OAK RIDGE NATIONAL LABORATORY LIBRARIES
3 4456 0550299 8

CENTRAL RESEARCH LIBRARY

ORNL-TM-4352

cy. 1

APPORTIONMENT OF ^{232}Th IN THE THREE PARTICLE STREAMS OF AN HTGR REACTOR

J. K. Munro, Jr.

OAK RIDGE NATIONAL LABORATORY
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.
UCN-7969
(3 3-67)

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ORNL-TM-4352

Contract No. W-7405-eng-26

COMPUTER SCIENCES DIVISION
UNION CARBIDE CORPORATION, NUCLEAR DIVISION

APPORTIONMENT OF ^{232}Th IN THE THREE PARTICLE STREAMS OF AN HTGR REACTOR

J. K. Munro, Jr.

SEPTEMBER 1973

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

OAK RIDGE NATIONAL LABORATORY LIBRARIES

3 4456 0550299 8

TABLE OF CONTENTS

	PAGE
List of Figures	v
List of Tables	vii
Acknowledgements	ix
Abstract	1
Introduction	3
Solution to the Problem	4
Results	9

LIST OF FIGURES

FIGURE		PAGE
1	Order of Zone Cycling	5
2	Flow Diagram of the Synthesis of the Three Particle Streams for an HTGR	6
3	Fraction of ^{232}Th in Each of the Three Particle Streams for the Simulated History of the Reactor	10

LIST OF TABLES

TABLE		PAGE
I	Cross-Sections for Uranium and Thorium in Units of Barns . .	9
II	Distribution of ^{232}Th Among the Three Streams at the Beginning of Each Cycle	11

ACKNOWLEDGEMENTS

The author appreciates the help J. W. Snider gave him in defining the problem and the opportunity to discuss the method for solving the problem with W. E. Thomas and L. L. Bennett. This work was performed for and supported by Chemical Technology Division.

APPORTIONMENT OF ^{232}Th IN THE THREE PARTICLE STREAMS OF AN HTGR REACTOR

J. K. Munro, Jr.

ABSTRACT

A method is given for determining how the total amount of ^{232}Th loaded into a high temperature gas-cooled reactor (HTGR) at the beginning of each fueling cycle is distributed among the three streams of heavy metals which constitute the fuel charge. The method is based on the assumptions that (a) the reactor contains a homogeneous thermal neutron flux distribution and (b) the ratio of neutron absorbing mass to fissile mass is constant for each stream throughout the life of the reactor. The fraction of total ^{232}Th in each of the streams is obtaind in terms of the solution of a set of three simultaneous linear equations. The method is applied to results from calculations of a simulated history of fuel breeding and burning for an HTGR reactor.

INTRODUCTION

The high temperature gas-cooled reactor (HTGR) considered in this problem burns ^{235}U and breeds ^{233}U from ^{232}Th. The bred ^{233}U is then recycled for burning. These heavy metals are formed into small spheres which are encapsulated in pyrolytic graphite. The thorium spheres are of a different uniform size from the uranium spheres. This size difference facilitates physical separation of the various mixtures of these two types of particles when their containers are removed for fuel reprocessing.

The reactor core is divided into 12 equal parts called zones. Each zone consists of 425 containers of the basic particle mixtures or streams. Three streams are utilized except for the initial reactor core loading and the first few fuel cycles. The initial loading consists of a single mixture of ^{232}Th and ^{235}U particles. After a year of operation, two zones are discharged. Any thorium remaining in these two zones is disposed of and the bred uranium extracted for use in producing another stream. The residual ^{235}U forms the basis for a second stream; fresh make-up ^{235}U forms the basis for the third stream. Particles of fresh make-up thorium are mixed with each of these streams which go together to make up the zones of fresh charge to replace the discharged zones.

At the end of the second year of operation, two more (different) zones are discharged. The residual thorium is discarded and the bred ^{233}U again used for recharge. The residual ^{235}U remaining from the single pass of fresh make-up ^{235}U is recycled for one additional pass. Fresh make-up ^{235}U is again added and fresh make-up thorium distributed

among the three streams for recharging. After the third cycle, residual ^{235}U particles from the second pass of what was loaded originally as fresh make-up will appear. This residual ^{235}U is discarded since it is by now approximately 99% burned. Figure 1 shows the order in which the zones are cycled; Figure 2 shows how the three particle streams are synthesized.

Information exists on the amounts of heavy element isotopes charged into the reactor at the beginning of a cycle, the amounts in the reactor at the beginning and end of each cycle and the amounts discharged at the end of each cycle. This information is broken down into the amounts for each stream except for the ^{232}Th. The total amounts for thorium are always listed with the information on the bred ^{233}U stream. The work to be reported here describes a method for determining the initial distribution of the thorium among the three streams which make up the fresh charge at the beginning of each cycle. This information is needed to plan for the processing of the discharged materials.

SOLUTION TO THE PROBLEM

The reactor is treated as a black box with an assumed homogeneous thermal neutron flux distribution. Since the reactor is designed to breed new fuel as well as produce heat, the ratio of neutron absorbing mass to fissile mass is a sensible quantity to consider in seeking a solution. This ratio is assumed to be constant for each of three streams; the constants do not have to be equal. The neutron absorbing uranium masses are weighted by the ratio of the neutron absorption cross-sections of the particular uranium isotope to the ^{232}Th. Likewise, the fissile masses are weighted by the ratio of fission cross-sections

		Zones			
Reload Segment:		A	B	C	D
Stream 3:	Bred ^{233}U	1	2	3	4
Stream 1:	Fresh ^{235}U	5	6	7	8
Stream 2:	Residual ^{235}U	9	10	11	12
			discard	discard	discard

Order of Zone Cycling Proceeds According to Columns

Fig. 1. Order of Zone Cycling.

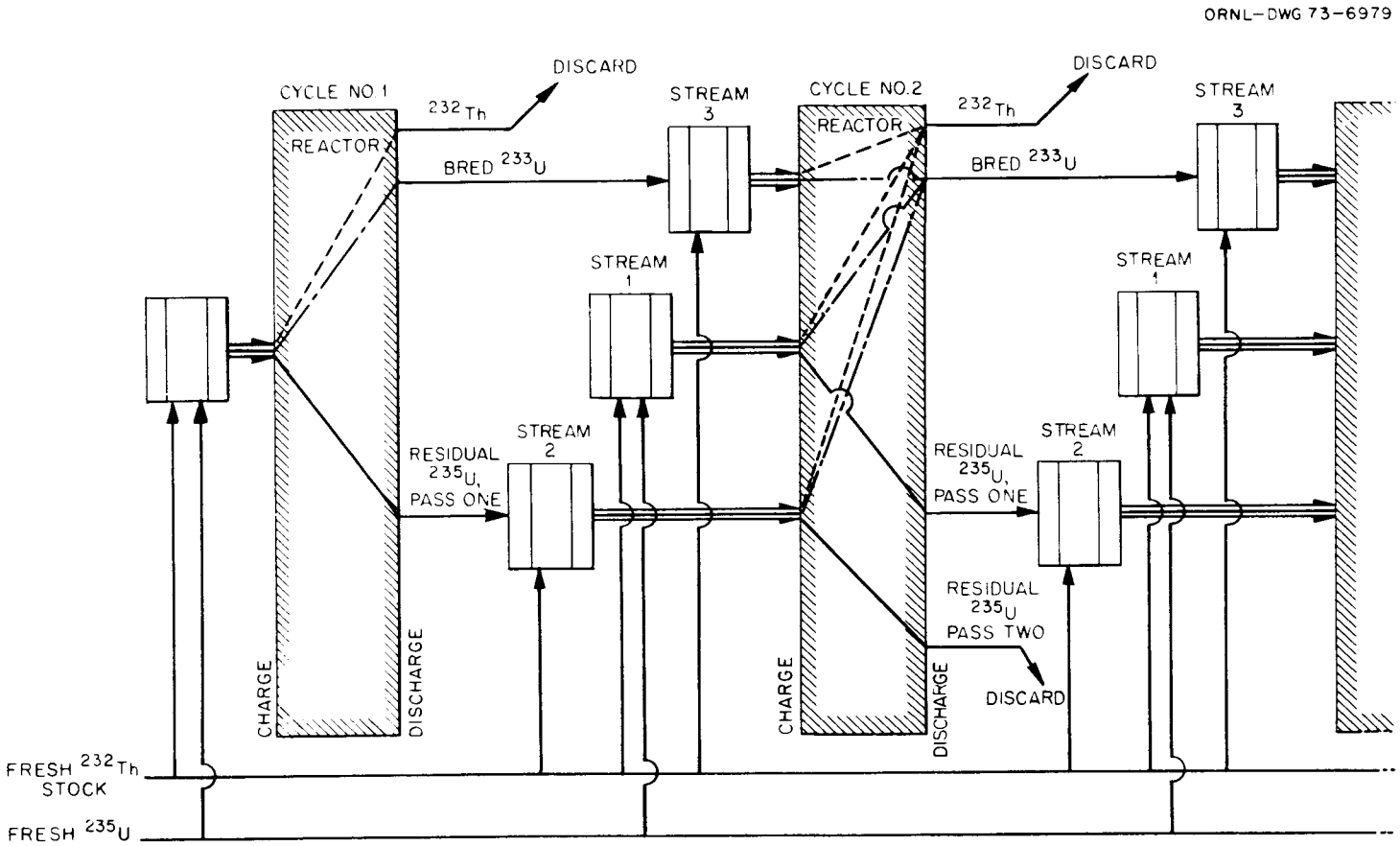

Fig. 2. Flow Diagram of the Synthesis of the Three Particle Streams for an HTGR.

of a particular isotope to the ^{235}U. In this problem the ^{233}U is the only other significant fissile isotope present. Only the masses of the heavy metals used for charging the various zones at the beginning of a given cycle are thus required in order to obtain a solution. The method fails for the first two cycles since there is no ^{235}U present in two of the streams and no ^{233}U has been bred and recycled. All cross-sections used are assumed to be energy independent.

There is probably an additional assumption implicit in the method: the final distribution of the amounts of the nuclides at the end of a cycle does not differ sufficiently from the initial distribution to affect the solution to the problem.

With these assumptions, one obtains the following system of equations:

$$(1) \qquad \frac{M_{Th232}\, x_1 + \frac{\sigma_a(U234)}{\sigma_a(Th232)} M^{(1)}_{U234} + \frac{\sigma_a(U238)}{\sigma_a(Th232)} M_{U238}}{M^{(1)}_{U235}} = K_1$$

$$(2) \qquad \frac{M_{Th232}\, x_2 + \frac{\sigma_a(U234)}{\sigma_a(Th232)} M^{(2)}_{U234} + \frac{\sigma_a(U236)}{\sigma_a(Th232)} M^{(2)}_{U236}}{M^{(2)}_{U235}} = K_2$$

$$(3) \qquad \frac{M_{Th232}\, X_3 + \frac{\sigma_a(U234)}{\sigma_a(Th232)} M^{(3)}_{U234} + \frac{\sigma_a(U236)}{\sigma_a(Th232)} M^{(3)}_{U236}}{M^{(3)}_{U235} + \frac{\sigma_f(U233)}{\sigma_f(U235)} M_{U233}} = K_3$$

The sum of the fractions of thorium in each of the three streams must be unity; hence

$$(4) \qquad x_1 + x_2 + x_3 = 1$$

Equations (1)-(4) may be combined to yield a system of three equations in the three unknown fractions of thorium in each of the streams. This system of equations may be expressed in matrix form as

$$\underset{\sim}{A}\underset{\sim}{x} = \underset{\sim}{b}$$

where

$$a_{11} = -a_{33} = M_{Th232}\, K_2\, M^{(2)}_{U235}$$

$$a_{12} = -M_{Th232}\, K_1\, M^{(1)}_{U235}$$

$$a_{13} = a_{31} = 0$$

$$a_{21} = a_{22} = a_{23} = 1$$

$$a_{32} = M_{Th232}\, K_3 \left[M^{(3)}_{U235} + \frac{\sigma_f(U233)}{\sigma_f(U235)} M_{U233} \right]$$

$$b_1 = K_1\, M^{(1)}_{U235} \left[\frac{\sigma_a(U234)}{\sigma_a(Th232)} M^{(2)}_{U234} + \frac{\sigma_a(U236)}{\sigma_a(Th232)} M^{(2)}_{U236} \right]$$

$$- K_2\, M^{(2)}_{U235} \left[\frac{\sigma_a(U234)}{\sigma_a(Th232)} M^{(1)}_{U234} + \frac{\sigma_a(U238)}{\sigma_a(Th232)} M_{U238} \right]$$

$$b_2 = 1$$

$$b_3 = K_2\, M^{(2)}_{U235} \left[\frac{\sigma_a(U234)}{\sigma_a(Th232)} M^{(3)}_{U234} + \frac{\sigma_a(U236)}{\sigma_a(Th232)} M^{(3)}_{U236} \right]$$

$$- K_3 \left[M^{(3)}_{U235} + \frac{\sigma_f(U233)}{\sigma_f(U235)} M_{U233} \right] \left[\frac{\sigma_a(U234)}{\sigma_a(Th232)} M^{(2)}_{U234} + \frac{\sigma_a(U236)}{\sigma_a(Th232)} M^{(2)}_{U236} \right]$$

Values of the cross-sections used are listed in Table I. The masses of the isotopes loaded at the beginning of each cycle were obtained from a tape supplied by the ORNL Reactor Division.

Table I. Cross-Sections for Uranium and Thorium in Units of Barns

(1 barn = $1 \times 10^{-24} cm^2$)

σ_a(Th232) = 7.4	σ_f(U233) = 530
σ_a(U234) = 95	σ_f(U235) = 580
σ_a(U236) = 6	
σ_a(U238) = 2.7	

The constants K_1, K_2, and K_3 were all set equal to the same value (arbitrary) as there is no way known at present for determining their values. The values of the masses for each cycle were read in from a tape.

RESULTS

The fractions (solution vector) and masses of ^{232}Th for each stream are given in Table II. Figure 3 shows graphs of the fractions of thorium in each stream. No method was found for determining the initial thorium distribution for the first two cycles so it is assumed that the thorium and the fresh make-up ^{235}U are initially evenly mixed according to the proportions (by mass) in which they are loaded, i.e., there is only a single stream for each of the first two cycles.

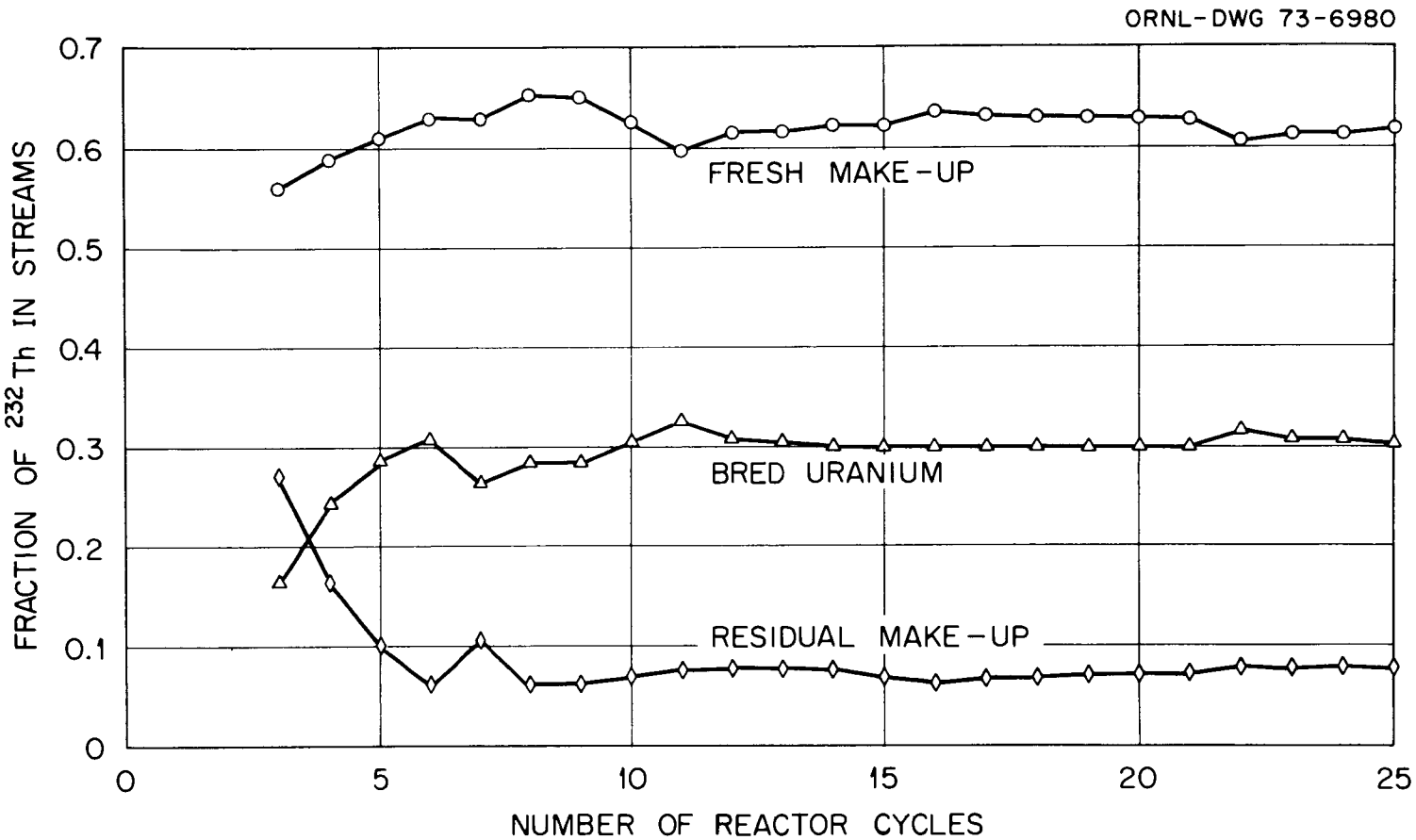

Fig. 3. Fraction of ^{232}Th in Each of the Three Particle Streams for the Simulated History of the Reactor.

Table II. Distribution of ^{232}Th Among the Three Streams at the Beginning of Each Cycle

	^{232}Th in Fresh Make-up ^{235}U Stream		^{232}Th in Residual ^{235}U Stream		^{232}Th in Bred ^{233}U Stream	
Cycle No.	Fraction	Mass (kg.)	Fraction	Mass (kg.)	Fraction	Mass (kg.)
1	1.0	32324.95	0.0	0.0	0.0	0.0
2	1.0	7264.58	0.0	0.0	0.0	0.0
3	0.5607	4073.25	0.2720	1975.96	0.1673	1215.36
4	0.5885	4275.20	0.1653	1200.84	0.2463	1789.27
5	0.6116	4443.02	0.1013	735.90	0.2871	2085.66
6	0.6301	4577.41	0.0610	443.14	0.3089	2244.03
7	0.6282	4563.61	0.1062	771.50	0.2656	1929.47
8	0.6540	4751.04	0.0607	440.96	0.2853	2072.58
9	0.6508	4727.79	0.0638	463.48	0.2854	2073.31
10	0.6248	4538.91	0.0698	507.07	0.3054	2218.60
11	0.5976	4341.31	0.0758	550.66	0.3266	2372.61
12	0.6156	4472.08	0.0770	559.37	0.3073	2232.40
13	0.6176	4486.60	0.0772	560.82	0.3052	2217.15
14	0.6231	4526.56	0.0765	555.74	0.3005	2183.01
15	0.6323	4593.39	0.0691	501.98	0.2985	2168.48
16	0.6364	4623.18	0.0631	458.39	0.3006	2183.73
17	0.6319	4590.49	0.0684	496.90	0.2997	2177.19
18	0.6315	4587.58	0.0693	503.44	0.2992	2173.56
19	0.6303	4578.86	0.0712	517.24	0.2984	2167.75
20	0.6290	4569.42	0.0732	531.77	0.2977	2162.66
21	0.6284	4565.06	0.0740	537.58	0.2976	2161.94
22	0.6056	4399.43	0.0781	567.36	0.3163	2297.79
23	0.6139	4459.72	0.0775	563.00	0.3086	2241.85
24	0.6142	4461.90	0.0778	565.18	0.3080	2237.49
25	0.6185	4493.14	0.0773	561.55	0.3042	2209.88
26	0.6232	4527.29	0.0765	555.74	0.3003	2181.55
27	0.6263	4549.81	0.0710	515.78	0.3027	2198.99
28	0.6247	4538.18	0.0733	532.49	0.3019	2193.18
29	0.6244	4536.00	0.0736	534.67	0.3019	2193.18
30	0.6234	4528.74	0.0751	545.57	0.3015	2190.27

INTERNAL DISTRIBUTION

1-2. Central Research Library
3. Document Reference Section
4-8. Laboratory Records
9. Laboratory Records - Record Copy
10. ORNL Patent Office
11-20. Mathematics Division Library
21-22. Technical Information Center, Oak Ridge
23. Research and Technical Support Division, ORO
24. G. M. Adamson
25. J. W. Anderson
26. H. Barnert-Wiemer
27. L. L. Bennett
28. R. E. Blanco
29. R. A. Bradley
30. A. A. Brooks
31 R. E. Brooksbank
32. K. B. Brown
33. H. P. Carter
34. J. H. Coobs
35. F. L. Culler
36. F. C. Davis
37. W. P. Eatherly
38. D. E. Ferguson
39. B. C. Finney
40. C. L. Fitzgerald
41. R. W. Glass
42. P. A. Haas
43. F. J. Honan
44. W. H. Jordan
45. S. I. Kaplan
46-75. P. R. Kasten
76-77. A. L. Lotts
78. A. P. Malinauskas
79. R. D. McCulloch
80. W. T. McDuffee
81. L. E. McNeese
82-86. J. K. Munro, Jr.
87. J. P. Nicols
88. K. J. Notz
89. J. R. Parrott
90. M. R. Patterson
91. J. L. Scott
92. J. D. Sease
93. A. H. Snell
94. J. G. Sullivan
95. J. W. Snider

96. W. E. Thomas
97. D. B. Trauger
98. W. E. Unger
99. A. M. Weinberg
100-111. R. G. Wymer
112. A. Zucker

EXTERNAL DISTRIBUTION

113. L. H. Brooks, Gulf Energy & Environmental Systems, Inc., P. O. Box 608, San Diego, California 92112
114. J. A. Buckham, Manager, General Allied Corporation, Idaho Chemical Programs, P. O. Box 2204, Odaho Falls, Idaho 83401
115. J. M. Chandler, USAEC Directorate of Licensing, Washington, D. C. 20545
116. D. F. Cope, RDT, SSR, AEC, Oak Ridge National Laboratory
117. F. E. Dearing, RDT, OSR, AEC, Oak Ridge Operations
118. W. V. Goeddell, Gulf General Atomic, P. O. Box 608, San Diego, California 92112
119. C. C. Haws, Jr., USAEC Directorate of Licensing, Washington, D. C. 20545
120. Dr. V. A. Kamath, Scientific Advisor, Attention: P. K. Patwardhan, Bhabha Atomic Research Centre, Trombay, Bombay, India
121. J. N. Rogers, Division 8321, Sandia Laboratories, P. O. Box 969, Livermore, California 94550
122. Dr. Milton E. Rose, Mathematics and Computer Branch Division of Research, U. S. Atomic Energy Commission, Washington, D. C. 20545