as the BF_3 content of mixtures of $(CH_3)_2O$, $(C_2H_5)_2O$, and BF_3 was increased. When the ethers were about 95% complexed, the decrease in rate became very pronounced and the activation energy rose from 11 to 14 kcal/mole, indicating a change in mechanism. The equilibrium constant for the reaction

$$(C_2H_5)_2O \cdot BF_3 + (CH_3)_2O = (CH_3)_2O \cdot BF_3 + (C_2H_5)_2O$$

was in the range 1 to 4 for various mixtures at temperatures from −62 to +26°C.

Chemical Applications of Nuclear Explosions. — A number of salt samples from the Gnome event are being studied to devise a method for recovering the transuranium elements to be produced in the proposed Project Coach detonation in salt. Water leaching studies, using the minimum quantity of water to dissolve the chlorides in the samples, showed that more than 99% of the activity was associated with the water-insoluble residue. This residue comprised 5 to 15% of the original salt and was composed of

anhydrite, silicates, silica, and clay. About two-thirds of the residue consisted of anhydrite, which can be dissolved in brine solution if necessary. The plutonium, gross beta, and total-rare-earth beta activities were easily leached by nitric or hydrochloric acids. Plutonium was concentrated 10,000-fold from nitric acid leach solutions by the use of ferric hydroxide scavenging at pH 7 from solutions that contained 500 ppm of ferric ion. In future experiments, ferric hydroxide scavenging will be investigated for use in concentrating americium and curium from the nitric acid leach solutions.

METALLURGY AND MATERIALS RESEARCH

Ceramics Research: Sintering Studies. — The sintering of ThO_2 containing 1.35 wt % CaO was found to proceed much more rapidly than the sintering of pure thoria. When heated to a specific temperature and immediately cooled, compacts achieved a density which is characteristic of the temperature and is independent of the heating rate. In addition, the variation in density with temperature variations is indicative of material transport by plastic flow, as in the case of pure thoria compacts. Preliminary measurements indicated that the diffusion coefficient of thorium ions in ThO_2—1.35 wt % CaO is approximately equivalent to that in pure ThO_2. On the other hand, creep occurred in sintered ThO_2—1.35 wt % CaO at a much lower stress than it does in pure thoria. These results suggest a model in which the presence of the calcium ions causes an increased initial sintering rate but does not cause diffusion to become the rate-controlling mechanism.

Physical Properties Studies. — An evaluation of the data obtained on the 93.4%-dense UO_2 in the radial heat flow apparatus in runs 1 to 4 indicates the existence of a heat transfer mechanism operating above 1200°K which is more effective than internal radiation transmission. A graph of thermal resistance (1/k) vs temperature is linear (±1%) from 500 to 1200°K, as expected for a solid in which heat transport is predominantly by phonons. Above 1200°K a significant negative deviation of the data occurs. A curve through the few data above 1200°K was used to calculate the difference (Δk) between the measured k values and those obtained by an extrapolation of the linear portion. This Δk evidently represents the effects of the summation of the additional heat transport mechanisms. A plot of log Δk vs 1/T yielded a straight line and indicated an apparent activation energy of 1.2 ev. If the heat transport mechanism was exclusively internal radiation transmission, theory predicts a curve with a slope of $-1.3T$, which corresponds to an apparent activation energy of about 0.35 ev in the temperature range of the observed deviation.

Tests were recently completed at 125°C in the thermal comparator apparatus, using a 27-g load on a single detector sphere in helium and in nitrogen atmospheres. The response of the contacting sphere, which is sensitive to the specimen thermal conductivity, was found to be linear with the log of time after contact. The slope of this line depends on the

contacting sphere size, and its placement in time depends on the specimen thermal conductivity and the heat transfer gas. The sphere response is more sensitive in nitrogen than in helium and indicates a ±1.2% reproducibility and a specimen thermal-conductivity-dependent accuracy of ±6% for $k < 70$ w m^{-1} $(°C)^{-1}$ and ±2% for $k < 13$ w m^{-1} $(°C)^{-1}$. Tests are in progress at 125, 275, and 425°C in nitrogen to study the effects of microstructure on heat conduction in multiphase mixtures of metals, oxides, and metal-oxides, the effects of porosity and grain size on the thermal conductivity of BeO, and the effects of alloying and preferred orientation in titanium and zirconium, and to determine the thermal conductivity of the isomorphous compounds US and ThS and their solid solutions.

CONTROLLED THERMONUCLEAR RESEARCH

DCX-1 Facility. — The energy distributions and the flux of fast particles lost through one of the mirrors of the DCX-1 were measured at about 10^{-7} torr. These data indicate that the mirror loss of stored protons is 3 to 4 orders of magnitude less than the charge exchange loss, confirming previous experiments in which the measured rates of loss by charge exchange were found to be equal to the calculated trapping rates. In addition, it appears that a class of protons previously thought to be lost very rapidly through the mirrors (those protons for which absolute containment theory permits access to the mirrors) may actually be trapped long enough for charge exchange. The class could make an important contribution to the plasma density in the event of significant trapping from Lorentz dissociation, but not for gas dissociation. The reason is that the trapping fraction for Lorentz dissociation is determined by the range of magnetic field strength encountered by the H_2^+ beam in the trapping region, and not by the beam path length in that region, as is the case for gas dissociation. Also for this reason, a single-pass device can more efficiently utilize Lorentz dissociation than can a multiple-pass device, with its larger volume.

Performance curves for the present facility were calculated to determine the contributions of varying amounts of Lorentz dissociation to the plasma density. These curves show that at injected beam currents less than those required for exponentiation, density could be increased by orders of magnitude if dissociation fractions calculated or measured elsewhere could be obtained in the DCX-1, even if the class of particles referred to above did not contribute materially to the trapped density. A program to measure and hopefully optimize this additional contribution to trapping has been planned. The first phase, replacing the ion source with one which will operate at extractor fields lower than the predissociation field for excited vibrational states of interest, has been completed.

Considerable time has been spent preparing the facility for a series of low-pressure runs (at $< 5 \times 10^{-9}$ torr), primarily for studies of stabilization of the plasma against ion-clumping instability by three quite promising techniques. Several monthly reports (beginning with ORNL-3331) described some results of changing the median-plane H_2^+ beam trajectory to

deliberately increase the precessional motion of initially trapped protons, and of shifting the beam trajectory slightly out of the median plane to increase the Z extent of their oscillations. Evidences for partial stabilization by these techniques were reductions in the amplitude and repetition rate of the coherent rf activity associated with the instability, and reductions in the steady-state volume of the plasma. The third technique, that of transmitting through the plasma a stream of electrons from an external source, in earlier experiments also resulted in changes in the coherent rf activity. Recently, studies have established criteria by which this technique could provide stabilization. These experiments are very important, because for a plasma stabilized to the extent that the instability does not appreciably increase the volume, calculations indicate that the injected molecular-ion current and the proton containment time required for the plasma to exponentiate to higher densities may be within the already demonstrated capabilities of the facility. These results do not depend on a contribution to trapping from Lorentz dissociation.

High-Current Injection. – An effort has been made to maximize the H_3^+ ion current from the duoplasmatron. By using the 100-kv laboratory facility with an einzel lens and a transverse magnetic field, total currents up to 100 ma were analyzed. The following examples are typical of the performance obtained:

Total Current (ma)	H^+	H_2^+	H_3^+
89.0	32.5	20.0	36.5
48.5	15.0	6.5	27.0
27.5	6.0	3.5	18.0

This work will be continued for total currents in excess of 100 ma with the 600-kv accelerator tube test facility.

The new accelerator tube with epoxy skirts cast around the porcelain insulators is performing very satisfactorily on the DCX-2 injector system. The problem of achieving a very stable system while accelerating high ion currents is still being pursued.

Theory. – An explanation for energetic electrons (> 250 kev) observed when a low-energy (few kev) electron stream in a magnetic field traverses a resonant cavity is that microwave power at the electron cyclotron frequency is generated when beam noise couples to the cavity. In support of this hypothesis, it has been shown that such a stream-cavity configuration in a magnetic field does indeed behave as a klystron oscillator generating microwaves at the cavity resonant frequencies and driven by the beam kinetic energy. Taking account of the shift in cavity frequencies caused by the plasma dielectric, it appears that at least one such mode would be in resonance with electron gyration somewhere in the magnetic mirror field employed in the experiments.

The tendency toward stability of an arbitrary state "near" a stable state, for example, a weak beam penetrating a Maxwellian, is being exploited. The method complements Gardner's bound on kinetic energy transfer to fields, obtained from bounds on the total allowed change in free

energy, which is minimal at the nearby stable state. The present method bounds the rate of change, the instability growth rate, which is just the upper bound on the rate of change of free energy, a constant for the stable state. Together, the methods provide approximate upper bounds on anomalous diffusion, as in quasi-linear theory. But the free-energy technique may be applied to complicated, spatially nonuniform cases. Results to date indicate that no instability grows faster than the plasma frequency, and the growth rate diminishes uniformly to zero as the stable state is approached. For example, for counter-streaming Maxwellians, the rate is diminished by the ratio of drift velocity to thermal velocity.

Radio-Frequency Heating. — Modification of the Physics Test Facility to provide increased pumping at the ends is substantially complete. Diffusion pumps with approximately six times the former gas handling capacity will prevent contamination of the primary hot plasma by recycling of cold plasma and impurities sputtered from the end walls.

Experimental work has continued on "Elmo," where ready accessibility of the plasma has permitted a more thorough application to the electron cyclotron plasma of some diagnostic techniques which were attempted briefly on the Physics Test Facility. The "Elmo" machine operates with about 1 kw of microwave power at 9.07 kMc with either a mirror or a folded-cusp magnetic field. During this period it has been used mostly with the mirror field.

Optical and near-ultraviolet spectroscopy of the plasma have been done, with the plasma being fed with helium, argon, and xenon. Emission lines of He^+, Ar^+, and Xe^+ were observed with Doppler broadening indicative of an ion temperature in the tens of volts. The low ion energy and short lifetime of the visible emission (less than 4 msec after electron heating is terminated) suggest that only a secondary plasma is involved. Emission lines from Cu, Ag, and Zn sputtered from the walls were also detected. After heating is turned off, microwave noise and xenon x rays were observed to have about eight times the lifetime of the visible radiation, suggesting that a plasma of much higher temperature is responsible.

Hot and cold plasma containment zones have been identified with considerable definition by optical and x-ray photography. For the x-ray photography, the Polaroid camera lens was merely replaced by a "pinhole" in lead. Exposure times for the x rays were about 10,000 times those for light because of lower lens and film efficiency at the higher energies. Use of the high-Z gas xenon permits a clear differentiation between plasma and wall x rays.

The intensity of the xenon plasma x rays, emitted mostly at the K alpha energy of 29.7 kev, has been measured with a scintillation spectrometer. Probability of excitation of this state in xenon by electrons above the K absorption energy (34.5 kev) is well known, as is the fluorescence yield. Since the product of excitation probability times electron velocity is substantially constant, an estimate of the density of these electrons is possible. A β-eucryptite source of Li^+ ions is being prepared to measure plasma potentials. The principal problem is measurement of the Li^+ output (a few microamperes) of the β-eucryptite source in

the presence of milliamperes of cold ions normally collected at the ends of the electron-cyclotron-heated plasma. Modulation at the source with synchronous detection at the collector will be used to separate the signal from the noise.

BIOLOGY AND MEDICINE PROGRAM

RADIATION EFFECTS

Genetic Control of Protein Synthesis. — In studies on the inheritance of mouse hemoglobins, two loci were identified, designated Sol and Hb. These loci influence the structure of the α and β chains, respectively, of mouse hemoglobin. A survey was made of the alleles at Sol and Hb in 20 strains of mice. At least four alleles at Sol and two at Hb have been distinguished among inbred strains. The alleles were identified by starch-gel electrophoresis, solubility in K_2HPO_4-KH_2PO_4 buffer, and analysis of tryptic peptides on paper chromatograms. Large quantities of tryptic peptides have been separated and purified by column chromatography on Dowex 50-X2 and Dowex 1-X2 resins, to determine the amino acid composition and sequence of the α and β chains. From such studies the correlation of allelomorphic and amino acid substitution, which is related to the base sequence in DNA, can be deduced. The amino acid sequence in hemoglobin can thus be used to analyze changes in the base sequence of DNA following various treatments with mutagenic agents.

RADIATION GENETICS

Mutagen Mechanisms: Bacterial Genetics. — It has been demonstrated (ORNL-3256, p 28; ORNL-3331, p 30) that a group of genes located in the region between the genes controlling proline and histidine synthesis on the linkage group of Escherichia coli K-12 are involved in determining the sensitivity of E. coli to ionizing radiation. Current experiments are designed to establish, by means of the conjugation system, the loci of individual genes of this type. In addition, attempts are being made to understand the biochemical expression of such genes. A mutant F^- strain is now available which, unlike almost all other E. coli strains tested, fails to become radiation-resistant when grown to stationary phase in a glucose broth. The failure cannot be attributed to inability to utilize glucose. This organism produces acid end products from aerobic glucose metabolism and consists of very large single cells in stationary phase, both characteristics previously thought to be closely associated with the development of radiation resistance. The data available from conjugation experiments between this mutant and a high-frequency donor strain that does become resistant when grown in glucose indicate that the phenomenon is under control of a gene located between the genes controlling lactose and galactose utilization.

MOLECULAR- AND CELLULAR-LEVEL STUDIES

Biophysics. – Studies continue on genetic damage as a function of linear energy transfer (LET). The methods of analysis briefly described in ORNL-3388 (p 32) have been applied to chromosomal aberrations of Tradescantia. For chromatid plus isochromatid deletions an empirical fit (good to ± 30% or less) was obtained in the form

$$R_1(L) = \alpha L + \beta e^{-\gamma(L-\lambda)^2} ,$$

where $R_1(L)$ is the coefficient of the first power of dose for aberration production at different LET values (L), and the Greek letters are empirically determined constants. This fit suggests that for the usual ionizing radiations most of the effect is produced by the energy deposited at 50 to 80 kev/μ.

RADIOLOGICAL PHYSICS, HEALTH PHYSICS, AND INSTRUMENTATION

Basic Instrumentation. – A simple, versatile hermetic enclosure for beta or gamma semiconductor detectors was devised. To minimize cost, Teflon compression seals through aluminum were used for electrical feedthrough. Kovar seals or ceramic seals soft-soldered or brazed to a copper shell are also suitable if bakeout is required. To admit radiation, a 2-mg/cm^2 mica window was attached with an inorganic (Pyroceram) cement. An aluminum window 0.010 to 0.020 in. thick may be substituted for the mica. Final closure was accomplished reliably by an Al-Al, Al-Cu, or Cu-Cu cold weld.

The techniques for producing a compensated, intrinsic region in silicon by drifting lithium ions into silicon and germanium were further developed. Good yield and reproducibility were achieved in drifting lithium to thicknesses of 5 mm in whole ingot sections (23 to 26 mm in diameter). Intrinsic regions in whole ingot sections of silicon were drifted as deep as 1 cm. Germanium p-i-n diodes were also made by the lithium-drift process. Some difficulty was experienced, because of the influence of surface treatment and gas atmosphere on reverse-current characteristics and because of lithium precipitation effects. However, intrinsic regions as thick as 1.5 mm were made.

Good resolution for alpha-, beta-, and gamma-ray spectroscopy was achieved in lithium-compensated silicon diode detectors. Only a few volts were required to extend the electric field throughout the entire device, and sufficient charge collection efficiency was realized for as little as 30 v bias on 2-mm-thick detectors.

ISOTOPE DEVELOPMENT PROGRAM

Application of Radioisotopes in Analytical Chemistry: Determination of Beryllium by the Photoneutron Method. – Apparatus for use in the determination of beryllium by a photoneutron method has been assembled and is now being used in service work. This apparatus incorporates an Sb^{124} source of gamma radiation and electronic equipment necessary for measuring the neutron flux produced by the interaction of gamma radiation with beryllium. With an Sb^{124} source of 300 to 400 mc, as little as 60 ppm of beryllium in solution or as much as 1.5 mg of total beryllium can be determined with a relative standard deviation of 1%. A few elements (Cd, Sm, Gd, and Eu) with high thermal-neutron capture cross sections can cause low results, and a large excess of deuterium can lead to high results because of the (γ,n) reaction on deuterium. The method has been applied to the determination of beryllium in fluoride salts containing Th, Zr, U, Li, and Be; to the mixed oxides of Be, Mg, and Th; and to alloys of Be and Cu.

Application of Radioisotopes in Analytical Chemistry: Novel Radiotracer Method for Fluoride. – A new, simple, and rapid radiotracer method has been developed for the determination of fluoride. A fluoride complex of Ta^{182} is extracted into diisobutyl ketone under highly selective conditions from a 6.5 M H_2SO_4 solution. The fluoride is then determined by measuring the gamma radiation from the extract, since the radioactivity extracted is proportional to the fluoride concentration. The counting rate is linear over the range 400 to 840 μg of fluoride; below 400 μg it is nonlinear but reproducible and useful. The sensitivity is about 40 μg of fluoride. The radiotracer method exhibits relatively high tolerance to some of the substances which seriously interfere in other methods. This method has a number of useful applications.

Analysis of Gamma-Ray Nuclides by Electronic Spectra Resolution. – Computer techniques for use in the resolution of gamma spectra of radioactive nuclides are near completion and will be used in developing a library collection of standard spectra. These programs are being developed at the Central Data Processing Facility. Data collected for each calibrated nuclide solution will be subjected to statistical tests to ascertain the reliability of such data. So far, data have been obtained from the gamma-ray spectrometer system, with standards from the National Bureau of Standards or calibrated by 4π beta-gamma coincidence, for Na^{22}, Co^{57}, Co^{60}, Zn^{65}, Mn^{56}, La^{140}, Na^{24}, K^{42}, and Au^{198}.

OPEN LITERATURE PUBLICATIONS

Bassel, R. H., R. S. Bender, and J. G. Innes, "Analyzing Methods for ORIC Magnetic Fields," Nucl. Instr. Methods 18, 303 (1962).

Bender, M. A, P. Carolyn Gooch, and D. M. Prescott, "Aberrations Induced in Human Leukocyte Chromosomes by ^{3}H-Labeled Nucleosides," Cytogenetics 1, 65 (1962).

Betterton, J. O., Jr., G. D. Kneip, Jr., D. S. Easton, and J. O. Scarbrough, "Size Effect and Interstitial Impurities in Nb_3Zr Superconductors. Superconducting Solenoids with Metal Insulation," in Superconductors (ed. by M. Tanenbaum and W. Wright), Interscience-Wiley, New York, 1962.

Bezkorovainy, Anatoly, and D. G. Doherty, "Comparison of Bovine and Human Orosomucoids," Nature 195, 1003 (1962).

Boom, R. W., K. S. Toth, and A. Zucker, "Radiation Survey at the LRL 184-Inch Cyclotron," Nucl. Instr. Methods 18, 472 (1962).

Boyce, R. P., and R. B. Setlow, "A Simple Method of Increasing the Incorporation of Thymidine into the Deoxyribonucleic Acid of Escherichia coli," Biochim. et Biophys. Acta 61, 618 (1962).

Brockman, H. E., "Viability of Neurospora crassa Ascospores After Heat Inactivation," Neurospora Newsletter 2, 16 (1962).

Cable, J. W., E. O. Wollan, W. C. Koehler, and H. R. Child, "Antiferromagnetism of the Antiphase Domain Structure of Pd_3Mn," Phys. Rev. 128, 2118 (1962).

Cartledge, G. H., "Radioisotopes in the Physical Chemistry of Corrosion Processes and Their Inhibition," p 549 in Radioisotopes in the Physical Sciences and Industry, International Atomic Energy Agency, Vienna, 1962.

Clayton, R. K., and P. S. Rudolph, "The Lethal Effects of Alpha Irradiation on Wild-Type and on a High-Catalase Mutant of Rhodopseudomonas spheroides," Radiation Res. 17, 839 (1962).

Coltman, R. R., C. E. Klabunde, D. L. McDonald, and J. K. Redman, "Reactor Damage in Pure Metals," J. Appl. Phys. 33, 3509 (1962).

Congdon, C. C, "Remarks in Round-Table Discussion: Embryological Development of the Immune System," J. Cellular Comp. Physiol. 60 (suppl 1), 159 (1962).

de Serres, F. J., "Heterokaryon-Incompatibility Factor Interaction in Tests Between Neurospora Mutants," Science 138, 1342 (1962).

Dolin, M. I., "Effect of Near-Ultraviolet Irradiation on the Peroxide Content of Solutions of Oxidized or Reduced Diphosphopyridine Nucleotide," Biochim. et Biophys. Acta 63, 219 (1962).

Drisko, R. N., R. H. Bassel, and G. R. Satchler, "Distorted-Waves Analysis of Quasi-Elastic (p,n) and (He^3,t) Reactions," Phys. Letters 2, 318 (1962).

Franco-Ferreira, E. A., and G. M. Slaughter, "Welding of Columbium-1% Zirconium," Welding J. (N.Y.) 42(1), 18-s (1963).

Gilliland, R. G., and G. M. Slaughter, "Fusion Welding of End Caps in Beryllium Tubes," Welding J. (N.Y.) 42(1), 29 (1963).

Goldstein, G., D. L. Manning, and H. E. Zittel, "Vanadyl Ion as a Back-Titrant for Indirect Amperometric Titrations with (Ethylenedinitrilo) Tetraacetic Acid," Anal. Chem. 35, 17 (1963).

Harmatz, B., T. H. Handley, and J. W. Mihelich, "Properties of Nuclear Levels in a Number of Odd-A Nuclei ($151 \leq A \leq 191$)," Phys. Rev. 128, 1186 (1962).

Howard, F. T., "Catalogue of Isochronous Cyclotrons," Nucl. Instr. Methods 18, 125 (1962).

Hudson, E. D., R. S. Lord, M. B. Marshall, W. R. Smith, and E. G. Richardson, Jr., "Achievement and Measurement of the ORIC Magnetic Field," Nucl. Instr. Methods 18, 159 (1962).

Inouye, H., "High-Temperature Reactions of Type 304 Stainless Steel in Low Concentrations of Carbon Dioxide and Carbon Monoxide," pp 317–42 in Corrosion of Materials, International Atomic Energy Agency, Vienna, 1962.

Jagger, John, "Photoreactivation," p 406 in McGraw-Hill Yearbook of Science and Technology: 1962 (W. H. Crouse, editor-in-chief), McGraw-Hill, New York, 1962.

Jones, R. J., "Remarks on Tune-up of Analogue II," Nucl. Instr. Methods 18, 469 (1962).

Jones, R. J., E. D. Hudson, R. S. Livingston, R. S. Lord, M. B. Marshall, W. R. Smith, W. H. White, Jr., and R. E. Worsham, "Unique Features in the Oak Ridge Isochronous Cyclotron," Nucl. Instr. Methods 18, 46 (1962).

Kelly, M. J., W. W. Johnston, and C. D. Baumann, "The Effects of Nuclear Radiation on Thermocouples," p 265 in Temperature: Its Measurement and Control in Science and Industry, vol III, part 2 (ed. by A. I. Dahl), Reinhold, New York, 1962.

Lamphere, R. W., "Fission Cross Section and Fragment Angular Distribution for Fast Neutron-Induced Fission of U^{234}," Nucl. Phys. 38, 561 (1962).

Livingston, R. S., E. D. Hudson, R. J. Jones, R. S. Lord, J. E. Mann, J. A. Martin, F. M. Russell, N. F. Ziegler, and A. Zucker, "Concepts of an Mc^2 Cyclotron," Nucl. Instr. Methods 18, 438 (1962).

Magni, G. E., and R. C. von Borstel, "Different Rates of Spontaneous Mutation During Mitosis and Meiosis in Yeast," Genetics 47, 1097 (1962).

Martin, J. A., and J. E. Mann, "Beam Characteristics in Cyclotron Analogue II," Nucl. Instr. Methods 18, 461 (1962).

McCoy, H. E., Jr., "The Influence of Various Gaseous Environments on the Creep-Rupture Properties of Nuclear Materials Selected for High-Temperature Service," pp 263–96 in Corrosion of Materials, International Atomic Energy Agency, Vienna, 1962.

Monesi, Valerio, "Relation Between X-Ray Sensitivity and Stages of the Cell Cycle in Spermatogonia of the Mouse," Radiation Res. 17, 809 (1962).

Murray, R. B., "Specific Heat of Single-Crystal $MnCl_2$ in Applied Magnetic Fields," Phys. Rev. 128, 1570 (1962).

Peck, H. D., Jr., "Metabolism of Inorganic Sulfur Compounds," p 312 in McGraw-Hill Yearbook of Science and Technology: 1962 (W. H. Crouse, editor-in-chief), McGraw-Hill, New York, 1962.

Picklesimer, M. L., "A Note on Some of the Intermediate Phases in the Nb-Sn System," Appl. Phys. Letters 1, 64 (1962).

Popp, R. A., "Studies on the Mouse Hemoglobin Loci. V. Differences Among Tryptic Peptides of the β-Chain Governed by Alleles at the Hb Locus," J. Heredity 53, 142 (1962).

Popp, R. A., "Studies on the Mouse Hemoglobin Loci. VI. A Third Allele, Sol^3, at the Sol Locus," J. Heredity 53, 147 (1962).

Popp, R. A., "Studies on the Mouse Hemoglobin Loci. VII. Differences Among Tryptic Peptides of the α-Chain Governed by Alleles at the Sol Locus," J. Heredity 53, 148 (1962).

Popp, R. A., and Diana M. Popp, "Inheritance of Serum Esterases Having Different Electrophoretic Patterns Among Inbred Strains of Mice," J. Heredity 53, 111 (1962).

Ritter, R. C., P. H. Stelson, F. K. McGowan, and R. L. Robinson, "Coulomb Excitation with Ne^{20} Ions," Phys. Rev. 128, 2320 (1962).

Robinson, M. T., D. K. Holmes, and O. S. Oen, "Monte Carlo Calculations of the Ranges of Energetic Atoms in Solids," p 105 in Le Bombardment Ionique, Centre National de la Recherche Scientifique, Paris, 1962.

Robinson, R. L., N. R. Johnson, and E. Eichler, "Decay of Cs^{132}," Phys. Rev. 128, 252 (1962).

Russell, Liane B., "Chromosome Aberrations in Experimental Mammals," p 230 in Progress in Medical Genetics, vol II (ed. by A. G. Steinberg and A. G. Bearn), Grune & Stratton, New York, 1962.

Schmitt, H. W., J. H. Neiler, F. J. Walter, and A. Chetham-Strode, "Mass Distribution and Kinetics of U^{235} Thermal-Neutron-Induced Three-Particle Fission," Phys. Rev. Letters 9, 427 (1962).

Sibley, W. A., and E. Sonder, "F- and M-Absorption in Heavily Gamma Irradiated KCl," Phys. Rev. 128, 540 (1962).

Smith, L. H., and T. W. McKinley, Jr., "Erythrocyte Survival in Guinea Pigs," Proc. Soc. Exptl. Biol. Med. 111, 768 (1962).

Smith, L. H., and O. Vos, "Sensitivity and Protection of Mouse Bone Marrow Cells X-Irradiated in Vitro," Intern. J. Radiation Biol. 5, 461 (1962).

Smith, M. J., "Determination of the Nonstoichiometric Doping Mechanism in Bi_2Se_3," Appl. Phys. Letters 1, 79 (1962).

Southern, A. L., W. R. Willis, and M. T. Robinson, "Sputtering Experiments with 1- to 5-kev Ar^+ Ions," J. Appl. Phys. 34, 153 (1963).

Stulberg, M. P., and G. D. Novelli, "Amino Acid Activation," p 401 in The Enzymes, vol 6 (ed. by D. Boyer, Henry Lardy, and Karl Myrback), Academic Press, New York, 1962.

Tong, K. N., and B. L. Greenstreet, "Experimental Observations on Creep Buckling of Spherical Shells," pp 587–96 in NASA TN D-1510, Collected Papers on Instability of Shell Structures – 1962.

Upton, A. C., "Comments on Report of the United Nations Scientific Committee on the Effects of Atomic Radiation," Cancer Res. 22, 1139 (1962).

von Borstel, R. C. (ed.), "Carbondale Yeast Genetics Conference (November 16–18, 1961)," Microbial Genetics Bull. 19 (suppl), 1963.

Watson, C. D., G. A. West, and W. F. Schaffer, Jr., "Performance of Mechanical Equipment for Dejacketing Spent SRE Core I Fuel," p 219 in Proceedings of the 10th Conference on Hot Laboratories and Equipment, American Nuclear Society, Washington, D.C., November 26–28, 1962.

White, W. H., Jr., B. Duelli, and R. J. Jones, "Beam-Phase Measurement Studies," Nucl. Instr. Methods 18, 601 (1962).

White, W. H., Jr., "Magnet Regulator for ORIC," Nucl. Instr. Methods 18, 170 (1962).

Williams, C. W., and J. H. Neiler, "Design Considerations for Maximum Bandwidth in Transistorized Pulse Amplifiers," IRE Trans. Nucl. Sci. 9(5), 1 (1962).

Young, F. W., Jr., "Etch Pit Studies of Dislocations in Copper Crystals Deformed by Bending: I. Annealed Crystals; II. Irradiated Crystals," J. Appl. Phys. 33, 3553 (1962).

Ziegler, N. F., "A High-Voltage Regulator for the ORNL 86-Inch Cyclotron," Nucl. Instr. Methods 18, 197 (1962).

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