ORNL-2371
C-84 - Reactors - Special
Features of Aircraft Reactors

OAK RIDGE NATIONAL LABORATORY

SPECIAL PROGRESS REPORT

PROGRAM 4700

JULY 1957

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
A Division of Union Carbide and Carbon Corporation
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C-84 - Reactors-Special Features
of Aircraft Reactors

ORNL-2371

This document consists of 13 pages.
Copy 24 of 68, Series A.

Contract No. W-7405-Eng-26

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OAK RIDGE NATIONAL LABORATORY

SPECIAL PROGRESS REPORT

July 1957

PROGRAM 4700 - REACTOR DEVELOPMENT

AIRCRAFT NUCLEAR PROPULSION PROJECT (AEC Activity 4701)

Aircraft Reactor Test (ART)

Components for the ART are being fabricated along with those for the ETU. Final assembly of the ART will not proceed, however, until the ETU has been operated, disassembled, and examined. A study is being made of the specific examinations to be performed and the results that will constitute an acceptable basis on which to proceed with the assembly of the ART.

All the tubes and the header were installed in an "experimental" fuel-to-NaK heat exchanger bundle at Black, Sivalls & Bryson (channel No. 3). This unit does not meet dimensional specifications, but it is being completely assembled in order to test the fabrication and assembly procedures. Channel No. 6 was put back on the brazing fixture and stress relieved in an effort to correct minor dimensional discrepancies. Channel No. 7 was completely welded and stress relieved. It is hoped that either No. 6 or No. 7 will meet specifications and will serve as a prototype bundle.

Engineering Test Unit (ETU)

The two sodium-to-NaK heat exchangers received from Griscom-Russell were accepted metallurgically and are being installed in the ETU north head. The lower-deck weldment is being machined to obtain the proper clearances between the heat exchangers and the surrounding surfaces. The rough machining of the north-head lower-deck-skirt forging is nearly complete.

A series of experiments conducted at the plant of the Kaiser Metal Products Company showed that it should be possible to produce acceptable thin (1/16-in. wall) shells by deep drawing. This method will be adopted for fabricating shells IV and V, which surround the heat exchanger region, and cold-formed, machined weldments will be used for the heavier core shells. The contract for the production of shells by Hydrospinning was cancelled.

The rough machining and stress relieving of the lower portion of shell III (the outer reflector shell) was completed. A shell II (outer core shell) lower portion and two shell I (inner core shell) pieces are ready for initial machining operations. A shell VII (pressure shell) lower forging is now available for machining.

[redacted]

The fabrication of the load ring is proceeding without difficulty; the lower surface of the assembly is being contoured at present. All the B_4C tiles required for the neutron shields of the ART and the ETU were received from the Norton Company.

The ETU facility work is proceeding on schedule. The main NaK piping of one isothermal system was installed during the month, and the components are on hand to proceed with the installation of the second isothermal circuit. One radiator bank was received from the York Corporation.

ART Facility Design and Construction

The extended package 3A contract work, which includes a hydraulic pumping unit for the control louvers, a filter for the process water system, and a wall to enclose the auxiliary control room, is approximately 94% completed. An extension of one day was allowed for time lost as a result of a strike, and an additional extension of time was requested because of late equipment delivery.

Testing of the louver hydraulic system indicated numerous leaks at the pipe fittings. The fittings were therefore replaced with Crawford Company Swagelok fittings. Tests showed the Swagelok fittings to be satisfactory.

Design work continued on the special equipment room, radiator pit, and radiator-penthouse area. One-twelfth scale models are being made of these areas to assist in detail design and to demonstrate equipment assembly and replacement procedures. The arrangement of the NaK purification equipment was revised as a result of equipment replacement requirements, clarification of flowmeter handling procedures, and elimination of plug indicators. Information on the permissible manufacturer's tolerances on the main and auxiliary radiators was prepared.

Controls and Instrumentation

An ART control rod assembly and drive have met all mechanical performance requirements in a 1000-hr test at approximately reactor operating conditions. The test included one cycle per hour between fully inserted and fully withdrawn positions. The control rod is now being held stationary in the inserted position for 200-hr intervals. At the end of a 200-hr interval the times required for withdrawal and insertion of the rod are measured. The times required have shown no deviations. As of July 31, 1850 hr of the scheduled 3000-hr test period had been accumulated. After 1800 hr of operation it was discovered that the temperature of the Inconel thimble in which the control rod is inserted was 1600°F rather than the design temperature of 1200°F. The temperature was corrected for the remainder of the test.

Layouts of the control panels for the ETU were prepared, and most of the specifications for these panels were determined. Recent changes in the ETU flow sheets will probably require minor changes in the control panel layouts and alter some of the control room instrument specifications. The layout and some of the instrument specifications were dictated to some extent by the requirement that use be made of available on-the-premise instruments wherever possible.

Evaluation studies of high-temperature pressure transducers were completed. Ten different units were tested at temperatures up to 1400°F and at pressures up to 200 psig. As a result of these tests, units having electrical or pneumatic outputs with accuracies of ±0.25% and ±0.5%, respectively, are now available.

Twelve magnetic flowmeters were calibrated with NaK at flow rates of up to 1500 gpm and fluid temperatures up to 1500°F.

Thermocouple drift data have now been taken for 5200 hr on 36 thermocouples exposed to sodium at 1500°F. Thirty-two similar units have been exposed to $NaF-ZrF_4-UF_4$ (fuel 30) for 3500 hr. The data obtained show that the units fall into three general categories: (1) units that have drifts to above the actual value of approximately 4°F; (2) units that have drifts to below the actual value of approximately 4°F; and (3) units that show large downward drifts of approximately 15°F.

Four ORNL-designed and -fabricated continuous level sensors for NaK were operated for 2150 hr at temperatures up to 1400°F. The linear level range of these units is approximately 7 in. Four additional units are undergoing acceptance tests for ETU pump service.

Reactor Component Testing

A series of tests is under way with the ART fuel pump to determine the optimum liquid level for priming and to determine whether the reactor can be filled without freezing fuel in the rotary element when the pumps are stopped. In the first test, the pump was stopped and the fuel, at 1200°F, was raised to 11/16 in. above the expansion tank floor. Full pump performance was attained without difficulty. In several repetitions of this procedure, no freezing occurred. The pump was stopped for periods of up to 1 hr and restarted satisfactorily. Other levels than this minimum operating level will be checked. Freedom to operate the pump at will at low expansion tank levels will permit delayed-neutron measurements over the full fuel flow range and eliminate the extrapolation previously believed necessary to obtain values for the static condition.

The water test mockup of the sodium pump and expansion tank region of the ART was leak-tested and is now in operation. Initial data at high-flow and low-head conditions with pump speeds of up to 3500 rpm (design point speed is 4100 rpm) show that the two sodium pumps perform satisfactorily

in parallel. The degassing characteristics of the pumps were found to be adequate.

The first test of an ART prototype NaK-to-air radiator, which was spring loaded to simulate air-flow induced forces, was terminated after a total of 980 hr of operation at elevated temperatures. Nine moderate thermal cycles were experienced during 480 hr of operation with temperature differentials of 100 and 430°F. A leak developed in the radiator tube matrix adjacent to the NaK inlet header during the first of a proposed series of rapid thermal cycles. Shutdown of the system was accomplished rapidly to limit fire damage to the affected tube. Preliminary metallurgical examination of this and adjacent tubes did not reveal stress damage or other defects to which the failure could be attributed. Further investigations are being made; meanwhile, the second prototype radiator is being installed for testing.

Examination of the guided-plug prototype fuel dump valve, which was leaktight in operation with $NaF-ZrF_4-UF_4$ (fuel 30) for 2460 hr at temperatures above ART requirements, revealed slight galling of the stem in the upper stem guide. Although the performance was adequate for the design condition of 1300°F, the use of cermet guides and increased clearances should make this a reliable valve for operation at temperatures up to 1500°F.

In the second thermal stability test of a one-fourth-scale model of the ART outer core shell, a scheduled program of 300 cycles alternating between isothermal and ART operating conditions was completed. Temperatures across the test piece are maintained by countercurrent sodium streams which also impose simulated ART pressure stresses. Since passage resistances have not changed during the test, operation will continue until failure or impending failure is noted. This is the second core shell which has exceeded the ART design requirements.

Both the sodium and the NaK pump vapor condensers successfully completed 1500-hr tests at 1200°F. An additional test of the NaK vapor condenser will be made during testing of an ART main NaK pump.

Tests of ART-type cold traps and plug indicators in the NaK circuits of heat exchanger test stands have confirmed that oxide is removed by the cold traps to concentrations in the main flow stream consistent with the concentrations indicated by the lower temperatures of the NaK in the cold traps. Plug indicators were therefore judged to be unnecessary in the ETU and ART NaK systems.

In-Pile Experimentation

Visual and microscopic examination have revealed no damage to the containers of the moderator materials (zirconium hydride, beryllium oxide, and graphite) irradiated in the MTR. Dimensional checks and removal of

the samples are in progress. The zirconium hydride sample is canned in molybdenum, the beryllium oxide sample in Inconel, and the graphite sample in nickel.

Advanced Design and System Analysis

A new north head layout incorporating three fuel pumps was prepared for a reactor core with a circulating-fuel-cooled moderator and a high fuel flow rate (low fuel temperature rise) that would be advantageous for high-power reactors. The arrangement shows particular promise for accommodating the one-pump-out condition.

Heat Transfer Research

The experimental investigation of the effect of thermal stress cycling on Inconel tubes containing flowing $NaF-ZrF_4-UF_4$ (fuel 30) was continued. It was learned that tubes with different grain sizes had been used in these studies, but a re-evaluation of the data to include this additional variable showed no apparent effect of grain size on depth of corrosion. The fine-grained tubes did, however, show a tendency toward intergranular attack. The presently available information shows that for exposures of less than 20 hr, the attack rate is greater for thermally cycled specimens than it is for specimens not cycled. For exposures of more than 20 hr, the isothermal and high-frequency thermal cycling curves are roughly parallel. Further, the low-frequency cycling data lie within the scatter band for the high-frequency cycling data, and thus it appears that cycling frequency has little effect on depth of corrosion.

An experimental study of the effect of core screens on the surface temperature fluctuations in the ART core was initiated. A half-scale volume-heat-source core model is being used for this investigation. Four screens, in addition to a thick inlet collimator, were placed in the upper half of the flow annulus. The screens were positioned at approximately equal axial distances, with the bottom screen located just above the core equator. The screens and collimator were constructed by drilling an acid-resistant plastic sheet (Boltaron) to give a solidity of approximately 0.34. Preliminary results show that the screens reduce the island wall fluctuations to approximately one-tenth the magnitude of those which occurred with a vaned entrance system. The fluctuations at the outer wall remained, however, at the same average level as those previously observed. It is planned to alter the screen solidities to increase the flow near the outer wall by decreasing the mainstream flow.

Metallurgy - Corrosion

Two specimens of Mallory 1000 (90% W-6% Ni-4% Cu) were exposed for 100 hr to sodium at 1500°F in Inconel containers in the hot zones of see-saw furnaces being cycled at a rate of 1 cpm. The use of Mallory 1000 as a transition layer between tungsten carbide-cobalt cermets and Inconel

in disk-and-seat brazed joints for sodium or NaK valves is being contemplated. One of the specimens was tested as-received and the other was heat treated to simulate a brazing operation. The sodium completely penetrated both specimens. Apparently, the quantity of copper in Mallory 1000 is enough to give it poor resistance to attack by sodium at 1500°F.

A nickel-molybdenum alloy forced-circulation loop was examined following 1000 hr of operation with NaF-KF-LiF-UF_4 (fuel 107). The nominal composition of the loop was 17% Mo-7% Fe-bal Ni; the maximum bulk fuel temperature was 1610°F; the maximum fuel-metal interface temperature was 1760°F; and the fuel temperature drop was 300°F. Metal deposits that were predominantly nickel, with some iron, were found in the pump and in the cooled portions of the loop. There was grain-boundary attack to a maximum depth of 4 mils at the point of maximum wall temperature. The outer surface of the hot leg, which had been exposed to air had a heavy, uniform oxide film; oxidation had proceeded preferentially along grain boundaries to a maximum depth of 9 mils. Cold-leg sections showed numerous surface pits and some areas of intergranular attack to a depth of 2 mils.

A Hastelloy B forced-circulation loop completed 2000 hr of testing with sodium at 1500°F and a 300°F temperature differential. The quantity of mass transfer was the same as that found in an Inconel loop operated under the same conditions. The deposited material in the Hastelloy B loop was predominantly nickel. The hot leg showed intergranular attack to a depth of 2 mils. Deposit thickness in the cold-leg section reached a maximum of 24 mils after 2000 hr as compared with 20 mils after 1000 hr. Similar results were obtained for Inconel.

A Hastelloy W forced-circulation loop operated with sodium at 1500°F for 1000 hr showed 17% more mass transfer than that in the Hastelloy B loop after 1000 hr. There was a spongy, heavily attacked area about 1.5 mils deep in the hot leg.

Metallurgy - Fabrication

Wrought products were fabricated from a 10,000-lb heat of the alloy INOR-8 by the Haynes Stellite Company, including 3-in.-dia forged round; 1-, 1/2-, and 1/4-in.-thick hot-rolled plate; and 0.063-in.-thick hot-rolled sheet. Strip material was also completed and is now at Superior Tube Company where it will be converted to small-diameter welded tubing.

Three each of 4- and 5-in.-dia extrusion billets were also prepared from the 10,000-lb Haynes heat and will be converted to composite tube shells of 50% INOR-8 over 50% type 316 stainless steel and 50% type 316 stainless steel over 50% INOR-8 at Allegheny-Ludlum Steel Corporation. These tube shells will be reduced to 0.500-in.-dia, 0.050-in.-wall composite tubing.

Metallurgy - Welding and Brazing

The Inconel-clad stainless-steel tubes for a duplex heat exchanger were assembled into duplex headers and are now ready for welding. Several of the external fittings were welded to the nozzle assemblies.

A butt-welded Inconel pipe specimen was prepared by using high-purity dry nitrogen as a back-up gas. The root discoloration was held to a minimum, and radiographic and bend test inspections indicated the procedure to be promising. Samples from this specimen are being tested in NaK and in fused salts.

A preliminary test was conducted to determine the extent of braze cracking during the fabrication of high-conductivity-fin NaK-to-air radiators at York. The cracking is the result of transverse shrinkage and distortion of the tube sheets during the deposition of the longitudinal welds.

Metallographic examination of simulated cracked joints revealed gross cracking in the braze fillets. In no cases, however, did the cracks penetrate into the tubes or tubesheet.

Sample joints were then rebrazed with and without the use of additional Coast Metals No. 52 braze slurry. The cracks appeared to completely heal in all cases examined. The addition of the slurry to the fillet before rebrazing appeared to be advantageous in that it permitted a more uniform fillet and provided an additional source of alloy for healing the crack.

Metallurgy - Mechanical Properties

Creep-rupture tests at 8000 psi and 1500°F in NaF-KF-LiF-UF_4 (fuel 107) have shown the INOR-8 type of alloy produced by the Haynes Stellite Company (16% Mo-7% Cr-5% Fe-0.02% C-0.35% W-bal Ni) to have the best creep properties of any of the alloys evaluated thus far. Alloy 30-62 (16% Mo-7% Cr-5% Fe-0.06% C-0.15% Zr-bal Ni), which is of the INOR-8 type with the addition of a small amount of zirconium, was found to have identical creep properties to those of the nominal INOR-8 composition (15% Mo-6% Cr-5% Fe-0.06% C-bal Ni) up to about 10% strain. The rupture life however, was 500 hr longer for alloy 30-62, and its final elongation was 67% compared with 26% for the nominal INOR-8 alloy. Neither of these alloys possessed as good creep properties as those of the Haynes melt. Alloy VT-51 (17% Mo-10% Cr-7% Fe-0.06% C-bal Ni) has a rupture life of over 1200 hr, but its creep properties are inferior up to 10% elongation. A heat produced by Westinghouse (17% Mo-7% Cr-4% Fe-0.14% C-bal Ni) is the poorest of the alloys tested with respect to both creep and rupture properties. Preliminary tests have indicated that the Haynes material is markedly superior to the other heats at 1800°F; however, only 7% elongation was obtained before fracture.

Metallurgy - Nondestructive Testing

The Metal Identification Meter, originally developed for the sorting of Inconel from the common Hastelloys and from austenitic stainless steels, was successfully adapted to the measurement of the thickness of thin sections of these same materials. This adaptation was accomplished by a minor alteration in the circuit to permit adjustment of the range of the meter. This change allows measurements of Inconel sheet thicknesses of up to 0.04 in., with a maximum error of ±0.001 in. Similar portable instruments for the measurement of the thickness of other metals and alloys can be constructed by simply altering the circuit parameters of the present instrument.

Chemistry - Fuel Research

The compound $KF \cdot 6UF_4$ does not exhibit a primary phase in the system $KF-UF_4$. The lower temperature of stability of the compound $2KF \cdot UF_4$ is about 620°C, and at that temperature the compound decomposes into $3KF \cdot UF_4$ and $7KF \cdot 6UF_4$. In addition to the tetragonal and cubic forms of $3KF \cdot UF_4$, there exists a less symmetrical form of the compound which is biaxial negative and has the refractive indices $\alpha = 1.41$ and $\gamma = 1.426$.

A study of the reaction

$$FeF_2 + Cr^0 = CrF_2 + Fe^0$$

in the reaction medium $RbF-ZrF_4$ (52-48 mole %) at 600°C has shown that the reduction of Fe^{++} in this system is essentially complete. For example, with an initial concentration of 6000 ppm of Fe^{++}, equilibrium iron concentrations of 100 to 140 ppm were found. The experimentally determined Cr^{++} concentrations were approximately 20% larger in virtually all cases than the concentrations calculated from the amount of Fe^{++} consumed. The reason for this discrepancy is not evident.

The determination of activity coefficients by hydrogen equilibrium reduction of NiF_2 in $NaF-ZrF_4$ (53-47 mole %) has been concluded. The equilibrium constants obtained have the values of 21,900 ± 2,000, 15,300 ±700, 11,000 ± 600, and 7,600 ± 400 atm at 625, 600, 575, and 550°C, respectively. Values for the free energies of formation of NiF_2 at the temperatures indicated were calculated from the equilibrium constants and the free energies of formation of HF gas. It was assumed that NiF_2 has an activity coefficient of one whether it is dissolved at unit mole fraction or it is at infinite dilution. The calculated values of the free energies of formation of NiF were -113.6, -114.6, -115.6, and -116.6 kcal at 625, 600, 575, and 550°C, respectively.

Shield Design

A Monte Carlo calculation was performed on the Oracle to estimate the gamma-ray heating in the shield for the proposed Tower Shielding Reactor-II (TSR-II). A code for an infinitely thick slab shield was

used. Hand calculations are being made to estimate the energy distribution of the flux incident upon the shield in order to weight the Oracle results, which are functions of the incident energy.

The study of gamma-ray penetration of lead and water slab shields was continued, with additional Monte Carlo calculations being performed on the Oracle. The results, which include heating, dose rate, energy flux, energy distribution, and angular distribution, are being analyzed.

Bulk Shielding Facility (BSF)

Mockup tests for obtaining information with which to predict the time required for paired control plates to drop in the UO_2-stainless steel core proposed for the BSF reactor were completed. The drop time of plates that had coil springs mounted on the holding magnets to give initial forces of 66 or 86 lb were compared with the drop times of plates that fell by the force of gravity alone. For a drop of 2.75 in., the time required by plates having a 66-lb initial force was 66 msec, as compared with 180 msec for plates accelerated only by the force of gravity. Little additional speed was gained by the use of the 86-lb initial force. Calculations on the Univac have indicated that the prompt neutron lifetime in the proposed core will be 15 μsec. (Each fuel element in the proposed core will contain 20 fuel plates, and each plate will have a 20-mil-thick fuel section. The value of the multiplication factor was assumed to be 1.025.)

A small, movable gamma-ray directional shield was designed for installation near the outer surface of the ART shield. This shield will aid in determining the background for gamma-ray spectroscopy measurements during the ART operation. As presently envisioned it will be a small right cylinder of lead capable of being positioned in the "line of sight" of each spectroscopy tube to block out the direct beam of radiation to that tube from the point of interest on the shield. The design of all handling and positioning equipment required for the ART shielding tests is 95% complete. Approximately 80% of all equipment ordered from vendors has been received. A proposal has been requested from a vendor for the fabrication of the gamma-ray spectrometer table.

Lid Tank Shielding Facility (LTSF)

A series of tests was performed to obtain information on the relative effectiveness of various gamma-ray shields and on secondary gamma-ray production in the shields as a function of distance from the source plate. The configurations consisted of 4 in. of beryllium followed by a gamma-ray shield and 12 in. of lithium hydride; all components were immersed in oil. The gamma-ray shields were 1 1/2 in. of depleted uranium, 4 in. of stainless steel, or 2 in. of Hevimet. The configuration could be shifted, as a unit, within the LTSF, to vary the oil thickness between the source plate and the configuration. This had the effect of varying the gamma-ray-to-neutron ratio incident on the heavy material. Bare and cadmium-covered gold-foil data were taken on both sides of each gamma-ray shield

at every shield position in the tank. In obtaining information on the secondary gamma rays, slabs of boral were placed at various positions within the configurations. Additional configurations are being tested to obtain further information.

Tower Shielding Facility (TSF)

Measurements were made of the dose rate inside a cylindrical crew compartment mockup from air-scattered fast neutrons which penetrated various thicknesses of an oil or water side shield of the mockup. The mockup was located 60 ft from the center of the reactor tank, and the dose rate measurements were made as a function of the position of the reactor in the tank. An estimate of the angular distribution of the fast neutrons entering the sides of the mockup was also made.

Edited by A. W. Savolainen

Approved by Alvin M. Weinberg, Director