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OAK RIDGE NATIONAL LABORATORY
SPECIAL PROGRESS REPORT
PROGRAM 4700
AUGUST 1957

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SPECIAL PROGRESS REPORT

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OAK RIDGE NATIONAL LABORATORY

SPECIAL PROGRESS REPORT

August 1957

PROGRAM 4700 - REACTOR DEVELOPMENT

AIRCRAFT NUCLEAR PROPULSION PROJECT (AEC Activity 4701)

Aircraft Reactor Test (ART)

A detailed stress analysis of the steel support structure for the lead gamma-ray shield of the ART was completed. The final structure follows the lines developed in the preliminary layout, and the design is now being detailed.

Recent tests of a mockup of the bellows to be used at the top of the inner core shell to accommodate differential thermal expansion between the inner core shell and the main pressure shell indicated that failure in the form of a fatigue crack would develop after 80 thermal cycles. Since it has been the policy in the design of the ART to provide a safety factor of 10 in design lifetime from the standpoint of the calculated stresses, the design of the island bellows was modified to reduce the severity of the thermal strain cycling. The depth of the convolutions was increased, and the over-all diameter of the bellows was increased slightly. The redesigned unit should have an operating life of at least 300 cycles.

A report covering developmental tests on the ART fuel, sodium, and NaK pumps was completed. This report includes a comprehensive discussion of all phases of the development, including hydraulic performance tests with water, the bearing and seal development work, the xenon-removal system, the expansion tank and fuel pump coupling, and the analyses and tests made on the contamination of the lubricating oil by fission products. Data obtained in subsequent tests with the working fluids have confirmed the water test data.

Engineering Test Unit

Installation work on the sodium-to-NaK heat exchangers of the ETU north head continued. As a result of this experience, changes were made in fabrication techniques for the corresponding heat exchangers for the ART assembly in order to decrease installation time. Machining of the lower deck weldment was essentially completed. The fabrication of the load ring assembly is continuing without difficulty, and contour machining operations were completed. A shell III (outer reflector shell) upper weldment was received, and machining operations are in progress on two shell II (outer core shell) weldments and on one shell III weldment that were received previously.

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A completed fuel-to-NaK heat exchanger tube bundle was received from the Black, Sivalls & Bryson Company on August 19. This tube bundle, which does not meet specifications in some minor respects, will be used for experimental studies. Stainless steel cans and lids which will enclose the boron carbide tiles were received, inspected, and found to be satisfactory.

Installation of the main NaK piping runs in the ETU facility was completed, and one radiator was installed in the air duct. Fabrication and installation work is now under way on the main stand structural cross bracing, pipe supports, and main floor electrical equipment supports. The installation of the electrical facilities in the basement area is continuing on schedule.

ART Facility Construction

Package 3A contract work on the ART facility was completed, including installation of the compressor house, NaK motor controllers, electrical heater distribution equipment, lube oil fill-and-waste system, louver hydraulic system, and some further building alterations. The completion of package 3A work marked the completion of all lump-sum contracts for the facility. The contract work on the facility has cost a total of $1,096,390.

A one-twelfth scale model of the major items of piping and equipment for the special equipment room was assembled. A preliminary demonstration of the model indicated that it will be possible to make any required equipment changes. Detail design work on equipment and layouts for the radiator-pit and the radiator-penthouse areas is continuing.

Work continued in the investigation of methods for the disassembly of the ART and the design of equipment and a facility for examination of the reactor. Visualization of the major reactor disassembly methods is obtained through the use of a hot-cell model.

Reactor Component Development and Testing

Priming tests of the ART fuel pump were continued with $NaF-ZrF_4-UF_4$ (fuel 30) at 1200°F at liquid levels of 0, 9/16, 2, and 3 in. above the expansion tank floor. The pump primed satisfactorily and produced the rated head and flow at all levels above 1/2 in. At levels of less than 1/2 in. only about 90% of the rated head is achieved because the fuel being pumped does not degas completely. After each priming test at a given fill level, the pump was left stationary for 24 to 48 hr to determine the effectiveness of a 50-liter/day helium purge in preventing diffusion of ZrF_4 into the shaft annulus. The shaft turned freely at any liquid level, and thus it was evident that ZrF_4 did not enter the shaft annulus in sufficient quantities to be detrimental. Preliminary tests of the sodium pumps with water in a mockup of the ART north head sodium system have indicated satisfactory performance at rated head and flow conditions.

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Tests were terminated, because of a gas furnace inlet line failure, of a 100-tube NaK-to-fuel heat exchanger bundle which was being thermally cycled ten times daily between NaK inlet temperatures of 1700 and 1200°F while a NaK temperature drop of 400°F was maintained. The test progressed without interruption for 168 thermal cycles, which was about 125 cycles more than predicted for these conditions.

Extensive examination of the first ART prototype NaK-to-air radiator, which failed during testing, has not revealed a specific cause for the leak. Sixteen representative tubes, four of which were from the section between stress-relieving slits, including the tube that failed, were examined metallographically. No evidence could be found of stress damage, defects, or the presence of impurities. A second prototype radiator has been installed for similar tests. The planned operating period is 1600 hr, and the unit is to be thermally cycled 300 times.

The second thermal stability test of a one-fourth-scale ART outer-core-shell model was continued to 339 cycles, at which point the test stand was shut down because of failure of the lube oil system for one of the sodium pumps. Since the test was originally scheduled for only 300 cycles, the equipment was disassembled and the core shell was removed for examination. No visual damage was evident; the dimensions are being measured.

A guided-plug NaK valve with a Stellite No. 6 overlay on the seat and poppet was found to be leaktight when tested with water after it was received from Black, Sivalls & Bryson. It leaked NaK badly, however, when it was heated to 1000°F, and, on the presumption that it had distorted thermally, it was disassembled, stress relieved at 1500°F, and relapped. Again it was leaktight with water and also initially with hot NaK, but the NaK leakage increased rapidly, becoming unacceptable after 100 hr. A second stress relief did not improve the leakage rate with NaK. After removal from the test stand, the valve was again leaktight with water. Although a small nick was noted on the seat, disassembly revealed no adequate cause for the unusual behavior. Other seat materials and designs are being considered. A NaK valve operator was received, and, after minor revisions, it performed satisfactorily in a 3000-cycle test.

Irradiation Testing

An ART-type fuel-pump rotary assembly is being irradiated in a gamma-ray facility in the MTR canal. Dose rates that average 6×10^6 rep/hr are obtained in this new facility, which utilizes fuel elements that were removed for xenon decay but which are to be returned to the reactor for further burnup. The fuel pump rotary assembly is to be exposed to a total dose of 10^{10} rep in order to investigate the effects of radiation on the lubricating oil at the seal, catch basin, and thermal shield.

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Advanced Design and System Analysis

At the request of the AEC Aircraft Reactors Branch a careful review was made of a Rand proposal for a helium turbojet cycle. Also, a review of subsonic applications of nuclear aircraft was carried out to assist the Air Force long-range planning committee now in conference at Woods Hole, Mass.

Metallurgy - Corrosion

A thermal-convection loop (No. 1159) fabricated of a nickel-molybdenum alloy composed of 17% Mo, 5% Fe, 6% Cr, 0.5% Al, 0.5% Mn, 0.06% C, bal Ni (INOR-8) was operated for 1000 hr with $NaF-KF-LiF-UF_4$ (11.2-41-45.3-2.5 mole %, fuel 107) at a maximum fuel-metal interface temperature of 1780°F. The maximum mixed mean fuel temperature was 1650°F. Metallographic examination of the loop revealed considerable corrosion along the hot-leg surfaces to a maximum depth of 12 mils. The attack, which was in the form of subsurface voids, closely resembled the attack normally found in Inconel systems operated with $NaF-ZrF_4-UF_4$ (50-46-4 mole %). In addition to fluoride attack, noticeable oxidation occurred along the tubing surfaces exposed to air. Oxidation took place preferentially along grain boundaries, and the depths of penetration ranged to 6 mils. Cold-leg surfaces of the loop contained scattered crystalline deposits, which were too small to be seen visually. An attempt to obtain an analysis of the deposits is now being made.

The attack in this loop was considerably greater than that found in a similar loop (No. 1155) operated with a maximum fuel-metal interface temperature of 1670°F. In loop 1155 the attack was evident primarily as surface pits and was limited to a depth of 3 mils. The attack of loop 1159 may also be contrasted with the attack of Hastelloy W in a similar test at the higher temperature level. The composition of Hastelloy W is similar to that of the alloy used in loop 1159 except that the molybdenum content is about 25%. In several tests of Hastelloy W at temperatures up to 1800°F, attack has been limited to 3.5 mils and has occurred as surface pits. It appears on the basis of the limited information now available that the molybdenum in these alloys serves to slow down the diffusion of such preferentially attacked elements as chromium and iron. While lesser amounts of molybdenum appear to be quite adequate at lower temperatures, larger amounts may be required to limit chromium diffusion and the resultant void formation at higher temperatures.

An unclad niobium thermal-convection loop has circulated lithium at hot- and cold-leg temperatures of 1500 and 1200°F in a vacuum chamber for a total of 100 hr. A vacuum of less than 1 μ has been maintained in the chamber. This loop is scheduled to operate 500 hr.

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Metallurgy - Welding and Brazing

Procedures were developed for the continuous production of Coast Metals No. 52 brazing alloy rings. Test rings of four different weights were prepared, and the optimum weight of the ring was established after visual and metallographic evaluation. A tool for drilling the graphite molds was designed that will provide for critical control of the inside diameter of the rings. The inside diameter must be precise so that the ring will conform to the fin lip and will operate satisfactorily in the York Corporation ring-ejector apparatus used for placing the rings prior to brazing.

The first of two semicircular fuel-to-NaK heat exchangers being fabricated for stress tests was completed. The dimensions of the bends of each of the 40 tubes were determined accurately, as required for the stress analysis.

Metallurgy - Mechanical Properties

Preliminary data on the influence of prior strain cycling on the creep properties of Inconel at 1600°F indicate that the creep rate is increased and the time to rupture is significantly reduced by prior strain. For example, a specimen that had undergone 300 cycles at 1% plastic strain per cycle showed a decrease in creep-rupture life of 50%. Creep data for specimens strain cycled at 1% strain for 100, 300, and 500 cycles prior to test indicate that with regard to creep-rupture life severe damage of the structure occurs within the first 100 cycles.

Metallurgy - Nondestructive Testing

An RCA (Model ITV-6) closed-circuit television system for direct x-ray imaging has been installed, and initial adjustments and alignment were accomplished.

The preliminary studies of this system show that the contrast sensitivity, although not so great as that attained with film, is sufficient for many applications and that the tendency for the image to be shadowed enhances the apparent contrast. This system will clearly resolve the x-ray image of a 500-mesh screen, and thus the possible resolution is in excess of 500 lines per inch. The inherent magnification appears to improve the resolution of the fine detail.

Chemistry - Fuel Research

A quenching study of the system KBF_4-$NaBF_4$ was completed that confirmed the liquidus temperatures obtained from thermal data and showed that the system does not contain either compounds or solid solutions. It is a simple binary system with a eutectic located near 90 mole % $NaBF_4$ at about 357°C.

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The solubilities of CrF_2, FeF_2, and NiF_2 in $RbF-ZrF_4$ (52-48 mole %) at 600 and 800°C were determined. The values obtained are given below:

Temperature (°C)	Metal Fluoride Added	Amount Added (wt %)	Solubility (wt %)
600	NiF_2	1.6	0.39
		7.7	0.87
800	NiF_2	1.6	0.89
		7.7	2.3
600	CrF_2	1.7	1.3
		26.0	14.0
800	CrF_2	34.0	27.0
600	FeF_2	8.4	3.0
800	FeF_2	17.0	14.0
		25.0	16.0

The values of Henry's law constants for argon, helium, and xenon in $NaF-ZrF_4$ (53-47 mole %) were also determined. The heats of solutions obtained from the temperature dependence were 6.2, 8.2, and 11.1 kcal/mole for helium, argon, and xenon, respectively.

Chemistry - Analytical Studies

Revisions were made in the method for the determination of oxygen in lithium, which is based on the reaction of lithium with an ethereal solution of butyl iodide and iodine. After dissolution of the metal, water is added to the ethereal solution to extract the lithium oxide as lithium hydroxide, which is then titrated with standard acid. Low results were noted in preliminary tests when unreacted iodine was present. This source of error was eliminated by adding mercury to the solution to react with the iodine. The presence of mercury in the solution, together with iodide ions, could yield high results. This error was avoided by adding a large excess of mercuric chloride after the addition of the mercury. Satisfactory results were obtained on samples with known quantities of lithium oxide added to lithium iodide.

In studies on the reaction products of NaK and pump lubricants, acetylene was positively identified as one of the product gases. In a specific test in which 2 ml of NaK and 2 ml of Gulfspin-35 lubricant were heated to 600°C, a pressure of about 450 psi developed. The evolved gas from this test was predominantly methane, with some hydrogen, in addition to the acetylene present. The production of acetylene was about 6 ml of acetyllene per milliliter of NaK.

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Lid Tank Shielding Facility (LTSF)

A series of tests was conducted to investigate a shield design proposed by Pratt & Whitney Aircraft. The configurations, which are immersed in borated water, consist of 2 in. of nickel, 1 in. of stainless steel, and 1 1/2 in. of depleted uranium. The spacing between the stainless steel and the uranium was varied to obtain data for different thicknesses of borated water between these two components. It is expected that this experiment will be repeated for a similar configuration in which the thickness of the uranium is 3 in. Bare and cadmium-covered gold foils were used to determine the thermal-neutron flux incident on the gamma-ray shield.

Tower Shielding Facility (TSF)

An attempt is being made to measure qualitatively the neutron capture and inelastically scattered gamma-ray spectra from nitrogen with a 3-in.-dia NaI crystal and two 20-channel analyzers in series. An 8-in.-dia collimator attached to the TSF reactor grid allows a cone of neutrons to be projected into the air at an angle of 60 deg from the horizontal. The collimator for the detector is positioned in a horizontal plane out of the direct neutron beam and pointed to intersect the axis of the beam. In this position both the scattered and capture gamma rays are observed. The neutron beam can then be rotated 90 deg so that the detector collimator, which has remained stationary, sees primarily capture gamma rays and relatively few inelastically scattered gamma rays. The capture gamma-ray peak is used as a point for normalization, and the inelastically scattered gamma-ray contribution can be obtained from the difference in the two spectra.

Bulk Shielding Facility (BSF)

In an attempt to improve the resolution of the large 9 3/8-in.-dia thallium-activated sodium iodide crystal, it has been decided to use seven 3-in.-dia photomultiplier tubes (Dumont 6363) with the crystal rather than three 5-in.-dia tubes. This will result in the loss of about 10% of the total photocathode surface exposed to the crystal, but it is believed that the over-all results will show an improvement in the response of the crystal-photomultiplier system. One of the advantages is that the 3-in.-dia tubes may be arranged on the crystal so that the total photocathode surface of each tube is exposed to the crystal; this condition cannot be obtained with the 5-in.-dia tubes.

Tower Shielding Reactor-II (TSR-II)

A simplified three-region model of the TSR-II used for calculations on the Oracle with the three-group three-region reactor code (as a two-group code) was used with the Eyewash code for calculations on the UNIVAC. Since the results from the two machines were identical, it was concluded that the Oracle treatment of thin shells would be reliable for various reactor control studies. A second experiment was also set up for a further study of the effectiveness of control plates in the inner water reflector.

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In addition, removal of heat from the lead region adjacent to the core was investigated. Assumed angular and energy distributions of the gamma-ray flux were used in an Oracle Monte Carlo calculation which was made to predict the heat generation throughout the lead. The results, together with the results of studies of flow throughout the core, will be used to obtain the expected temperature distribution in the lead. Since adequate heat removal from the lead depends on the quality of the bond between the aluminum container and the lead, two methods, both satisfactory, were tried to obtain a bond. In one method an electroplating technique is used, and in the other the aluminum is cleaned ultrasonically in molten lead. An experiment is being set up with which to verify the results of the Oracle calculations and to test the aluminum-to-lead bonds obtained.

It was found that the longer fuel plates in the completed annular dummy elements varied somewhat in radius. The variation is believed to be due to flexure in the forming rolls. The hand rolls are being modified therefore to reduce the flexure and, it is hoped, to eliminate the variation in radius.

Edited by A. W. Savolainen

Approved by Alvin M. Weinberg, Director

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