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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

JULY 1961

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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

JULY 1961

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

REACTOR DEVELOPMENT PROGRAM

GAS-COOLED REACTOR PROJECT

EGCR Multiplication Factor. – The enrichment and the loop configuration of the EGCR at startup have now been specified to the extent that some degree of permanence may be attached to calculations of the absolute multiplication factor of the core. Results available from the first series of calculations on the exact configuration are listed below:

Core Condition	k_{eff}
Cold, clean	1.161
Hot, clean	1.115
Hot, equilibrium Xe and Sm	1.087
Cold, clean, 21 control rods	0.921
Cold, clean, 20 rods (N withdrawn)	0.938
Cold, clean, 17 rods (G, Φ, T, M withdrawn)	0.986
Cold, clean, 17 rods (F, H, U, S withdrawn)	0.972
Cold, clean, 17 rods (C, P, X, L withdrawn)	0.977

A full core loading of 234 channels at 2.46% enrichment was used for the calculations. The four large loop positions and two small loop positions are to be plugged with graphite on steel support rods. The calculations indicate that the reactor will be subcritical with any five rods withdrawn unless one of them is the central rod (rod N). The control conditions described above give the maximum multiplication factors for the reactor; fission product poisons and fuel burnup will reduce the closeness of approach to critical.

Measurement of Absorption Cross Section of Coated Graphite for EGCR. The thermal-neutron absorption cross sections of EGCR graphite support

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sleeves before and after application of a siliconized-SiC coating were measured in the Hanford Test Reactor. The average increase was 0.836 mb/wt % coating. This measured increase is about 10% higher than the value predicted from the chemical analysis; however, an increase of 6 ppm in the boron content would account for the difference.

Beryllium-Clad Fuel Element for EGCR. – The design of a beryllium-clad fuel element for the EGCR has progressed to the point where only tolerance and detail drawings are required for completion. The assembly consists of nineteen 0.5-in.-OD elements arranged on an equilateral triangular pitch. It fits into a hexagonal hole with rounded corners in the graphite support sleeve for the fuel assemblies.

Irradiation Program. – Additional examinations of ORR-irradiated EGCR prototype capsules were completed. These capsules consist of UO_2 pellets clad with stainless steel. The fuel pellets from the group I capsules, the first group irradiated in the ORR, were somewhat more cracked than those in the group II capsules. No significant dimensional changes were noted on the two pellets, which were removed intact. As with capsules previously examined, slight decreases in bulk density and increases in immersion density were found. The average diameter of the central BeO rod from capsule 04-1 decreased from 0.321 to 0.318 in., a somewhat greater change than was observed in the BeO rod from capsule 04-2.

Metallographic examinations of samples of cladding from group II capsules have resulted in definite identification of sigma phase in the grain boundaries. In addition, an unidentified spherical precipitate, with the greatest concentration at the inner surface, was observed. Two cladding samples containing embedded UO_2 gave some indication of chemical reaction, but no fission-fragment damage was observed in either sample.

The measured Kr^{85} release from ORR-irradiated group I and group II capsules was compared with the calculated release, and good agreement was obtained. In the calculations the thermal conductivity of the UO_2 was assumed to be 0.028 w cm^{-1} $(°C)^{-1}$. Capsules with a 3-mil helium-filled gap between the pellets and the cladding and capsules with no gap were treated in the calculations. The release-rate parameter (D') values were estimated from the BET (nitrogen) surface areas of the pellets. Most of the measured values of Kr^{85} release from capsules irradiated at a surface temperature of ~700°C were near those predicted for a capsule with a 3-mil gap, whereas the measured values for capsules irradiated at a surface temperature of ~800°C agreed more nearly with those predicted for the no-gap case.

Three beryllium-clad UO_2 pellets from the ORR-irradiated group III capsules are being examined. Two of these capsules, designated 03-3 and 04-3, were fabricated by the French CEA, and ORNL made a counterpart that is numbered 02-3. The only change observed in the appearance of the capsules was some darkening and roughening of the central protion of the cladding of capsule 02-3. Small increases in diameter, up to about 0.003 in., were measured in the central regions of all three capsules. Bowing increases of about 0.010 in. were measured for capsules 02-3 and 03-3. This was more than twice the bowing increase for capsule 04-3.

Gas samples obtained by drilling the capsules gave fission-gas release data that were consistent with previous data. Capsules 03-3 and 04-3 were cut open with a high-speed abrasive wheel in a manner identical

to that used to open stainless steel capsules. No unusual appearance of the cladding or UO_2 pellets was noted. Although the pellets were badly cracked, four were removed intact and measured. There was no significant difference from nominal preirradiation dimensions. When the attempt to open capsule 02-3 was made, the central portion of the beryllium cladding broke into about six pieces, indicating that the capsule was under considerable stress and was extremely brittle. Also, the UO_2 pellets appeared to be more thoroughly broken than those in capsules 03-3 and 04-3.

The first four MTR-irradiated graphite-clad UC_2-fueled capsules are being examined. Metallographic examination of the threaded seal plugs has indicated that only the top, or outermost, thread was effectively sealed in both can A and can B of assembly MTR-48-1. The top half of the seal region in assembly MTR-48-2 contained siliconized-SiC seal material. There was a crack in the bottom of this sealed region, however, which corresponds to the externally observed defect, and the seal material had diffused throughout the end plug. Radiochemical analysis of the Inconel flux-monitor wire from assembly MTR-48-3 showed that fuel pellet A received a considerably larger neutron dose than the other three pellets of the assembly: 2.7×10^{19} compared with 1.4×10^{19} to 1.7×10^{19} neutrons/cm^2. Assembly MTR-48-4 was examined visually and then leak-checked in hot oil and under a helium pressure of 20 psig. No failure in the graphite can has been detected.

An examination was made of the thin-plate sample of UO_2 which had exhibited an increasing rate of gas release with time in the LITR instantaneous fission-gas release apparatus. The UO_2 had a burned, flaky appearance, and the oxygen-to-uranium ratio was 2.66, which is the composition of U_3O_8. It seems apparent that the UO_2 was oxidized during irradiation, although just how and when remain to be determined.

The UO_2 now being irradiated is in a 3% hydrogen–97% helium sweep gas. This atmosphere has apparently been effective in preventing in-pile oxidation of the UO_2 by trace amounts of oxygen in the sweep gas. This was determined by allowing the sample to operate at constant conditions for one reactor cycle. During this time, the rate of emission of Xe^{133}, Xe^{135}, Kr^{85m}, and Kr^{88} remained constant. Since oxidation of the UO_2 results in an increased fission-gas release rate, this constant rate is considered evidence that the UO_2 has not been oxidized.

GCR-ORR Loop No. 2. – The GCR-ORR loop No. 2 components test program is approximately 80% complete. The heater, regenerator, evaporator, and condenser have been tested as separate entities. Construction of the loop is 90% complete. All main piping runs have been fabricated and installation is 40% complete. Construction work has started on the 24-in. top plug, which is scheduled for insertion in the reactor beam hole during the October shutdown. The control panels and the instrument penetration plugs and connector plates are being assembled. All tie-ins to the reactor cooling water, pool cooling water, process cooling water, and demineralized cooling water and to the drains associated with these systems were made during the most recent reactor shutdown.

Transport of Gas Through Graphite Pores. – Experimental measurements of the interdiffusion rates of noble gases in AGOT, Speer, and CEY (coated and uncoated) graphite specimens at uniform pressure were completed. This information is now being used for testing the validity of various concepts

incorporated in a proposed diffusion model for porous media. Application of the model to more permeable graphite indicates that all conclusions and flow equations for uniform pressure conditions remain valid. It appears that the model is applicable to all porous materials that possess continuous porosity at all pressures.

Drift of Thermocouples at High Temperatures. – Stability tests of stainless-steel-sheathed Chromel-P–Alumel thermocouples in pure atmospheres at 870°C were continued. Couples exposed to carbon monoxide maintained a constant positive error (+0.22 mv, +5.5°C) after 85 days. The couples being tested in a hydrogen atmosphere have continued to drift negatively at a rapid rate. After 46 days they indicate an average error of −1.22 mv (−40°C). A new series of tests is being started in a graphite-helium environment at 705°C.

Chromel-A and Chromel-AA bare wires do not exhibit large negative emf drifts in helium atmospheres at 1000°C, but Chromel-P and Special Chromel-P do undergo large negative drifts because of selective intergranular attack on chromium by oxidizing impurities. Metallographic examination of Chromel-A and Chromel-AA wires exposed for 600 hr at 1000°C revealed slight surface corrosion but essentially no intergranular oxidation. A small amount of precipitate was noted along the grain boundaries of the exposed wires; however, the phase has not yet been identified.

Coated-Particle Fuel Element Studies. – The coefficient for diffusion of Xe^{133} through pyrolytic carbon was calculated for a sample irradiated at 2180°C. The calculated coefficient agreed with tentative measurements at Battelle.

Fueled-graphite specimens, representative of those to be irradiated in helium-sweep capsules (MTR-48-5), are being checked for fission-gas release by neutron activation and postirradiation annealing. A specimen containing 1.37 g of normal UC_2 as pyrolytic-carbon-coated UC_2 spheres released 0.001% of the Xe^{133} while being heated for 2 hr at less than 200°C, and about 0.03% during the entire test, which included about 20 hr at 600°C and 20 hr at 1000°C. A significant fraction of the gas collected was released during the brief intervals in which the temperature was being increased.

Two static capsule assemblies (L-CP1 and L-CP2ab) are being irradiated in the LITR. Assembly L-CP1, containing highly enriched UC_2 particles coated with pyrolytic graphite by High Temperature Materials, Inc., is operating at central temperatures of 1775 and 1995°F, respectively, in the "a" and "b" capsules. Initially these specimens operated at 1950 and 2150°F. These temperatures are lower than those indicated initially because an incorrect reference-junction compensation was applied in determining the earlier values.

Assembly L-CP2ab contains highly enriched UC_2 particles coated by the Minnesota Mining and Manufacturing Company. Initial central temperatures of 2355 and 2475°F were observed for the "a" and "b" specimens respectively. The "b" thermocouple failed shortly after startup; the "a" thermocouple has shown a gradual decline of approximately 3°F per day and is presently indicating a temperature of 2210°F.

THORIUM UTILIZATION PROGRAM

Planning and Evaluation Studies. — Studies of a large, one-region, graphite-moderated (impervious graphite), molten-salt thorium reactor fueled with U^{233} indicated that fuel-cycle costs as low as 0.85 mill/kwhr can be achieved. Burnup costs were 0.25 mill/kwhr and the breeding ratio was 0.86; fissionable isotopes were assumed to be recovered by the fluoride volatility process, with the salt and thorium discarded on a 1000-day cycle.

For the two-region molten-salt thorium reactor considered in ORNL CF-61-3-9, it was assumed that impervious graphite would contain the salt. If INOR-8 liners 20 mils thick were placed inside the bayonet fuel tubes, the maximum breeding ratio of this reactor would be about 1.0, and the associated fuel-cycle cost would be about 1.8 mills/kwhr. At lower breeding ratios and with U^{233} feed, the fuel-cycle cost could approach 0.85 mill/kwhr.

Fuel-cycle costs were studied for CANDU-type reactors fueled with thorium. Based on the old uranium price schedule ($17 per gram of U^{235} for highly enriched uranium), 4% inventory charge, countercurrent fueling, $15 per gram for U^{233}, and AEC cost bases, the fuel-cycle costs for the first cycle were about 2.4 mills/kwhr for U^{235} fueling and about 2.1 mills/kwhr for U^{233} fueling. In the latter case it was assumed that the fuel-fabrication cost for U^{233} elements was $64 per kilogram more than that for U^{235} elements. If no fabrication-cost penalty were associated with the use of U^{233}, the fuel cost would be about 1.8 mills/kwhr. (The above figures include a 1.0-mill/kwhr inventory-plus-loss charge for heavy water.) Based on the present cost schedule ($13.7 per gram of U^{235} for highly enriched uranium, and 4.75% fuel inventory charge), the above fuel costs would be about 2.1, 2.2, and 1.9 mills/kwhr respectively.

Testing of Thoria-Pellet and -Suspension Fuels. — Evidence of radiation damage to thoria and thoria-urania slurries suspended in D_2O and exposed to high temperature and reactor irradiation in autoclaves has recently been obtained from crystallite-size measurements by x-ray diffraction. The samples (sometimes quite small) were taken from slurry which remained in previously opened autoclaves and which had not been included in the main bulk of slurry recovered initially.

Small samples of a slurry of pure thoria, autoclaved under O_2 at 280°C without any irradiation, showed crystallite sizes of between ~500 and ~1000 A; the thoria irradiated for 261 hr in the HB-6 facility of the LITR indicated crystallite sizes of between 320 and 420 A.

Unexposed thoria-urania containing 0.5% U (based on Th) showed a crystallite size of greater than 2500 A. A slurry of this material that had been irradiated under an O_2 overpressure at 280°C, developing a dose of 8.0×10^{16} fissions per gram of solids, had an average crystallite size of 115 A. An average crystallite size of 105 A was obtained for a slurry of this material that had been irradiated at 280°C under a D_2 overpressure to a dose of 1.3×10^{17} fissions per gram of solids.

The original unexposed thoria-urania containing 5% U (based on Th) used in the next four experiments indicated an average crystallite size of 1715 A. The slurry autoclaved at 280°C under an O_2 overpressure for 1143 hr without any reactor irradiation indicated an average crystallite

size of 1040 A. A similar slurry irradiated to a dose of 2.4×10^{17} fissions per gram of solids showed an average postirradiation crystallite size of 125 A. In a slurry irradiated under a D_2 overpressure to a dose of 4.3×10^{16} fissions per gram of solids, an average crystallite size of 240 A was obtained. In the fourth experiment an average crystallite size of 145 A was observed for a slurry irradiated under an O_2 overpressure to a dose of 6.3×10^{17} fissions per gram of solids.

Engineering of Thorium Reactor Systems. – Turbulent friction factors of an aqueous thoria slurry containing particles with an average diameter of 0.8 μ were measured at various velocities in the temperature range 25 to 280°C. The friction-factor–Reynolds number correlation was the same as that observed earlier with slurries containing larger particles. Suspensions containing up to 10 vol % solids were readily circulated in the 200B loop.

The new high-temperature capillary viscometer associated with the 200B loop became plugged after a few successful runs at temperatures up to 41°C.

Homogeneous Reactor Experiment No. 2. – The last of six corrosion-specimen assemblies was removed from the HRE-2 piping. The core-tank thickness was measured, and the interior of the core was examined. There was no significant change in thickness in the 2900 hr of operation during the past year. The general condition of the inside surface of the core was also unchanged. All systems are secured for indefinite standby except for those parts which will be used during the fuel and heavy-water removal operations later this year.

MOLTEN-SALT REACTOR PROGRAM

MSRE Design: Components, Systems, and Structures. – Component designs for the MSRE reactor vessel, drain tanks, heat exchanger, and radiator were completed. Drawings and specifications were issued to the Purchasing Department.

Some changes in design of the reactor cell were necessary to make the cell closure and penetrations consistent with the cell vessel in pressure rating. The cell containment was modified in this regard, and the drawing changes were made a part of the lump-sum facility bid package.

The fuel-pump support was detailed. Structural-steel design for the fuel system was completed. Design of the reactor thermal shield is 75% complete.

Work was begun on the process flowsheets which had not been completed previously – those for the cooling-water and sampler systems. All other flowsheets are being revised following the original issue for comment.

The basic power distribution plan was decided. Detailing of circuit layout is continuing without difficulty.

Layouts for the cover-gas and off-gas systems were issued for review and comment.

MSRE Design: Instrumentation. – Instrument application diagrams for the cooling-water system and the containment air system were prepared, and the containment air system drawing was issued for comment. Application

diagrams are being prepared for the liquid-waste system and the sampler-enricher system. Tabulation of instrumentation in these systems is in progress.

Instrument application diagrams for the fuel- and coolant-salt systems and for the associated gas and lubricating-oil system are being revised in order to incorporate the changes which result from revision of the design of the reactor system and to include new information.

A drawing which shows a conceptual graphic layout of instrumentation on the main control panel was completed and was issued for comment.

A preliminary panel layout was made for the lubricating-oil system instrumentation located in the spectrometer tunnel.

Specifications were prepared for the 30-in. butterfly valves and operators. These valves will be used in the reactor exhaust system. Additional specifications were prepared for damper operators that are used in the high-bay area and radiator-head exhaust ducts, and for rotameters and control valves used in the cooling-water system.

Discussions were held to develop criteria for the reactor safety control system, and work was started on the elementary control-circuit diagrams.

MSRE Design: Maintenance Equipment. – Design and drafting of the manipulator track and supporting frame and the specifications for the manipulator were completed. Design for the television vehicle is continuing.

A preliminary design of the jigs for assembling and thermal cycling the major components of the MSRE was completed, the concept was accepted, and detail design was begun.

The design of the top-shield beam-lifting tool and the specifications for the lower-shield plug-lifting tongs were completed.

MSRE Procurement and Construction. – Purchase contracts were awarded for furnishing INOR-8 plate, sheet, rod, and weld wire. Bids are being reviewed for INOR-8 pipe, tubing, and fittings.

Requests for bids to furnish the MSRE moderator graphite in the finished machined condition were sent to prospective suppliers. Bids will be opened August 14.

Drawings and specifications were sent to prospective fabricators for bidding on the fabrication of the MSRE heat exchanger, radiator, reactor vessel, and fill and drain tanks. Contracts for fabricating these components will probably be awarded in August.

Drawings and specifications for the first lump-sum contract package for major modifications to Building 7503 were sent to contractors for bidding. The closing date for bids is August 22. This package includes structural changes to the building and the reactor cell and installation of air-handling, electrical, and mechanical services.

The cost-plus-fixed-fee contract work to prepare Building 7503 for the major changes was completed in June on schedule. This work consisted in stripping out old structural steel, wiring, and conduit; demolition of walls; excavation of pits; and the construction of a new outside fire-exit stairway.

Chemical Development. – Removal of oxide ions during molten-salt fuel purification is accomplished by a thorough treatment of the melt with HF. In the past, excessively long periods of treatment with H_2 have been required to remove the corrosion products arising from attack of the nickel

or copper containers by HF. Difficulties of this nature are aggravated by the fact that the reduced metal produced during finishing treatment with H_2 remains as a heel, and the processing containers are used repeatedly with only the liquid product being withdrawn through a dip tube. In this way iron and nickel, for example, accumulate in increasingly large amounts of dendridic or powdery deposits of great surface area; such deposits are readily attacked by HF and lead to difficultly removable high concentrations of reducible cations.

The 600 kg of MSRE fuel purified during the past two months has been treated with HF diluted with slightly more than an equal volume of H_2. The effect of the H_2 has been to reduce markedly the corrosion during the HF step, with little noticeable effect on the oxide removal rate, and to reduce processing times for a 100-kg batch from two weeks to one week.

Radiation Effects. – Control MSRE graphite-fuel capsules for comparison with those currently undergoing irradiation in the MTR (experiment ORNL-MTR-47-3) were opened after five freeze-thaw cycles to emulate the effect of reactor shutdowns. The contents were in good condition, revealed distinctly nonwetting characteristics, and showed no damage or change other than that the fused salt was cracked into several pieces. Presumably the cracking was due to cooling contraction around an inserted graphite blade, since customarily, or in the absence of inserts, the fuel freezes without cracking.

Heat Transfer and Physical Properties of Molten Salts. – In order to further clarify the heat-balance discrepancy noted in the heat-transfer studies with the salt mixture $LiF-BeF_2-ThF_4-UF_4$ (67.0-18.5-14.0-0.5 mole % nominal), the enthalpy of the liquid was redetermined by using a sample of circulated salt. Analysis of the data yielded the following expression for the enthalpy between 500 and 800°C:

$$H_t - H_{30}\ (\text{cal/g}) = -17.1 + 0.354t - (1.37 \times 10^{-5})t^2$$

for t in °C. The value obtained earlier with a salt sample taken prior to exposure in the loop was

$$H_t - H_{30} = -61.5 + 0.493t - (11.71 \times 10^{-5})t^2 \ .$$

While the maximum variance in enthalpy as calculated from these two equations is only 1%, the difference in the curvature of the two sets of data is sufficient to cause significant difference in the heat capacities. Thus, over the same temperature range (500 to 800°C), the heat capacity of the uncirculated salt varies from 0.376 to 0.306 cal g^{-1} $(°C)^{-1}$ and that of the circulated sample varies from 0.340 to 0.332 cal g^{-1} $(°C)^{-1}$.

STUDIES AND EVALUATIONS

Reactor Evaluation Studies. – Calculations were made for determining the fuel value of U^{233} in various reactors. The fuel cycles studied considered U^{235} in thorium, and U^{233} in thorium with uniform-batch irradiation. Based on the old uranium price schedule and assuming U^{233} elements

to have the same fabrication costs as U^{235} elements, the value of U^{233} was \$20.3 and \$21.4 per gram in Dresden- and Yankee-type reactors respectively; if the fabrication cost of U^{233} elements were about \$60/kg more than that of U^{235} elements, the above values would be \$17.7 and \$19.5 per gram respectively. Calculations were also performed by using the present uranium price schedule (about \$13.7 per gram of U^{235} for highly enriched uranium). The U^{233} value was a function of reactor type and fuel composition; it ranged from \$15 to \$20 per gram of U^{233} in Dresden, Yankee, GCR-2, and CANDU reactor types fueled with thorium.

The Expire reactivity-lifetime program was modified so that it now incorporates a P-3 and a neutron-temperature calculation as an integral part of the computation.

HIGH-TEMPERATURE MATERIALS DEVELOPMENT

Oxidation and Cladding of Columbium. – The presence of a columbium nitride layer on columbium exposed to low-pressure oxygen at 1000°C was found to be ineffective in lowering the oxidation rate. These tests lend support to the concept that N_2 in air lowers the oxidation rate of columbium by an order of magnitude as a result of competition for adsorption sites rather than the formation of a protective nitride layer.

Oxidation tests of several alloys were conducted at 1800°F in air to aid in the selection of cladding suitable for protecting columbium. Type 446 stainless steel and Haynes alloy No. 25 had weight gains of about 2.4 mg/cm^2 after 300 hr of exposure. Although type 310 stainless steel oxidized to the same extent as the above alloys, an acceleration in its oxidation rate was observed after about 200 hr. The weight gain of an aluminum bronze (94% Cu–6% Al) at 1800°F was only about 0.3 mg/cm^2 in 300 hr of exposure to air.

Columbium was clad with an aluminum bronze (92% Cu–8% Al) by hot rolling at 1750°F using the picture-frame technique. Attempts to mechanically strip the bronze from the columbium indicated good bonding; however, subsequent cold rolling of samples resulted in bond failure because of an intermetallic compound at the interface. The outer surfaces of Cb–1 wt % Zr tubes were clad with aluminum bronze and with type 446 stainless steel by co-drawing, and evaluation of these types of tubing is in progress.

Aging Studies of Columbium-Zirconium Alloys. – Lattice parameter measurements were made on Cb–0.88% Zr specimens contaminated with up to 1500 ppm O_2. These measurements were made on specimens solution annealed at 2912°F and on specimens which were annealed and then aged 100 hr at 1700°F. The lattice parameters for specimens in the as-annealed condition increased with increasing oxygen content to a value of approximately 3.3025 A at 400 ppm and subsequently decreased to approximately 3.3010 A at 1500 ppm. The lattice parameters for the aged specimens showed considerable scatter but had a general downward trend as the oxygen increased from 200 to 1500 ppm. These data indicate that there is a solubility limit of approximately 400 ppm O_2 in columbium-zirconium alloys at 2912°F and a lower solubility at 1700°F.

Internal Friction Studies on Columbium-Zirconium Alloys. – Internal friction measurements were made on Cb–0.66% Zr alloy specimens which had

been annealed at 3500°F in order to place their oxygen content in solution. Specimens contaminated with large amounts of oxygen showed a high peak in the logarithmic decrement at ~155°C and a lower peak at ~285°C. Measurements made at the 155°C peak are:

Peak Height, δ (logarithmic decrement)	O_2 Content (ppm)
< 0.002	277
0.3	6500
< 0.0005	487
0.134	4260

A specimen of Cb–0.74% Zr showed a peak at ~210°C and a complex damping peak between 300 and 500°C. This latter peak apparently consists of at least two peaks superimposed. All the peaks in this damping spectrum decline in height on aging and almost disappear after 90 hr at 800°C.

Stability of Materials in Boiling Potassium. – Thermal-convection loops constructed of Inconel and Haynes alloy No. 25 were placed in operation with the potassium boiler temperature at 1600°F. The design was completed of thermal-convection loops for testing refractory alloys at high temperatures in inert atmospheres. Preliminary designs were prepared for loops containing a potassium boiler section, a constriction to provide dust deposition, converging-diverging nozzles to provide condensation, samples of turbine blade materials to test dust deposition and erosion effects, a condenser section, and a pump for forcing liquid potassium back into the boiler. Loops of this type are to be operated in air when constructed of oxidation-resistant material, such as type 316 stainless steel, and in high vacuum when the structural material is a refractory alloy that is readily oxidized.

ADVANCED REACTOR DEVELOPMENT

High Flux Isotope Reactor Design and Development

Control and Instrumentation. – Drawings are nearly complete for the instruments and associated equipment which are to be installed in the initial contract.

Calibration tests have been completed on the prototype safety temperature sensors, which appear to be satisfactory.

The performance of the HFIR regulating system was studied with an analog computer. The simulation included the reactor, the heat exchanger, flow systems including transport lags, and pump startup and rundown characteristics. Used in conjunction with the computer was a mockup of the triple servo controller and a flux-calibrating reset mechanism. The simulation showed that the conceptual design of the regulating system is stable

and adequate for all anticipated maneuvers and operating conditions. The simulator was most helpful in developing a rather sophisticated scheme for achieving safe and adequate control at reduced flow rates in the presence of afterheat. The effects of certain failures on system performance were examined. Notable examples are the loss of all main coolant pumps and failure of the secondary heat exchanger. The regulating system will apparently handle these events without the necessity for a scram. All the above studies were made with a variety of temperature coefficients bracketing the predicted values.

The simulation will be repeated for the full-scale control drives designed for the HFIR.

Corrosion. – The experimental corrosion program has been completed, and all the data obtained are being evaluated and correlated. Preliminary results indicate that in most, but not all, cases the measured fluid-film heat-transfer coefficients were higher than those predicted by either the modified Hansen or the Seider-Tate equations and that the thermal conductivity of the corrosion product is somewhat greater than the value of 1 previously reported.

Related to the HFIR work, an experimental program in support of the Advanced Test Reactor has begun. In tests with 6061 and X8001 aluminum, at a heat flux of approximately 1.5×10^6 Btu hr^{-1} ft^{-2}, coolant temperatures of 266 to 284°F, a pH of 6 (HNO_3), and flow rates of 45 fps, maximum rates of temperature increase during the first few days of test were about 39 and 29°F/day respectively. During the latter stages of each test, "film stripping" occurred, and specimen temperatures decreased slightly. Localized attack of the 6061 specimen occurred in the film-stripped region; only uniform attack was noted on the X8001 specimen.

Metallurgy. – Work has begun on the preparation of components for the HFIR flow-test element.

In an effort to improve the uranium segregation in Al–24 wt % U alloy, several types of slab castings were induction-melted in air in graphite crucibles. Stirring was necessary to ensure melt homogeneity, and attempts were made to minimize gaseous impurities by degassing. The thinner castings were found to exhibit a more uniform uranium distribution.

A study of the Marforming variables associated with forming involute plates indicated that rubber hardness and rubber deterioration are the major factors that influence dimensional reproducibility.

The blister problem in roll-bonded outer-annulus fuel plates was qualitatively defined. Information obtained from a series of experiments indicates that the outer-fuel-plate blistering can be eliminated by using frames and cover plates clad with 6061 aluminum and by vacuum-annealing the components prior to plate rolling.

A modified welding procedure was devised for the flow-test element. The modified procedure is more suited to mass production, is replaceable by automatic techniques, and should involve less weld shrinkage and distortion than techniques previously used.

Design. – Revised assembly drawings, giving criteria for detail drawings, were completed for the HFIR core. The detail drawings are now being prepared for use in procurement of parts for the full-scale HFIR hydraulic mockup. In the revised design, provisions are made for the optional use of either sleeve bearings or skids on the ends of the control rods.

The beam-tube thimbles were revised to permit independent cooling of the thimble wall.

Detailed drawings of the beryllium reflector are now being prepared. The coolant-gap thickness in the removable reflector assembly was reduced from 50 to 27 mils because of the adverse reactivity effects of water in this region.

Nine additional 3-in.-diam vertical holes were provided in the permanent reflector. Seven of these are located in the outermost 4 in. of the permanent reflector. Experiments inserted into these holes may be cooled either with reflector cooling water or cooling water directly from the primary reactor supply.

Analyses of the control-rod hydraulic pressure differentials and resultant deflections and stresses indicated that use of holes in the control-rod plates would be one of the methods of maintaining the bearing stresses within tolerable limits for the size of bearings under consideration. Therefore, 1/4-in. holes on 2-in. centers are being proposed for the gray (nickel) and white (aluminum) regions of the control rods.

Drawings of the control-rod release mechanism were issued for procurement of the mechanism for testing in the mockup. Design of the drives was completed, and all components are being procured except the drive-position indication equipment, drawings for which are now being reviewed.

Current target-assembly designs are based on a concept utilizing a clamped bundle of finned tubes. The fins provide additional cooling surface and serve as spacers between individual rods. The clamp arrangement provides a convenient method of assembling and servicing the target array.

A study of after-shutdown cooling requirements indicates that emergency forced circulation should be provided for about 1 hr after shutdown, or until the target assembly can be removed to provide an ensured downcomer area for the fuel element.

Studies to evaluate the effects of blistering are now in progress. The off-center location of the "meat" in the HFIR fuel plates will result in a hot-spot temperature increase of about 10°F (364°F oxide-water surface temperature) and a maximum heat flux increase of 9.5% (1.73×10^6 Btu hr^{-1} ft^{-2} maximum heat flux) over the values previously reported.

Critical Experiments. – HFIR critical experiment No. 2 has been in progress for nearly two months, and the temperature coefficient of reactivity, void and fuel coefficients of reactivity, and relative power distributions have been determined. The experiment was critical with the control plates adjusted to a 10.5-in.-long overlap of the nickel (gray) sections – that is, with a 10.5-in.-long "gray window" and the fuel element juxtaposed. In this position the copper-silver (black) section of each plate was inserted about 4.7 in. When the target was removed, the gray-window length was increased to 13.4 in. From 25 to 70°C the over-all isothermal negative temperature coefficient of reactivity with the target in place was $(2.8 \times 10^{-5})/°C$; without the target it was less than $(2.8 \times 10^{-6})/°C$. The fuel-region temperature coefficient of reactivity was $(-1.1 \times 10^{-4})/°C$ at 25°C and $(-1.8 \times 10^{-4})/°C$ at 70°C. The water content of the target region, with the target removed, was decreased progressively by adding cylinders of Styrofoam, and the resulting change in reactivity was observed to reach a maximum of \$4.4 when 70% of the water was displaced. Although with the target in place a distributed void representing 40% of

the volume was worth $2.3, it was not possible to achieve the maximum reactivity change. Fuel and void coefficients of reactivity were measured in the fuel element. The power distributions measured with foils punched from fuel plates have shown that, for the above position of the control plates, the beam holes in the beryllium are not perturbing the power distributions significantly. Measurements of the power distribution with foils in a fuel plate having a reversed uranium gradient indicate that a single reversed plate does not change the flux appreciably and that local power distributions can be estimated from the local flux and the uranium content. Some flux measurements were completed in the water reflector outside the beryllium and also below the fuel element. The control plates were calibrated over a limited range by using the rod-bump method and positive periods only. For estimation of reactivity from the periods, it was assumed that the delayed photoneutron contribution from the beryllium was negligible and that $\beta_{eff} = 0.0064$.

SPACE POWER PROGRAM

Power Plant Design. – Conceptual design studies were continued on the single-fluid boiling-potassium space power plant system in order to achieve additional definition of the design. Experimental work has provided some data on materials and heat transfer problems, and analytical work has led to the design of experiments for investigating the hydrodynamic stability of the boiling-potassium reactor. A reference reactor core has been described for use in a program of critical experiments and calculations to determine the requirements for a neutron-stable system.

Reactor Core Design. – The key design features and parameters of reference core I are given below:

Thermal power	1 Mw
Fuel-pin-to-potassium heat transfer	2×10^5 Btu hr^{-1} ft^{-2}
Surface of fuel pins	17 ft^2
Number of fuel pins	261
Fuel-pin pitch	0.437 in., triangular
Fuel-pin length	8 in.
Fuel-pin diameter	0.375 in.
Core diameter	8 in.
Free-flow area	43%
Potassium-vapor outlet quality	≧50% vapor by weight
Potassium temperature at core inlet	~1540°F
Potassium-vapor temperature at outlet	1540°F
Vapor velocity at outlet (50% quality)	131 fps
Liquid-potassium velocity at inlet (based on 50% vapor production)	0.37 fps
Structural material	Type 316 stainless steel

Fluid Flow Stability. – The use of boiling heat transfer in a nuclear reactor leads to the possibility of flow instability within the reactor. The primary parameters affecting the flow characteristics are the amount of subcooling of the fluid entering the core, the fluid latent heat of

vaporization, and the ratio of vapor to liquid specific volumes. With proper design, it should be possible to select the operating conditions so as to avoid the unstable regime. In order to test these conclusions experimentally and to delineate the boundaries for stable operation, a forced-circulation loop for studying boiling-flow stability has been designed. The loop consists of a boiler section employing a cluster of seven 5/8-in.-diam Firerod heaters with a maximum heat input of approximately 55 kw (corresponding to a heat flux of nearly 100,000 Btu hr^{-1} ft^{-2}), a condenser and subcooler section, a pump, and a preheater section. The loop will be constructed primarily from standard Pyrex pipe and fittings to provide for visual observation of the flow phenomena. Freon-11 will be used for the fluid because of its experimentally desirable properties: low latent heat, useful vapor pressures at moderate temperatures, good range of specific-volume ratio, and nontoxicity. At the operating temperature of 120°F and pressure of 18.5 psig, a vapor quality of about 64% should be attainable at an inlet subcooling of 24°F and a flow of 1 lb/sec.

Heat Transfer. – Preliminary data have been obtained on the boiling characteristics of potassium in a temporary boiler section consisting of an 0.87-in.-ID tube with low liquid inlet velocities and low thermal fluxes. Large-scale wall-temperature fluctuations were observed during initial operation. These oscillations appear to be induced by flow instability related to the extent of inlet subcooling. Flow stability was achieved by increasing the temperature of the liquid at the inlet to the saturation value. Peak heat fluxes, determined under stable flow conditions, agreed closely with results for water boiling under similar experimental conditions. Unstable flow gave rise to burnout fluxes that were only 60% as great as the stable-flow values. Typical data taken under stable-flow conditions are given below:

Flow Rate (lb/hr)	Potassium Temperature (°F)		Heat Flux (Btu hr^{-1} ft^{-2})	Quality (%)
	Inlet	Exit		
147.2	1402	1405	31,887	33
147.2	1404	1393	32,967	34
90.9	1384	1361	33,065	61
64.6	1361	1364	32,368	81
55.5	~1360	~1360	32,368	92

Potential burnout was indicated by the wall temperature rise in the last of the runs listed above.

Shielding. – An understanding of the shielding requirements for manned space vehicles requires a new evaluation of the interaction of protons and neutrons with biological tissue. The interaction of high-energy protons from the sun with shielding materials results in the production of high-energy neutrons. Calculations are available on the physical and biological dose deposited by neutrons with energies between thermal and 10 Mev and

protons with energies up to 200 Mev. For protons with energies between 0.01 and 200 Mev the main energy-loss mechanism is ionization; for neutrons with energies between 1 kev and 10 Mev the energy is lost mainly by elastic collisions with the hydrogen in the tissue. The calculations in the current evaluation show that for neutrons with energies above 15 Mev and protons above 300 Mev the removal of energy from the primary beam by absorption is greater than the removal through elastic scattering and ionization and that as the primary energy increases, the importance of the absorption events increases. The fact that the secondary particles resulting from absorption have, on the average, much lower energies means that more energy is deposited in the tissue and with a larger RBE than would be expected from ionization and elastic scattering of the primary beam alone.

NUCLEAR TECHNOLOGY AND GENERAL SUPPORT

Basic Reactor Physics. – The special multiplate fission chamber intended for use in a measurement of the capture-to-fission ratio for U^{235}, U^{233}, and possibly Pu^{239} has been constructed and is being tested. Studies, drawing heavily on previous ORNL designs, are also in progress to optimize the design of the large aluminum tank of liquid scintillator which will be required for measurements in the region of 30 kev.

Nondestructive Test Development. – Recent investigations in the field of ultrasonic behavior in thin metal sections have included the detection and evaluation of nonbonded areas between thin clad material and heavy metal sections. Two techniques for such applications are the use of Lamb waves and the establishment of "ringing." The former technique establishes a traveling wave vibration within a thin metal section or area of nonbond. The properties of such a wave are dependent upon the ultrasonic velocity and thickness of the specimen and the ultrasonic frequency of the driving force. The "ringing" technique is characterized by an elongated reflection pulse from an area of nonbond if the clad thickness is an integral number of half-wavelengths of the ultrasonic frequency.

A typical application would be a large copper assembly used as a liquid-metal boiler for the high-temperature materials program. The component consists of a 3/8-in. stainless steel tube surrounded by concentric copper disks which are, in turn, encased in a stainless steel can. The tube-to-copper and can-to-copper interfaces are braze-bonded. A 0.30-in.-diam probe was designed to generate and detect Lamb waves for the detection of tube-to-copper nonbonds from the tube bore. A "ringing" technique was successfully applied to the detection of nonbonds in the can-to-copper joint. For such an application, nonbond areas of approximately 0.0075 $in.^2$ were detectable.

Mechanical Properties Research. – One of the many problems in designing experimental loops and tubular fuel elements is in determining, with confidence, the external pressures which will cause collapse of the tube. Elastic solutions to this problem have been performed; however, these solutions are inadequate for conditions where plastic flow occurs in the tube prior to collapse. Progress in solving the elastic-plastic problems has reached the point where pressures to cause instantaneous collapse by

surge loading can be calculated quite readily. This solution in general is similar to the elastic solution, except that a reduced modulus is used to correct for the redistribution of stresses caused by plastic flow. The more complex problem occurs at elevated temperatures, where the plastic flow is time dependent and causes a time-dependent collapse. This problem is solved at present, however, in a fairly conservative manner. The approach to the problem is now toward reducing to a more practical level the inherent built-in safety factor of the present solution.

Solid Reaction Studies. – An experiment was performed to determine the diffusion rates of Al^{26} in high-purity coarse-grained aluminum. Diffusion coefficients (cm^2/sec) were found to be: 1.134×10^{-10} at 456°C, 1.879×10^{-10} at 476°C, 4.179×10^{-10} at 502°C, 9.486×10^{-10} at 534°C, 2.543×10^{-9} at 571°C, 5.000×10^{-9} at 599°C, 8.218×10^{-8} at 622°C, and 1.180×10^{-8} at 643°C. The fit of the experimental data to an Arrhenius-type equation resulted in a frequency factor of $D_0 = 1.98\ cm^2/sec$ and an activation energy of $Q = 34{,}300$ cal/mole. Thus the self-diffusion of aluminum as a function of absolute temperature may be described by $D = 1.98e^{-34,300/RT}$.

The reaction between hot-pressed beryllium and arc-cast uranium carbides having stoichiometries of 4.8 and 5.1 wt % carbon was studied at 1000°C. Heat treatments of 24, 50, 96, 120, and 190 hr resulted in UBe_{13} layers 125, 177, 243, 255, and 300 μ thick respectively. No significant differences were noted in the rates of reaction between the beryllium and the two compositions of uranium carbide.

Materials Compatibility Studies. – The advantages of using potassium as the working fluid in Rankine-cycle turbogenerator systems for space power applications have been reported [Nucleonics 19(4), 76 (1961)]. Past work indicates that oxygen contamination of sodium and NaK adversely affects the corrosion resistance of most container materials (Liquid Metals Handbook, Sodium-NaK Supplement, p 175), and it is expected that potassium will act similarly. Potassium-oxygen studies in this laboratory have been divided into four categories: (1) solubility studies of oxygen in liquid potassium, (2) evaluation of analytical methods for determining oxygen in potassium, (3) investigation of purification techniques for lowering the oxygen content in potassium, and (4) detailed studies of the effect of oxygen as an impurity in systems containing potassium.

A limited amount of prior work indicates that the solubility level of oxygen in potassium is considerably higher than that for sodium and lithium (NRL-3894, p 8). As far as is known, the terminal oxide of potassium is the monoxide, K_2O, and this compound will be equilibrated at various temperatures in potassium to determine the oxygen solubility from subsequent chemical analyses. The preparation of high-purity K_2O has been attempted by using several techniques. Best results to date involve exposure of liquid potassium to air, followed by oxygen exposure, which has produced a product 90 wt % K_2O and 10 wt % K_2O_3.

Reactor Controls Development. – Two prototype ionization chambers of the new RC-300 series were tested in the BSR. Each chamber enclosure contains three separate active sections: two are uncompensated neutron sensitive, and one is gamma sensitive. The electrode configuration of all sections is parallel circular plate; 0.015-mm-thick aluminum plates are

used for the neutron-sensitive sections, and 0.007-mm-thick titanium plates are used for the gamma-sensitive section. The plates are spaced 1 mm apart. The chamber filling is N_2 at 1075 mm Hg pressure.

Measured sensitivities of the four neutron-sensitive sections varied from 2×10^{-15} to 4×10^{-15} amp/nv (thermal). The gamma sensitivity was $\sim 5 \times 10^{-12}$ amp-hr/r. More precise measurements are in progress.

Measurements of the voltage saturation characteristics of the chambers gave the following results:

Section	Saturated Current (amp)	Saturation Voltage (> 99%)
Gamma	1.5×10^{-6}	250
Neutron	1×10^{-4}	300
	5×10^{-4}	600

A small interaction between sections is attributable to the high-voltage leads from the "front" sections passing near the plates of the "rear" section. The interaction is entirely negligible for the neutron-sensitive sections. The interaction for the gamma-sensitive sections is also negligible for ordinary variations in the high-voltage supply.

The multiple-servo concept described in ORNL CF-61-1-82 was tested, using small motors and gears and transistor amplifiers, with the nuclear reactor simulated on the ORNL Reactor Controls Analog Computer. The calculations for the multiple-servo system were confirmed by the performance of the model, both in normal operation and with simulated failures. In this type of system, a multiplicity of identical servo systems (at least three) have their outputs added algebraically. Failure of any one servo system will not interrupt the process, since the others will always be able to "overpower" its saturated output.

Power Reactor Fuel Processing: Uranium-Graphite and Uranium Carbide Fuels. — Recovery of > 99% of the uranium and thorium from fuel specimens containing 1.5% uranium and up to 15% thorium as pyrolytic carbon-coated UC_2-ThC_2 particles by either the grind-leach (70% HNO_3) or combustion-dissolution processes was demonstrated. Recoveries were high in leaching with boiling 70% HNO_3 only when the fuel specimens were ground finer than 200 mesh, which ensured crushing of the fuel particles. The ThO_2-U_3O_8 ash from combustion of specimens in oxygen at 800 to 900°C dissolved in less than 7 hr in boiling 13 M HNO_3—0.04 M NaF—0.1 M $Al(NO_3)_3$ to yield a solution 1 M in thorium. The 90% HNO_3 disintegration-leach process was not applicable to fuels of this type; uranium and thorium recoveries were both < 10%.

Disintegration and leaching of a bed of 3/8-in. cubes of 3% U—graphite by a continuously flowing stream of 90% HNO_3 at 60°C confirmed the superiority of this method to a single extended or several successive batch leaches. Despite incomplete disintegration of the cubes, uranium was 99.86% recovered at a flow of 6 gal ft^{-2} hr^{-1} through the 2-in.-diam by 15-in.-high column. The permeability of the bed was equivalent to that of loose sand, $\sim 10^{-6}$ cm^2.

The reaction of uranium monocarbide with water at 99 and at 40°C gave virtually the same reaction products reported (ORNL-3149) at 90, 80, and 60°C, with no evidence of change with temperature. The values were, per gram of sample:

Temp (°C)	Vol (STP) (ml)	Amount (%)							
		H_2	CH_4	C_2H_6	C_3H_8	Butane	Pentane	Hexane	Unidentified
99	93.8	11.6	86.6	1.82	0.75	0.36	0.098	0.37	0.02
40	92.1	10.8	86.3	1.76	0.63	0.33	0.076	0.029	0.02

Power Reactor Fuel Processing: Solvent Extraction. – Laboratory countercurrent batch solvent extraction experiments showed no variation in fission product decontamination of zirconium-containing fuel solutions prepared by either the modified Zirflex or the Idaho hydrofluoric acid method. Ruthenium and zirconium-niobium decontamination factors were 2.6×10^3 and $> 2 \times 10^5$, respectively, with a 5% tributyl phosphate flowsheet, a 1 M HNO_3 scrub, and a modified Zirflex feed solution. Uranium losses in duplicate experiments were 0.015 and 0.004%.

A laboratory-scale Thorex process run was made in which a simulated Darex clad solution was used as the feed. Decontamination factors from ruthenium, zirconium-niobium, and rare earths were 560, 9000, and 2.5×10^5 respectively. Uranium and thorium losses were < 0.001 and 0.4% respectively.

The extraction coefficient for Nb^{95} from 4 M HNO_3 into 30% TBP–dodecane, in which 10% of the TBP had been chemically degraded, was 0.54. About 8% of the niobium was in an unextractable form. The stripping coefficient for organic-to-aqueous transfer was 0.84. The initial concentration of the Nb^{95} in the aqueous feed was $\sim 2 \times 10^5$ counts min^{-1} ml^{-1}.

Power Reactor Fuel Processing: Corrosion Studies. – Welded Haynes alloy 6B, exposed to boiling, initial, modified Zirflex dissolvent for 192 hr, was corroded at maximum rates of 3.6 and 9.6 mils/month for as-welded and solution-annealed specimens respectively. Specimens showed intergranular attack and weld decay. The same alloy exposed to boiling, initial Darex dissolvent for 72 hr was corroded at maximum rates of 10.6 and 305 mils/month in the solution and vapor phases respectively.

In 336 hr of exposure to modified Zirflex process solutions (0.75 to 1.5 M HNO_3–0.6 to 1.0 M $Al(NO_3)_3$–0.36 to 0.49 M Zr^{4+}–2.44 to 3.33 M F^-) at 50°C, type 304L stainless steel and Carpenter 20SCb suffered grain-boundary attack; type 347 stainless steel and LCNA were corroded at minimum and maximum over-all rates of 0.05 to 0.26 and 0.04 to 0.25 mil/month, respectively, with only minor local etching on the LCNA. The least corrosive of the Zirflex solutions tested was 0.75 M HNO_3–1.0 M $Al(NO_3)_3$–0.36 M Zr^{4+}–0.244 M F^-.

During exposure at 300 and 450°C for 24 hr in N_2 saturated (room temperature) with CCl_4, maximum corrosion rates (mils/month) were, respectively: Haynes alloy No. 25, 0.12 and 7.33; Nichrome V, 0.11 and 1.13; INOR-8, 0.08 and 1.16; Pyroceram, 0.01 and 0.02. Downstream specimens

of all candidate materials failed at 600°C. The reason for differences observed between upstream and downstream specimens is not clearly understood.

Power Reactor Fuel Processing: Mechanical. – The SRE core I fuel, irradiated to 675 Mwd/ton and decayed for approximately two years, is being dejacketed at a rate of 7 to 8 kg of U per hr, which is a factor of ~3 greater than the rate for the first five clusters; for these, auxiliary equipment was required to slit and pry the jackets from the uranium slugs of 4 of the first 34 rods processed. A total of 62 rods have now been processed; the uranium slugs were removed from 5 rods by auxiliary dejacketing, 23 rods were hydraulically flushed from the cladding, and 34 rods were dejacketed by running a jackscrew through the length of the fuel cladding.

The 6 in.^{3} of NaK from each fuel rod was satisfactorily disposed of in the redesigned disposal unit. Enlargement of the NaK transfer lines, rerouting of the nitrogen blanket gas, continuous blowdown of reactant steam, and isolation of water wash lines have so far resulted in safe, controlled NaK disposal; about 40 batches of NaK have now been treated in the new unit without incident.

All the dejacketed uranium slugs showed various degrees of camber and pitting, probably depending on their location in the reactor. Profilometer measurements made on a slug from a center rod in a cluster near the outer edge of the reactor showed that the slug has swollen uniformly about 18 mils in diameter. This slug was only slightly pitted and discolored. All slugs from this cluster were essentially straight, whereas slugs from other clusters showed a 10- to 30-mil camber.

Power Reactor Fuel Processing: Beryllium- and BeO-Containing Fuels. – The initial dissolution rates of BeO–5% UO_2 fuels were 0.07, 1.5, and 3.3 mg min^{-1} cm^{-2} in 8 M NH_4F, 8 M NH_4F–5 M HF, and 8 M NH_4F–20 M HF respectively. In 3.2 M KF–5 M HF, the initial dissolution rate was only 0.36 mg min^{-1} cm^{-2}, or one-third the rate in the corresponding NH_4F-HF mixture. In 3 M HNO_3–0.5 M HBF_4–0.3 M $(NH_4)_2Cr_2O_7$, the initial dissolution rate was 0.03 mg min^{-1} cm^{-2}, essentially the same as in 0.5 M HBF_4 alone. This reagent was of interest because of its potential as a dissolvent for zirconium in titanium equipment.

PHYSICAL RESEARCH PROGRAM

Reactor Operations. – The proposal to increase the operating power to 40 Mw has been completed and is being reviewed. The operating time at the ORR during the quarter ending June 30 was 81.2%.

Waste Disposal. – The proportional samplers in the White Oak Creek drainage system were completed, and it was possible to measure the amounts of radioactivity coming from different sources. About half the strontium was identified as coming from Melton Branch.

Waste trench No. 6 is almost complete. It will be treated with copper to aid in retention of ruthenium, and then filling of the open pits will begin.

Hot-Cell Operations. – The SRE fuel elements are being disassembled in cell A, Building 3026D; approximately 40% of the work is completed.

All the physical examination cells in Building 3025 are in operation. A second shift is being used whenever the work load is sufficient.

PHYSICS AND MATHEMATICS RESEARCH

Charge Spectrometry. – The distribution of charged ions resulting from the removal of a K or L electron in an argon atom has been calculated on the IBM 7090 computer by using a Monte Carlo technique. The calculation is based on the summation of various sequences of Auger processes. The relative probabilities of the different sequences are, in turn, obtained from transition rates for Auger processes as determined by Rubenstein (thesis, University of Illinois, 1955). A provision was also made for altering the rates during a given vacancy cascade.

The calculation has been compared with the experimentally obtained charge spectra of Ar^{37} [Phys. Rev. 100, 1396 (1955)]. If shake-off excitation as determined by Wolfsberg and Perlman [Phys. Rev. 99, 1833 (1955)] is included in the calculation, the agreement is quite satisfactory.

Plans have been made to extend the calculations to krypton and xenon.

Neutron Diffraction. – The magnetic properties of palladium and its alloys with iron-group elements have been considered in terms of the splitting of the d orbitals. The paramagnetic properties of pure palladium are accounted for on the basis that the holes in the d shell are associated with the nonoverlapping e orbitals, whereas the ferromagnetic coupling in the face-centered 3d elements and their alloys is associated primarily with holes in the overlapping t orbitals. On this basis and on the basis of a change in the splitting when palladium is alloyed with 3d metals, it has been found possible to account for the paramagnetic and ferromagnetic properties of the palladium-dilute iron-group alloys.

The magnetic properties of the Pd-Fe system have been considered in detail because of the relatively large amount of available data.

Fast-Chopper Time-of-Flight Spectrometer. — The new 1.25-m-diam liquid scintillator detector for radiative capture gamma rays has been installed at the fast-chopper 25-m flight station. This scintillator is unique in that only two 16-in.-diam photomultipliers are utilized in collecting the light. Each photomultiplier has approximately nine times the photocathode area of a 5-in.-diam tube, and hence in light collection these two tubes are equivalent to approximately eighteen 5-in.-diam tubes. The time resolution (or jitter) of this scintillator was measured to be ~25 nanoseconds.

Differential pulse-height spectra have been obtained with this scintillator from neutron radiative capture in tungsten and from monoenergetic gamma-ray sources. These spectra are quite similar in shape to those obtained with the 1.2-m-diam tank installed at the 3-Mev Van de Graaff. The effect of neutron binding energy is quite apparent in comparing the pulse-height spectra from capture in W^{183} to those from capture in W^{182} and W^{186}; the pulse-height distributions are observed to be proportional to the neutron binding energies.

Low-Temperature, Nuclear and Solid State Physics. — Further work was done on the isomer shift for Au^{197}, using the Mössbauer effect. This shift is analogous to the isotope shift occurring in the optical spectra of the heavy elements. Here, it depends on the change of nuclear charge radius with the emission or absorption of the Mössbauer gamma ray and on the change, between source and absorber, of electron charge density near the nucleus. A calculation of the isomer shift as it pertains to the above Au^{197} measurement was partially completed. Calculations based on a single proton in both a square well and in a Wood-Saxon potential have been made. With reasonable approximate electron charge configurations for the gold, qualitative agreement of the measured and calculated isomer shifts is obtained. This corresponds to a shrinkage of Au^{197} when it is excited from the $d_{3/2}$ ground state to the $s_{1/2}$ excited state, and a valence of about 1+ for gold in aluminum, iron, cobalt, and nickel alloys.

High-Voltage Experimental Program. — The method of Mott scattering was used to determine the longitudinal polarization of (616 ± 15)-kev beta particles from the allowed Gamow-Teller decay of P^{32}. After rotation of the spin from longitudinal to transverse by a spherical electrostatic analyzer, the up-down asymmetry was measured over a wide range of gold foil thickness. Source depolarization, plate scattering depolarization, multiple and plural scattering in gold and aluminum foils, and instrumental asymmetry effects were carefully investigated experimentally. Corrections were made for various backgrounds, wall scattering, geometry, finite solid angles, and fringing fields. The final value of

$$\bar{p} = -0.988 \pm 0.009 \ v/c \ ,$$

for $v/c = 0.891 \pm 0.003$, depends upon a calculated value of the Mott scattering function, $S(\theta)$, which has not been corrected for screening, inelastic scattering, or finite nuclear size effects. These are estimated to be the order of 1% or less.

A beam of partially polarized deuterons was obtained in the first model of a polarized-ion source. The beam is characterized by deuteron spin states m_i = 1, 0, -1 having populations 4, 4, 1 or 2, 2, 5 respectively. Either polarization state may be selected. The deuterons have been used to study the angular distribution of the neutrons from the $d(T,n)He^4$ reaction. If the neutron background resulting from unpolarized deuteron contamination is subtracted, a 30% anisotropy is observed with respect to the direction of the ion beam. The effect can be reversed by choosing the other polarization state. Work at present is directed toward increasing the beam intensity and reducing the background contamination.

Spectroscopy Research Laboratory. — Infrared spectral studies of alkali halides containing trace impurities showed that many of the impurity bands arise from carbonate ions in solid solution. Traces of heavy metals, upon fusion of the alkali halide in air, form metal oxides which react with atmospheric CO_2 to produce carbonate "complexes" in the melt. Upon cooling, these are incorporated in the alkali halide lattice, with the carbonate group at an anion site and the metal atom at a cation site. Metal-to-oxygen bonding produces two types of carbonate ions, each with C_{2v} symmetry, corresponding to one and to two metal-oxygen bonds. The spectra of these complexes with Pb^{2+}, Cu^+, alkaline earths, and other metals were characterized.

CHEMISTRY RESEARCH

Mechanisms of Separations Processes. — In experiments on foam separation using the soft-beta emitter Ca^{45} for surface counting, the calcium distribution coefficient, surface/bulk calcium, was at least as large as 1.4×10^{-2} cm, in the presence of the sulfonate surfactant RWA-100, although potentially practical values are near 4×10^{-3} cm. Further evidence was obtained with cerium solutions, in support of the concept developed with H^+, Na^+, and Ca^{2+} solutions, that for a specified concentration of a complex between a cation and the sulfonate group of RWA-100, surface activity is independent of cation valence to a first approximation. Thus cesium is separated from strontium because strontium complexes the sulfonate strongly while cesium does not, the cesium being ionized in aqueous solutions. Foam density was very dependent on bubble size when foam linear flow rates exceeded 2 to 3 cm/min, but was nearly independent of bubble size at a linear rate < 1 cm/min. Specific foam areas range up to 3×10^5 cm^2 per cubic centimeter of foam condensate. Cesium was 95% removed from 6 M $NaNO_3$–10^{-5} M $CsNO_3$, a synthetic waste, by frothing $K_2Cu_3[Fe(CN)_6]_2$ formed in situ. The cesium was subsequently separated from sodium and ferrocyanide by dissolution in triethanolamine, sorption on Duolite S-30 resin, and elution with 6.5×10^{-3} M HCl solution.

A 6-in.-ID foam-separation column system was installed and tested. The 0.4-in.-diam cyclone used as a foam breaker gave a wet foam about 1/500 the inlet foam volume.

Ion Exchange Studies. – Amberlite 200 (16–50 mesh), a highly cross-linked, but porous, sulfonated styrene–divinylbenzene resin, was placed in a system of flowing demineralized water and irradiated in a 10,000-curie Co^{60} source. A dose of 0.82×10^9 r decreased the resin volume 2%. Similarly irradiated Dowex 50W-X8 (20–50 mesh) resin decreased 20% in volume with a dose of 0.85×10^9 r. The pH of the liquid after passing through the exposed resin bed, which was continuously monitored, decreased from its original 6.4 to a steady-state range of 2.9 to 3.1.

The rate at which chloride ions elute uranyl sulfate from Dowex 21K was shown not to be controlled by the counterdiffusion of chloride and $UO_2(SO_4)_2^{2-}$ ions but probably by diffusion of chloride ions counter to both sulfate and uranyl ions. Because no data are available on the mobility of uranyl ions in Dowex 21K, this mechanism cannot be tested adequately, but if it is assumed, a reasonable value for the uranyl ion self-diffusion coefficient in the resin can be calculated, namely, ~1/5 that of the sulfate ion.

Volatility Studies. – Operation of the Volatility Pilot Plant was discontinued in April for repair and modification of equipment and installation of containment features required for radiochemical operation. Changes in the building ventilation system were completed which permit better control of air flow and pressure in various areas. The KOH scrubbing system for off-gas from cells 1 and 2 was completed and is being operated to determine the degree of entrainment of KOH in the exit gas from the scrubber.

The degree of corrosion sustained by the INOR-8 hydrofluorinator and the L nickel fluorinator in previous operations was determined by nondestructive techniques such as ultrasonic measurements and gamma radiography to determine wall thickness. Ultrasonic measurements indicated a localized maximum corrosion rate of 0.05 mil/hr in the hydrofluorinator and 1.3 mils/hr in the fluorinator. Gamma radiography showed only three regions in the hydrofluorinator with a possible pitting attack, with pits estimated to be < 7 mils deep; the fluorinator showed a shallow pitting attack mostly in the vapor region, with pits ~10 mils deep.

Solvent Extraction Research. – The equation describing the distribution of 0 to 5 M HNO_3 between aqueous and tributyl phosphate–Amsco 125-82 solutions,

$$\log \frac{(HNO_3)_{org}}{[HNO_3]_{aq}\,\{3.75493 - (HNO_3)_{org}\}} = a + b\,(HNO_3)_{org}$$

[brackets refer to molal activities, parentheses to molal concentrations, and a and b are functions only of the ratio (Amsco)/(TBP)], together with material-balance equations and measured H_2O and HNO_3 concentrations of the organic phases, indicated that the fundamental equilibrium reaction for extraction at low acidities is

$$TBP_{org} + TBP{\cdot}H_2O_{org} + HNO_{3aq} \rightleftharpoons TBP{\cdot}HNO_3 + TBP{\cdot}HNO_3{\cdot}H_2O\ .$$

The quantity a may be interpreted as the product of the equilibrium constant K_1^m for the extraction reaction and the mean activity coefficient

$\gamma_{\ddagger}$ of the species TBP and TBP·HNO_3. The product $K_1^m\gamma_{\ddagger}$ increases from 0.27 to 1.51 as the TBP concentration in Amsco increases from 5 to 100 vol %.

Further studies of the radiolysis of 1 M TBP solutions in Amsco 125-82 containing dissolved H_2O and HNO_3 showed an increase in the yield of nitric acid destruction, G(-HNO_3), from ~4 to ~11 molecules per 100 ev at a dose of 45 whr/liter as the acidity in the organic phase increased from ~0.1 to ~0.7 M; this corresponds to ~0.7 and ~4.5 M HNO_3 in aqueous phases at equilibrium. Associated yields of dibutyl phosphoric acid, G(HDBP), increased from ~1 to ~3 molecules per 100 ev under the same conditions. At constant acidity the value of G(HDBP) at a dose of 135 whr/liter was only 60 to 80% of its value at 45 whr/liter. These results were used to show that the rate of decomposition of TBP in a radiation field of 1 w/liter is about the same as that resulting from heating the solution to 100°C in the absence of radiation.

Radiation Chemistry of Organic Moderators. — Exposure of purified biphenyl samples at 300 and 400°C was continued for 718 and 772 hr, respectively, without visible signs of decomposition.

Various diffusion-pump oils were exposed to high temperatures in order to determine their relative thermal stabilities. Small samples of the oils were placed in 10-mm-OD Pyrex tubes and were evacuated and heated gently before being sealed preparatory to pyrolysis. Sample pairs of m-bis(m-phenoxyphenoxy)-benzene were placed in furnaces at regulated temperatures of 400, 450, and 500°C. A slight yellow discoloration of the material became apparent after 34, 2, and 1.5 hr of exposure at the respective temperatures. After 20 hr at 500°C, the sample was dark colored and extremely viscous at room temperature. Samples of Consolidated Vacuum Corporation's Octoil-S (2-ethylhexyl sebacate) and Octoil (2-ethylhexyl phthalate) were also prepared for pyrolysis in the manner described above. The Octoil-S became yellow after 1 hr at 450°C, and upon cooling to room temperature formed a crystalline solid with very little oil remaining. Both of the ampoules containing Octoil exploded after 15 min at 450°C. The chemical stability of this oil will also be determined at 400°C.

Nuclear Methods of Chemical Analysis. — The feasibility of using Am^{241} in the preparation of suitable radioisotope-beryllium neutron sources was demonstrated by fabricating and testing a unit of this type. In preparing this neutron source, 1 g of Am^{241} as the fluoride was mechanically mixed with 10 g of beryllium power (particle size ≥44 μ). This mixture was dried at 500°C and then pressed into a cylindrical pellet 3/4 in. in diameter and 1-1/4 in. high under a static load of 20,000 lb. The pellet was then encapsulated in a sealed nickel container (1 by 1-1/2 in.) which was placed in an outer stainless steel container. A similar technique can be used to prepare larger source units containing several grams of Am^{241}.

The total neutron emission from this source at a 4π geometry was 6.3×10^6 neutrons/sec, with the neutron-energy distribution spectrum covering a range of energies up to about 14 Mev; the significantly greater portion of these energies lies between 2 and 4 Mev. With regard to safe handling practices for a unit of this type, it can be shown that the alpha activity at the surface of the external container is negligible. The gamma radiation level at contact is no more than 150 mr/hr.

Neutron sources of this type are being used in a neutron absorptiometer for determining B, Cd, Li, Hg, Ag, and Cl at the ppm level and for making isotopic analyses of B, Li, and U. A neutron transmission apparatus incorporating an Am^{241}-Be source is also being utilized in the analysis of plastics, metals, and alloys containing high neutron-absorbing components, such as boron.

Physical Chemistry of Ion Exchangers. – Calorimetric measurements of the heats of dilution of several linear cationic polyelectrolyte salts (i.e., "linear Dowex 1") were completed. These studies were a part of a continuing general thermochemical program directed toward an understanding of the heats of ion exchange reactions in ion exchange resins. The dilution of the linear polyelectrolyte chloride and bromide from 0 to 22 m was accompanied by the absorption of heat. With the chloride and the bromide salts, heats of dilution of 1250 and 2100 cal/equiv, respectively, were observed at the highest concentrations. Throughout the entire concentration range the heats absorbed for the chloride and bromide salts were smaller than for the corresponding model compounds (e.g., trimethylbenzyl ammonium chloride and bromide).

Spectrophotometric investigations were completed on a liquid anion exchanger prepared by dissolving small amounts of tertiary alkylamine in toluene. "Ligand field" spectra were observed for the organic phase in studies on the exchange extraction of the halo-complexes of Fe, Co, Cu, and Mn. It was possible to conclude that the species taken up selectively by the anion exchangers from aqueous hydrochloric acid solutions were the four-coordinated complex ions: $FeCl_4^-$, $FeBr_4^-$, $CoCl_4^{2-}$, $CuCl_4^{2-}$, $CuBr_4^{2-}$, and $MnCl_4^{2-}$. Divalent nickel, which does not form a four-coordinated ion under the same conditions as the other 3d transition elements, was not observed in the organic phase.

Organic Chemistry. – The isotope effects in the formation, at 0°C, of the 2,4-dinitrophenylhydrazones of trideuteroacetophenone (I) and hexadeutero t-butyl phenyl ketone (II) (two methyls completely deuterated) were determined by the differential method previously used in the establishment of an isotope effect (k^{14}/k^{12}) of 1.0085 ± 0.0004 in the same derivatization of acetophenone-β-C^{14} (III). In the determinations of the isotope effects attending the reactions with I, compound I was mixed with III and then, in a separate experiment, with acetophenone-carbonyl-C^{14} (IV). The changes in molar radioactivity of the derivative as a function of fraction of reaction allowed the calculation of k_{III}/k_I (0.915 ± 0.002) and k_{IV}/k_I (0.847 ± 0.003). A separate determination of the C^{14} isotope effect during 2,4-dinitrophenylhydrazone formation of acetophenone-carbonyl-C^{14} (k_{IV}/k_V = 0.949 ± 0.002) allowed two independent calculations of the deuterium hydrogen isotope effect k_I/k_V (1.119 ± 0.006 and 1.104 ± 0.002), values which are identical within two standard errors.

These rate differences are ascribed to the reduced inductive effect in those molecules containing deuterium; it appears that hyperconjugation is of very little importance in the reactions studied.

Chemistry of the Heavy Elements. – High-temperature spectrophotometric studies were continued on the reduction by H_2 and reoxidation by O_2 of

aqueous solutions containing either UO_2SO_4 (0.0123 m), $CuSO_4$ (0.0085 m), or both in 0.0072 m D_2SO_4. Solutions of D_2SO_4 with no metallic constituents were also studied. Rates of reduction of copper (95% in 10 min) and uranium (complete in 75 min) were independent of the presence of the other constituent.

Spectral monitoring of the reoxidation of the UO_2SO_4-$CuSO_4$ solution was usually complicated, both by unidentified absorbing species and by turbidity, the latter persisting for as long as several hours. No such complications were encountered in the solutions containing only $CuSO_4$ or UO_2SO_4. Nevertheless, the reoxidation process (Cu, < 1 min; U, 30 min) was clearly more rapid than the reduction in all solutions and occurred in competition with recombination of H_2 and O_2. Interestingly enough, the rate of the recombination reaction was about the same, regardless of which solution was in contact with the gaseous mixture; this fact strongly suggests a heterogeneous reaction, occurring at the cell walls.

High-Temperature Aqueous Solution Chemistry: Electrical Conductance at High Pressures and Temperatures. – The equivalent conductances of 0.005 m K_2SO_4 in H_2O solution were determined at temperatures of 250, 422, and 529°C and at hydrostatic pressures varying from 300 to 3000 atm. At 250°C and 300 atm the equivalent conductance was near 680 ohm^{-1} cm^{-2}; $\Delta\Lambda/\Delta P$ was -0.03 ohm^{-1} cm^{-2} per atmosphere over the entire range of pressure. At 422 and 529°C the equivalent conductances increased from values below 150 ohm^{-1} cm^{-2} at a pressure of 300 atm to values between 600 and 700 ohm^{-1} cm^{-2} at pressures between 1500 and 3000 atm.

High-Temperature Aqueous Solution Chemistry: Effect of Pressure on Liquid-Liquid Immiscibility. – For the first time the effect of hydrostatic pressure in raising the temperature of liquid-liquid immiscibility of solutions containing UO_2SO_4, H_2SO_4, and H_2O was observed visually in apparatus utilizing a tubing connection of metal to glass and capable of withstanding high pressure. Easily reproducible values at pressures up to 340 atm were obtained for a 1.4 m solution of UO_2SO_4 in H_2O and for a D_2O solution 0.6 m in UO_3 and 1.0 m in D_2SO_4. Pressure-temperature coefficients of +0.080 and +0.120°C per atmosphere, respectively, were calculated from the data for these two solutions. These coefficients were in agreement with the expectation that pressure effects would be relatively large in the vicinity of 300°C and could become very large near the critical temperature of the solutions (i.e., near 374°C, the critical temperature of pure H_2O).

High-Temperature Aqueous Solution Chemistry: The System ThO_2-HNO_3-H_2O. – Additional determinations of the solubility of ThO_2 in HNO_3-H_2O solutions were made at 200°C and at an additional temperature of 150°C (ORNL-3009, p 5). There was little change in the saturation molal ratio, $m_{ThO_2}:m_{HNO_3}$, between 150 and 200°C at HNO_3 concentrations between 1.0 and 10 M (at 25°C). These molal ratios were 0.11 in 1.0 M HNO_3 and 0.24 in 10 M HNO_3. Refractory ThO_2 dissolved moderately rapidly in HNO_3-H_2O solutions at 150, 200, and 300°C. This constituted additional evidence that aqueous solutions of HNO_3 at these temperatures could be useful for dissolving ThO_2 solids in chemical processing.

Physical Chemistry of Molten Salts. – A program was initiated for the determination of the crystal structure of heavy-metal fluorides by x-ray diffraction. The principal aim is to ascertain the structural parameters involving fluoride ions so that quantities such as interionic distance, coordination number, and degree of thermal motion will be available to aid in the interpretation of thermodynamic and spectral data.

Since the contribution of fluoride ions to the scattering of x rays is relatively small in crystals of the actinide and lanthanide fluorides, the diffracted intensities must be measured with considerable accuracy if the fluoride ions are to be located. To this end, apparatus has been assembled which makes use of a single-crystal orienter and a scintillation-counter detector.

With this apparatus, diffraction intensities were measured, from which the crystal structure of $LiSbF_6$ was determined. Values for the Sb-F distance (1.88 A) and the Sb-F-Li angle (147.5°) were obtained, and the orientation of the SbF_6^- octahedron was determined.

While the ratio of atomic numbers (51:9) is not so great in this fluoride as in the actinide fluorides, the ability to locate the fluorides in $LiSbF_6$ with precision indicates that the technique is practicable for fluoride study.

Chemical Separation of Isotopes. – The oxygen isotopic fractionation factor between acetaldehyde vapor and paraldehyde liquid was measured for a single-stage equilibration at 26°C and 1 atm pressure. The isotopic analyses were performed on CO obtained by cracking the aldehyde on a hot wire in the presence of Br_2. The observed separation factor was 1.017 ± 0.002 (95% confidence interval), with the heavy isotope enriching in the liquid phase.

METALLURGY AND MATERIALS RESEARCH

Ceramics Research: Sintering Studies. – Weld-neck growth was measured between ThO_2 spheres at temperatures of approximately 1800°C by placing the spheres on a sapphire sheet and taking periodic readings with a movable-hairline measuring microscope. The logarithm of neck width was plotted as a function of the logarithm of time at temperature in order to determine the exponent in the equation $x^n = A(T)t$, where x is the neck width, A(T) is a function of temperature and is related to the transport mechanism, and t is the time. The results showed some irregularities, but the majority of cases had a value of n near 2. According to deductions of Frenkel and Kuczynski, this implies a plastic flow mechanism of material transport during the ThO_2 sintering. Macroscopic flow has rarely been indicated by model studies in the case of crystalline materials.

Physical Property Studies. – The thermal conductivity of 93.4% theoretically dense $UO_{2.02}$ has been measured to 200°C in a radial heat flow apparatus. This apparatus has previously yielded data on INOR-8 to 800°C which was reproducible to ±2% and accurate to ±5%. Small radial temperature gradients (~3°C) are being maintained in order to minimize the possibility of rupture of the specimen by thermal stresses. For determining these small temperature gradients, a six-dial potentiometer, with a

precision of ±0.01 μv, is being used to measure the thermal emf's produced by the Pt vs Pt–10% Rh thermocouples. The measurements on this specimen will be extended to 1600°C. When the data thus far obtained is corrected to theoretical density, it agrees with that reported by Howard and Gulvin, by Deems and Lucks, and by Ross; falls 30% below that of Kingery; and is 12% above that of Hedge and Fieldhouse. A part of these differences may be attributed to variations in stoichiometry of the specimens used from one study to the next.

CONTROLLED THERMONUCLEAR RESEARCH

DCX-1 Facility. – Work continued on a number of modifications being made to reduce the dynamic pressure in the plasma region to 10^{-9} mm Hg. These modifications include the removing of one section of the high-vacuum liner so that the incoming H_2^+ beam will pass through the intermediate vacuum region before entering the plasma region, relocating and reducing the conductance of the apertures through which the H_2^+ beam enters and leaves the plasma region, installation of a steam superheater to permit high-temperature baking of the vacuum liner, and addition of two liquid-helium-cooled traps to the plasma vacuum region. The liquid-helium traps are now being installed; the other modifications were completed.

Checks of an electronic regulator, designed to improve the stability of the 600-kv dc supply against very rapid fluctuations, showed that the initial design was inadequate. This device has been modified and is being reinstalled for further performance checks.

High-Current Injection. – Hydrogen ion beams of up to 215 ma at 600 kv have been obtained, and beam profile measurements have been made at currents up to 180 ma. The profile measurements were made by means of three rotating probes spaced 19 in. apart. It was found that the beam diameter is 3.7 in. at the center of the solenoid lens at a current of 180 ma at 600 kv. From the variation of the beam diameter obtained as a function of current, it is expected that the goal of 400 ma can be reached. The accelerator tube has held a total of 700 kv with no current and 650 kv with 100 ma of current. There are, however, more electrical breakdowns inside the tube at 600 kv and above than are desirable. Also, an incipient PIG-type discharge in the lower section of the tube has not been completely eliminated. An attempt will be made to improve these conditions by changes in the electrodes.

Theory. – A new solution of the statistical equations for a plasma and radiation has yielded a formula for cyclotron radiation. The result reduces to that of Trubnikoff to lowest order in an expansion in $(\omega_p/kc)^2$. To next order, the principal effect is the renormalization of the oscillators from vacuum to plasma oscillators. In the exact formula, longitudinal and transverse waves are coupled.

The threshold for the "negative mass" instability, studied by the MURA accelerator group, has been calculated for the DCX-1. With present low densities, the energy spread necessary to quench the instability, a few tens of kev, is of the order of the observed energy spread.

Results obtained with the Fokker-Planck code for calculating steady-state ion and electron energy distributions in the DCX indicate that, because only the high-energy tail of the electron distribution is able to escape over the plasma potential barrier, the electron distribution is almost exactly Maxwellian. The distribution of ions, free to escape at all energies, is not Maxwellian.

BIOLOGY AND MEDICINE PROGRAM

SOMATIC EFFECTS OF RADIATION

Pathology and Physiology: General. — The radiosensitivity of cells engaged in the homograft reaction was evaluated by determining the incidence of wasting disease in irradiated F_1 hybrids injected intraperitoneally with parental liver cells exposed to varying doses of x rays in vivo. Recipient mice were (C57BL × 101)F_1 and (C3H × 101)F_1 hybrids given 600 r of whole-body x irradiation; parental donors were C57BL and C3Hf mice, respectively, the latter presensitized to the 101 spleen cells. Whereas the incidence of fatal wasting disease was 100% in both hybrid strains within 60 days after injection of nonirradiated parental liver, irradiation of the donor mice 30 min before sacrifice reduced the mortality among recipients. The lowest dose of x rays required to abolish morbidity and mortality was 350 r for C57BL donors and 450 r for C3Hf donors, the difference possibly reflecting differences in absolute numbers of cells involved in primary and secondary immunological responses, since the C3Hf donors were preimmunized. Bone-marrow donors of (C57L × A)F_1, (C57BL/+ × DBA/2)F_1, and (BALB/c × A)F_1 strains were also exposed to 400 r of x rays prior to transplantation of their marrow (30×10^6 cells) into 950-r-irradiated (101 × C3H)F_1 and (C57BL × 101)F_1 recipients. Recipients of such irradiated homologous marrow showed little mortality and secondary disease, whereas all the control chimeras failed to survive beyond 60 days. These results suggest a possible method for circumventing the immunological complications of homologous bone-marrow transplantation in clinical medicine, which merits further study.

RADIATION GENETICS

Genetic and Cytogenetic Effects of Radiation. — Experimentally observed dose curves for two-hit chromosome aberrations induced in plant cells or for translocations induced in *Drosophila* sperm usually follow the relation: yield = $KD^{1.5}$. It was thought that the theoretical yield should have been proportional to the square of the dose. Consequently, various *ad hoc* schemes have been devised to account for the discrepancy between observed and theoretically expected results. A re-examination of the theoretical expectations has shown that the yield should not increase as the square of the dose but proportionally to $(1 - e^{-KD})^2$. In the dose ranges utilized in radiobiological experiments, the observed values do not deviate from the expected values as calculated from this expression.

COMBATING DETRIMENTAL EFFECTS OF RADIATION

Mammalian Recovery: General. — Lethally irradiated parent strain mice treated with leukocytes from peripheral blood of F_1 hybrids survived the period of bone-marrow failure, gained weight, and appeared to recover from the acute radiation syndrome. Iron-59 injected into such chimeras a week or so after irradiation was incorporated into new erythrocytes. Hemolytic antiserum specific for donor cells was used to show that the newly formed red blood cells were derived from the injected leukocytes.

Acid mucoprotein fractions obtained from the crude erythropoiesis stimulating factor of rabbit urine origin were collected on diethylamino ethyl cellulose and carboxymethyl cellulose columns. These fractions contained the active material that stimulates the residual immune response in the spleen of heavily irradiated mice. Materials with this capability are thought to be closely related chemically to the transplantation antigens. Substances with similar capabilities are also present in Salmonella endotoxin, cow urine, and rat tissue, according to recent chemical studies.

The chronology of deoxyribonucleic acid (DNA) synthesis and mitosis in human peripheral leukocyte cultures has been determined. Ribonucleic acid and protein synthesis in these cells is now being investigated. Spontaneous and x-ray-induced chromosome-type aberration rates have been measured for human leukocyte cultures. A comparative study of aberration rates in monkey leukocytes under the same conditions has been initiated. Feasibility studies for the NERV-II space project have been completed.

Radiation Immunology. — By use of the in vivo culture model, it was demonstrated that the relative antibody-forming capacity of spleen cells of normal mice changes with age. The maximum activity was noted with cells from 1-year-old mice. In relation to the activity of spleen cells from 1-year-old mice, those from 1-week-old mice showed only 1% efficiency and those from 30-month-old mice showed 10% efficiency. Three-month-old mice, which are being used routinely as "adult" mice, showed only 40% efficiency.

Work on the radiation protective role of S,2-aminoethylisothiourea (AET) clearly shows that AET can protect against radiation damage those cells which are essential in promoting survival of mice exposed to a lethal dose of x irradiation. On the other hand, AET did not protect those cells which are involved in the immune process.

Studies on the relative radiosensitivity of the homograft-rejecting and antibody-forming capacities of spleen cells revealed that the former activity is less susceptible to radiation damage. Studies of this nature should, in time, indicate whether the difference in functional property of spleen cells is related to difference in types of cells or difference in stage of maturation of a given cell type.

MOLECULAR- AND CELLULAR-LEVEL STUDIES

Cell Growth and Reproduction: Indole Acetic Acid Restoration of the Colchicine-Induced Inhibition of Root Growth. — The hypothesis has been

proposed that cells of the apical meristems of growing roots of Vicia secrete growth factors and also that when roots are exposed to a growth-inhibiting agent the secretory activities of the apical cells are disturbed. Colchicine inhibits the growth of primary roots of Vicia. Following 1 hr in 0.05% colchicine, roots show almost no growth for five to seven days. If the failure to grow is due to a lack of natural auxin, it should be compensated, at least in part, by an exogenous supply of auxin. Colchicine-inhibited roots were exposed to 10^{-5} M indole acetic acid (IAA) for one to two days. The roots treated with IAA recover faster (i.e., show a greater total increase in length in five to seven days) than roots not treated with IAA but also exposed to colchicine, in spite of the fact that this concentration of IAA is inhibitory to normal roots. The results indicate that the inhibition of root growth produced by colchicine can be partially reversed by IAA. Restoration of growth is never immediate, however, showing that the original inhibition is the result of lack of more than one natural auxin. These results indicate a way to a better determination of the growth-factor secretion of apical cells and the complex of factors that are responsible for root elongation.

Cell Growth and Reproduction: DNA Doubling and the End Point for Chloramphenicol Modification of the Mutation Process. — A number of agents, including the protein synthesis inhibitor chloramphenicol, decrease recessive lethal mutations in Paramecium when they are used as posttreatments after x rays. Previous evidence had suggested that these agents were only effective when exposure was started before the first postirradiation chromosome replication, that is, the first deoxyribonucleic acid (DNA) doubling. The evidence on this point was not as precise as desirable, however, and did not include direct measurements of the amount of DNA. A series of repeat experiments was carried out, therefore, in which the paramecia were exposed to chloramphenicol at various times after x irradiation, and at the same time samples were fixed, stained for DNA, and measured microspectrophotometrically. The data show a very close correspondence between the end of the period during which chloramphenicol treatment is effective in modifying mutation and the time of DNA doubling. These results confirm in a more precise way an earlier conclusion and contrast with studies of others on ultraviolet-irradiated bacteria showing that the period of sensitivity to chloramphenicol modification of the mutation process ends well before DNA doubling.

Biophysics: Electron Spin Resonance Studies. — Phenomena related to radiation-induced free radicals include energy transfer from radiation to target molecule, G, to produce a radical pair, R_i* and H_{ij}*, and then the disappearance of radicals. These phenomena, as measured by electron spin resonance (ESR) are generally interrelated. Such measurements are usually thought to depict only the heavier, R*, radical, with the H* radical being atomic hydrogen, possibly liberated as gas. Apparatus has been constructed for irradiating typical materials and measuring gas production and ESR signals. Analytic descriptions of the time variation of R* and H* have been obtained for various recombination possibilities, such as the assumption that the only radical recombinations are R_i* plus H_i* and H_i* plus H_j*. This qualitatively yields the experimentally observed results: apparent saturation at high dose; decay

of a number of observed resonances, approaching a constant value; and more rapid decay of highly irradiated materials. Quantitative analysis is beginning.

Dose curves have yielded radiochemical G values ranging from 1.6 to 0.4 for succinic acid and from 0.64 to 0.44 for disuccinyl peroxide, both materials showing a saturation effect.

Work has been initiated to study photodynamic action and photooxidation in 12 fluorescent dyes. ESR signals, probably stable free radicals, have been found in all dyes after visible irradiation.

Biophysics: Visible and Near-Visible Light. – Data previously reported suggested protection from ultraviolet light damage by pretreatment with light in the 4000 to 6000 A wave bands. The present work has been an attempt to isolate the wavelengths responsible for protection. Apparently the most effective wavelength in reducing aberration frequency is 5170 A. It was also found that 7680 A (the far-red) will double or triple aberration frequencies. No action spectrum was possible, since the initial time-dose-response curves were nonlinear. Further dose-response studies are in progress.

Biophysics: Ultraviolet Action Spectrum of Phage T4 Containing 5-Bromodeoxyuridine. – The radiation sensitivity of biological systems may be increased by substituting 5-bromodeoxyuridine (BUDR) for thymidine. Stahl *et al*. [Virology 13, 98 (1961)] have shown that phage T4 containing BUDR is four times more sensitive to 2537 A radiation and 75 times more sensitive to "visible" light. In an attempt to arrive at an understanding of the effects of BUDR substitution on radiation sensitivity, the action spectra were determined for inactivation of normal and of BUDR phage. The wavelength range covered was 2300 to 3130 A. For wavelengths below 2800 A the BUDR phage are four times more sensitive than normal virus. As the wavelength increases, the BUDR phage become relatively more sensitive (100 times more at 3130 A). An analysis of the data should aid in deciding whether the BUDR-substituted virus is more sensitive because its DNA is more unstable or whether quanta absorbed in BUDR are more efficient in inactivation than those absorbed in the other nucleic acid bases.

Microbiology. – Genetic analysis of the factors determining radiation resistance in *Escherichia coli* has been initiated. It has been established that radiation resistance is inherited by some of the progeny of a cross between a radiation-resistant male and a radiation-sensitive female. Attempts to locate this property on the genetic map indicate that it is a polygenic trait. One of the genes involved seems to be located close to the region controlling histidine synthesis.

TRAINING, EDUCATION, AND INFORMATION PROGRAM

International Reactor Programs at ORSORT. – Eight students in the hazards evaluation program and 17 in the operation supervision program have completed 36 weeks of school since November 1960. This completes the academic work for both programs. The hazards evaluation students will begin preparing reactor hazards reports on two types of reactors, and the

operation supervision students will be assigned to a rotating shift at one of the Laboratory's reactors for three months. Both programs will terminate October 27, 1961.

In addition to the two foreign programs, fourteen AEC employees, fourteen ORNL employees, two ORGDP employees, and four TVA employees are currently enrolled in courses at ORSORT.

Approximately 30 applications from the United States and from abroad have been received for the fourth session starting in September 1961. Applications are now being reviewed.

ASEE-AEC Summer Institute. — Plans are being made for presenting a series of ORSORT experiments in physics and radiochemistry to participants in the 1961 ASEE-AEC Basic Summer Institute, conducted by North Carolina State University during the week of August 7–11, 1961.

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