

~~SECRET~~

CENTRAL RESEARCH LIBRARY

DOCUMENT COLLECTION

ORNL-2012, Part I, II, III

C-84 - Reactors-Special Features of Aircraft Reactors

AEC RESEARCH AND DEVELOPMENT REPORT

cy. 129A

DECLASSIFIED

CLASSIFICATION CHANGED TO
BY AUTHORITY OF: *AEC-6-17-68*
BY: *A. Beeman, 8.14.62*

MARTIN MARETTA ENERGY SYSTEMS LIBRARIES



3 4456 0349900 6

79
AVY

AIRCRAFT NUCLEAR PROPULSION PROJECT
 QUARTERLY PROGRESS REPORT
 FOR PERIOD ENDING DECEMBER 10, 1955

CENTRAL RESEARCH LIBRARY
 DOCUMENT COLLECTION
LIBRARY LOAN COPY

DO NOT TRANSFER TO ANOTHER PERSON

If you wish someone else to see this document, send in name with document and the library will arrange a loan.



OAK RIDGE NATIONAL LABORATORY

OPERATED BY

UNION CARBIDE NUCLEAR COMPANY

A Division of Union Carbide and Carbon Corporation



POST OFFICE BOX P • OAK RIDGE, TENNESSEE

RESTRICTED DATA

This document contains Restricted Data as defined in the Atomic Energy Act of 1954. Its transmission or the disclosure of its contents in any manner to an unauthorized person is prohibited.

~~SECRET~~



ORNL-2012, Part I, II, III
C-84 - Reactors-Special Features of Aircraft Reactors

This document consists of 244 pages.
Copy 129 of 324 copies. Series A.

Contract No. W-7405-eng-26

AIRCRAFT NUCLEAR PROPULSION PROJECT
QUARTERLY PROGRESS REPORT
For Period Ending December 10, 1955

W. H. Jordan, Director
S. J. Cromer, Co-Director
A. J. Miller, Assistant Director
A. W. Savolainen, Editor

DATE ISSUED

FEB 20 1956

OAK RIDGE NATIONAL LABORATORY
Operated by
UNION CARBIDE NUCLEAR COMPANY
A Division of Union Carbide and Carbon Corporation
Post Office Box P
Oak Ridge, Tennessee

This document is a technical report and its contents
are not to be distributed in any manner to an unauthorized person.



MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0349900 6

INTERNAL DISTRIBUTION

- | | |
|-------------------------|-------------------------------|
| 1. R. G. Affel | 49. R. S. Livingston |
| 2. C. R. Baldock | 50. R. N. Lyon |
| 3. C. L. Barton | 51. F. C. Maienschein |
| 4. D. S. Billington | 52. W. D. Manly |
| 5. F. F. Blankenship | 53. E. R. Mann |
| 6. E. P. Blizard | 54. L. A. Mann |
| 7. C. J. Borkowski | 55. W. B. McDonald |
| 8. G. E. Boyd | 56. F. R. McQuinkin |
| 9. M. A. Bredig | 57. R. V. Mesnreblian |
| 10. F. R. Bruce | 58. R. P. Milford |
| 11. A. D. Callihan | 59. A. J. Miller |
| 12. D. W. Cardwell | 60. R. E. Moore |
| 13. J. V. Cathcart | 61. L. Z. Morgan |
| 14. C. E. Center (K-25) | 62. E. J. Murphy |
| 15. R. A. Charpie | 63. J. P. Murray (Y-12) |
| 16. G. H. Clewett | 64. G. J. Nessel |
| 17. C. E. Clifford | 65. R. B. Oliver |
| 18. J. H. Coobs | 66. L. G. Overholser |
| 19. W. B. Cottrell | 67. P. Patriarca |
| 20-21. D. D. Cowen | 68. R. W. Peelle |
| 22. S. Cromer | 69. A. M. Perry |
| 23. R. S. Crouse | 70. J. C. Pigg |
| 24. F. L. Culler | 71. W. G. Piper |
| 25. J. H. DeVan | 72. H. F. Poppendiek |
| 26. D. A. Douglas | 73. P. M. Reyling |
| 27. E. R. Dytko | 74. H. W. Savage |
| 28. L. B. Emler (K-25) | 75. A. W. Savolainen |
| 29. M. J. Feldman | 76. R. D. Schultheiss |
| 30. D. E. Ferguson | 77. E. D. Shipley |
| 31. A. P. Fraas | 78. A. Simon |
| 32. J. H. Frye | 79. O. Sisman |
| 33. W. T. Furgerson | 80. G. M. Smith |
| 34. H. C. Gray | 81. A. H. Snell |
| 35. W. R. Grimes | 82. C. D. Stano |
| 36. E. E. Hoffman | 83. J. A. Swainout |
| 37. A. Hollaender | 84. E. H. Taylor |
| 38. A. S. Householder | 85. R. E. Thoma |
| 39. J. T. Hoye | 86. D. B. Trauger |
| 40. H. K. Jackson | 87. E. R. Van Artsdale |
| 41. W. H. Jordan | 88. F. C. VonderLage |
| 42. G. V. Keilholtz | 89. G. M. Watson |
| 43. C. P. Keim | 90. A. M. Weinberg |
| 44. M. T. Kelley | 91. J. C. White |
| 45. F. Kertesz | 92. G. D. Whitman |
| 46. E. M. King | 93. E. P. Wigner (consultant) |
| 47-48. J. A. Lane | 94. G. C. Williams |

[REDACTED]

ORNL-2012, Part I, II, III
C-84 – Reactors-Special Features of Aircraft Reactors

- | | |
|--|--|
| 95. J. C. Wilson | 107-126. Laboratory Records Department |
| 96. C. E. Winters | 127. Laboratory Records, ORNL R.C. |
| 97-106. ORNL-Y-12 Technical Library,
Document Reference Section | 128-130. Central Research Library |

EXTERNAL DISTRIBUTION

131. AF Plant Representative, Baltimore
132. AF Plant Representative, Burbank
133. AF Plant Representative, Marietta
134. AF Plant Representative, Santa Monica
135. AF Plant Representative, Seattle
136. AF Plant Representative, Wood-Ridge
137. Air Materiel Area
138. Air Research and Development Command (RDGN)
139. Air Research and Development Command (RDZPA)
140. Air Technical Intelligence Center
141. Aircraft Laboratory Design Branch (WADC)
142-144. ANP Project Office, Fort Worth
145. Argonne National Laboratory
146. Armed Forces Special Weapons Project, Sandia
147. Assistant Secretary of the Air Force, R&D
148-153. Atomic Energy Commission, Washington
154. Battelle Memorial Institute
155. Bettis Plant
156. Bureau of Aeronautics
157. Bureau of Aeronautics (Code 24)
158. Bureau of Aeronautics General Representative
159. Chicago Operations Office
160. Chicago Parent Group
161-162. Chief of Naval Research
163. Convair-General Dynamics Corporation
164. Director of Laboratories (WCL)
165. Director of Requirements (AFDRQ)
166. Director of Research and Development (AFDRD-ANP)
167-169. Directorate of Systems Management (RDZ-1SN)
170-172. Directorate of Systems Management (RDZ-1SS)
173. Equipment Laboratory (WADC)
174-177. General Electric Company (ANPD)
178. Hartford Area Office
179. Headquarters, Air Force Special Weapons Center
180. Idaho Operations Office
181. Knolls Atomic Power Laboratory
182. Lockland Area Office
183. Los Alamos Scientific Laboratory
184. Materials Laboratory Plans Office (WADC)
185. Mound Laboratory
186. National Advisory Committee for Aeronautics, Cleveland



ORNL-2012, Part I, II, III
C-84 – Reactors-Special Features of Aircraft Reactors

- 187. National Advisory Committee for Aeronautics, Washington
- 188. Naval Air Development Center
- 189. New York Operations Office
- 190. North American Aviation, Inc. (Aerophysics Division)
- 191. Nuclear Development Corporation
- 192. Patent Branch, Washington
- 193-195. Powerplant Laboratory (WADC)
- 196-199. Pratt & Whitney Aircraft Division (Fox Project)
- 200. San Francisco Operations Office
- 201. Sandia Corporation
- 202. School of Aviation Medicine
- 203. Sylvania Electric Products, Inc.
- 204. USAF Project RAND
- 205. University of California Radiation Laboratory, Livermore
- 206-208. Wright Air Development Center (WCOSI-3)
- 209-323. Technical Information Extension, Oak Ridge
- 324. Division of Research and Development, AEC, ORO





Reports previously issued in this series are as follows:

ORNL-528	Period Ending November 30, 1949
ORNL-629	Period Ending February 28, 1950
ORNL-768	Period Ending May 31, 1950
ORNL-858	Period Ending August 31, 1950
ORNL-919	Period Ending December 10, 1950
ANP-60	Period Ending March 10, 1951
ANP-65	Period Ending June 10, 1951
ORNL-1154	Period Ending September 10, 1951
ORNL-1170	Period Ending December 10, 1951
ORNL-1227	Period Ending March 10, 1952
ORNL-1294	Period Ending June 10, 1952
ORNL-1375	Period Ending September 10, 1952
ORNL-1439	Period Ending December 10, 1952
ORNL-1515	Period Ending March 10, 1953
ORNL-1556	Period Ending June 10, 1953
ORNL-1609	Period Ending September 10, 1953
ORNL-1649	Period Ending December 10, 1953
ORNL-1692	Period Ending March 10, 1954
ORNL-1729	Period Ending June 10, 1954
ORNL-1771	Period Ending September 10, 1954
ORNL-1816	Period Ending December 10, 1954
ORNL-1864	Period Ending March 10, 1955
ORNL-1896	Period Ending June 10, 1955
ORNL-1947	Period Ending September 10, 1955







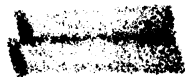
FOREWORD

This quarterly progress report of the Aircraft Nuclear Propulsion Project at ORNL records the technical progress of the research on circulating-fuel reactors and other ANP research at the Laboratory under its Contract W-7405-eng-26. The report is divided into three major parts: I. Reactor Theory, Component Development, and Construction, II. Materials Research, and III. Shielding Research.

The ANP Project is comprised of about 530 technical and scientific personnel engaged in many phases of research directed toward the achievement of nuclear propulsion of aircraft. A considerable portion of this research is performed in support of the work of other organizations participating in the national ANP effort. However, the bulk of the ANP research at ORNL is directed toward the development of a circulating-fuel type of reactor.

The design, construction, and operation of the Aircraft Reactor Test (ART), with the cooperation of the Pratt & Whitney Aircraft Division, are the specific objectives of the project. The ART is to be a power plant system that will include a 60-Mw circulating-fuel reflector-moderated reactor and adequate means for heat disposal. Operation of the system will be for the purpose of determining the feasibility, and the problems associated with the design, construction, and operation, of a high-power, circulating-fuel, reflector-moderated aircraft reactor system.






CONTENTS

FOREWORD	vii
SUMMARY	1
PART I. REACTOR THEORY, COMPONENT DEVELOPMENT, AND CONSTRUCTION	
1. REFLECTOR-MODERATED REACTOR	15
ART Facility Design and Construction	15
ART Design	19
System Flow Sheets	19
Fuel-to-NaK Heat Exchanger	19
Fuel Fill-and-Drain System	20
Reactor Shield	20
Core Flow Studies	23
Engineering Test Unit	25
Controls and Instrumentation	25
Procurement of Special Reactor Materials and Components	25
Beryllium	25
Shell Fabrication	26
CX-900 Inconel	26
Main Heat Exchangers and Radiators	26
Operation of ZrF_4 Vapor Traps in the High-Temperature Critical Experiment	26
2. EXPERIMENTAL REACTOR ENGINEERING	27
In-Pile Loop Development and Tests	27
In-Pile Loop Operation	27
Loop Purge System	29
Forced-Circulation Corrosion and Mass Transfer Tests	30
Fused-Salt-Inconel Systems	30
Liquid Metals in Multimetal Loops	32
Pump Development	33
Bearing-and-Seal Tests	33
Sodium-Pump Water Performance Tests	35
High-Temperature Tests of ART MF-2 Fuel Pump with NaK	36
High-Temperature Pump-Performance Test Stands	41
Heat Exchanger Development	41
Intermediate Heat Exchanger Tests	41
Small Heat Exchanger Tests	49
Heat-Transfer and Pressure-Drop Correlations	49
Structural Tests	54
Outer-Core-Shell Thermal-Stability Test	54
Inconel Strain-Cycling Tests	56
Thermal-Cycling Test of Sodium-Inconel-Beryllium System	58
Reactor Component Development	59
Dump Valve	59
Cold Trap and Plugging Indicator	60



Zirconium Fluoride Vapor Trap	60
Water Test of Aluminum Mockup of Top of ART	64
3. CRITICAL EXPERIMENTS	66
Room-Temperature Reflector-Moderated-Reactor Critical Experiments.....	66
Power and Neutron-Flux Distributions	66
Neutron Production in the Fuel-to-NaK Heat Exchanger	66
Radial Importance of Uranium in the Fuel Annulus.....	67
Importance of Beryllium at End of Reactor	67
Axial Importance of a Neutron Source	70
High-Temperature Reflector-Moderated-Reactor Critical Experiments	71
Compact-Core Reflector-Moderated-Reactor Critical Experiments.....	73

PART II. MATERIALS RESEARCH

4. CHEMISTRY OF REACTOR MATERIALS.....	77
Phase Equilibrium Studies.....	77
The System ZrF_4-UF_4	77
The System $LiF-UF_4$	77
The System $NaF-LiF-UF_4$	78
The System $KF-UF_4$	78
The System $NaF-KF-ZrF_4$	79
The System $NaF-LiF-BeF_2$	80
The System $NaF-LiF-BeF_2-UF_4$	83
The System $KF-BeF_2$	84
The System $NaF-KF-BeF_2$	84
Systems Containing Alkaline-Earth Fluorides	84
Chemical Reactions in Molten Salts.....	85
Equilibrium Reduction of FeF_2 by H_2 in $NaZrF_5$	85
Reduction of UF_4 by Structural Metals	86
Stability and Solubility of Chromium Fluorides in Various Molten Fluorides	88
Reaction of UF_3 with Alkali Fluorides.....	90
Reduction of Alkali Fluorides by Uranium Metal.....	91
Experimental Preparation of Pure Fluorides	91
Production of Purified Fluorides	92
Removal of CrF_2 from $NaF-ZrF_4-UF_4$ Mixtures.....	92
Laboratory-Scale Purification Operations.....	94
Special Preparation of $NaF-ZrF_4-UF_3-UF_4$	94
Evaluation of Raw Materials for Fuel Preparation	94
Pilot-Scale Purification Operations.....	95
Production-Scale Operations.....	95
Batching and Dispensing Operations.....	95
Special Services	96
Fundamental Chemistry of Fused Salts	96
Relative Viscosity-Composition Studies of $NaF-LiF-ZrF_4$ Mixtures at $600^\circ C$	96
EMF Measurements in Fused Salts	97
Optical Properties and X-Ray Patterns for Various Compounds in Fluoride Systems	99
5. CORROSION RESEARCH.....	103
Forced-Circulation Studies	103



Fluorides in Inconel.....	103
Sodium in Inconel	106
Thermal-Convection Studies	107
Effect of Difference Between Loop Wall Temperature and Fluid Temperature	107
Effect of Zirconium Hydride Additions to Fluoride Mixture.....	107
Loops Fabricated from Special Inconel-Type Alloys	110
Nickel-Molybdenum Alloy Loops	111
Effect of Nitrogen Atmosphere	111
General Corrosion Studies	112
Thermal-Convection Loop Tests of Brazed Inconel T-Joints in NaF-ZrF ₄ -UF ₄	112
Seesaw Tests of Brazed Inconel T-Joints in Sodium and in Fuel Mixtures.....	113
Static Tests of Brazed Materials	117
Static Tests of Brazed Hastelloy B T-Joints in Sodium and in NaF-ZrF ₄ -UF ₄	120
Seesaw Tests of Chromel-Alumel Thermocouple Joins to Inconel Thermocouple Wells	120
Effect of Ruthenium on Physical Properties of Inconel	122
Boiling Sodium in Inconel Loop	122
Decarburization of Mild Steel by Sodium.....	123
Static Tests of Special Stellite Heats in Lithium	124
Solubility of Lithium in NaK.....	125
Seesaw Tests of Titanium Carbide Cermets in NaF-ZrF ₄ -UF ₄	127
Thermal-Cycling Tests of Inconel Valve Disks and Seats Flame-Plated with a Mixture of Tungsten Carbide and Cobalt	130
Static Tests in NaF-ZrF ₄ -UF ₄ of Kentanium Cermet Valve Parts Brazed to Inconel	131
Effect of an Air Leak Into an Inconel-Fused-Salt Test System	131
Fundamental Corrosion Research	133
Self-Decomposition of Fused Hydroxides.....	133
Mass Transfer and Corrosion of Various Materials in Fused Sodium Hydroxide	133
Chemical Studies of Corrosion	138
Reaction of Inconel with Sodium and NaK	138
Reaction of Sodium Hydroxide with Nickel.....	139
Study of Eutectic Mixtures by Zone Melting.....	139
6. METALLURGY AND CERAMICS	141
Fabrication of Test Components.....	141
NaK-to-Air High-Conductivity-Fin Radiators	141
Twenty-Tube Fuel-to-NaK Heat Exchangers	143
Intermediate Heat Exchanger No. 3	143
Intermediate Heat Exchanger Job-Sample Evaluations	144
Examination of NaK-to-Air Radiators That Failed in Service	145
Brazing-Alloy Development	149
Mechanical-Property Studies of Nickel-Molybdenum Alloys	152
Influence of Aging Heat Treatments on the Creep Properties of Hastelloy B.....	152
Preliminary Investigation of Creep Properties of Hastelloy W	153
Investigation of the Creep Properties of Some New Nickel-Molybdenum Alloys.....	153
Special Materials Studies.....	155
Extrusion of Seamless Duplex Tubing.....	155
Neutron Shielding Material for ART	162
Inconel-Clad Niobium.....	163
Gamma-Ray Shield Material for ART Pumps.....	163



Control-Rod Fabrication	163
Nondestructive Testing	164
Ceramic Research	167
Rare-Earth Cermet Fabrication.....	167
Boron Carbide Shield Material	168
7. HEAT TRANSFER AND PHYSICAL PROPERTIES	170
Fused-Salt Heat Transfer.....	170
ART Fuel-to-NaK Heat Exchanger	170
ART Core Hydrodynamics	171
ART Core Heat Transfer	174
Volume-Heat-Source Convection Analyses	177
Heat Removal from Fuel Dump Tank	177
Heat Transfer in Helical Pipes.....	177
Heat Capacity Measurements on Fluoride Mixtures	178
Heats of Fusion of Fluoride Mixtures	179
Viscosity Measurements on Fluoride Mixtures	179
Thermal Conductivities of Liquids.....	181
8. RADIATION DAMAGE	182
Disassembly and Examination of Irradiated Equipment.....	182
MTR In-Pile Loop.....	182
LITR Miniature In-Pile Loop	182
ARE Components	183
Thermocouple Errors in In-Pile Loop Temperature Measurements.....	183
Holdup of Fission Gases by Charcoal Traps	183
Creep and Stress Corrosion	184
In-Pile Tube-Burst Creep Tests	184
Alternate In-Pile Apparatus	184
9. ANALYTICAL CHEMISTRY OF REACTOR MATERIALS	186
Determination of Oxygen in Sodium	186
<i>n</i> -Butyl Bromide Method.....	186
Distillation Method.....	187
Determination of Traces of Rare-Earth Elements in Stainless Steels.....	189
Spectrophotometric Determination of Aluminum in Fluoride Salts with Aurin Tricarboxylic Acid	189
Determination of Water in Hydrogen Fluoride Gas	190
Determination of Oxygen in Zirconium Oxide by Bromination	191
Determination of Tantalum in Fused Fluoride Salts	192
Direct Determination of Traces of Fe(III) in NaF-KF-LiF-UF ₄	192
Determination of Traces of Fe(III) in Mixtures of Alkali-Metal Fluoride Salts	192
ANP Service Laboratory.....	193





10. RECOVERY AND REPROCESSING OF REACTOR FUEL	194
Pilot Plant Design	194
Engineering Developments.....	194
Contactor	194
Freeze Valves.....	194
Resistance Heating of Transfer Pipes and Waste-Discharge Nozzle	194
Process Development	195
Fused-Salt Fluorination Studies.....	195
NaF Absorption Capacity and UF_6 Loss on Desorption.....	196
UF_6 Decontamination in NaF Absorption Step.....	197

PART III. SHIELDING RESEARCH

11. SHIELDING ANALYSIS	203
Air Scattering of Co^{60} Gamma Rays: Theory vs Experiment.....	203
Energy Absorption Resulting from Gamma Radiation Incident on a Multiregion Shield with Slab Geometry.....	203
Integral Equations for the Flux Density near a Thin Foil and for Neutron Scattering in Air in the Presence of the Ground	203
12. SHIELD DESIGN	204
Calculation of the Sodium Activation in the Heat Exchangers of Circulating-Fuel Reactors	204
Calculation of Activation by Core Neutrons.....	204
Calculation of Activation by Delayed Neutrons.....	207
Calculated Total Activations for Several Reactors.....	209
13. LID TANK SHIELDING FACILITY	210
Static Source Tests with Mockups of a Reflector-Moderated Reactor and Shield	210
Effect of Varying Lead Thickness.....	210
Study of Secondary Gamma-Ray Production	213
Effect of Heavy Metals in the Reflector	218
Effect of Borating the Water Shield	219
Dynamic Source Tests with Mockups of a Reflector-Moderated Reactor and Shield	219
Sodium Activation in the Heat Exchanger.....	220
Fission-Product Gamma-Ray Spectrum	223



