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TRANSIENT TESTS OF THE FULLY ENRICHED, ALUMINUM
PLATE-TYPE, B CORES IN THE SPERT I REACTOR:
DATA SUMMARY REPORT

A. P. Wing

PHILLIPS
PETROLEUM
COMPANY

ATOMIC ENERGY DIVISION

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**TRANSIENT TESTS OF THE FULLY ENRICHED, ALUMINUM
PLATE-TYPE, B CORES IN THE SPERT I REACTOR:**

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by

A. P. Wing

**PHILLIPS
PETROLEUM
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Atomic Energy Division

Contract AT(10-1)-205

Idaho Operations Office

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ABSTRACT

This report is a documentation of experimental data from three series of tests performed in the Spert I reactor with light water moderator and fully enriched fuel. The tests consisted of step-wise insertions of excess reactivity under varying conditions ranging from ambient temperature to $\approx 96^{\circ}\text{C}$. The data obtained from these tests are presented in tabular form and as plots of the time behavior of reactor power and fuel plate surface temperature. Summary data figures displaying measured test data as functions of asymptotic reactor period are also included.

TRANSIENT TESTS OF THE FULLY ENRICHED, ALUMINUM
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CONTENTS

ABSTRACT	ii
I. INTRODUCTION	1
II. REACTOR DESCRIPTION	2
III. TEST DESCRIPTION	7
VI. INSTRUMENTATION	8
1. POWER MEASUREMENT	8
2. TEMPERATURE MEASUREMENT	9
3. PRESSURE MEASUREMENT	9
4. SPECIFICATION OF TRANSDUCER LOCATION	9
V. DATA PROCESSING PROCEDURES	10
VI. DISCUSSION OF TEST DATA	11
VII. REFERENCES	13
APPENDIX A -- PLOTS OF B-24/32 CORE	15
APPENDIX B -- PLOTS OF B-16/40 CORE	43
APPENDIX C -- PLOTS OF B-12/64 CORE	61
APPENDIX D -- SUMMARY DATA PLOTS	79
APPENDIX E -- SUMMARY TABLES OF EXPERIMENTAL DATA	87

FIGURES

1. Spert I reactor-cutaway view	3
2. B core fuel assemblies	4
3. Geometrical configuration of the B-12/64, the B-16/40, the B-24/32, the B-12/70, and the B-12/63 operational cores	5
4. B core coordinate system	9
A1. Spert I B-24/32 core transient, $\theta_1 = 22^\circ\text{C}$, $t = 13.2 \text{ sec}$	17

A2. Spert I B-24/32 core transient, $\theta_i = 21^\circ\text{C}$, $\tau = 11.0$ sec	17
A3. Spert I B-24/32 core transient, $\theta_i = 22^\circ\text{C}$, $\tau = 5.11$ sec	18
A4. Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 4.95$ sec	18
A5. Spert I B-24/32 core transient, $\theta_i = 26^\circ\text{C}$, $\tau = 2.45$ sec	19
A6. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 1.34$ sec	19
A7. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 1.14$ sec	20
A8. Spert I B-24/32 core transient, $\theta_i = 27^\circ\text{C}$, $\tau = 626$ msec	20
A9. Spert I B-24/32 core transient, $\theta_i = 28^\circ\text{C}$, $\tau = 522$ msec	21
A10. Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 212$ msec	21
A11. Spert I B-24/32 core transient, $\theta_i = 28^\circ\text{C}$, $\tau = 151$ msec	22
A12. Spert I B-24/32 core transient, $\theta_i = 24^\circ\text{C}$, $\tau = 112$ msec	22
A13. Spert I B-24/32 core transient, $\theta_i = 22^\circ\text{C}$, $\tau = 96.7$ msec	23
A14. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 80.0$ msec	23
A15. Spert I B-24/32 core transient, $\theta_i = 24^\circ\text{C}$, $\tau = 61.1$ msec	24
A16. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 54.6$ msec	24
A17. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 46.7$ msec	25
A18. Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 37.4$ msec	25
A19. Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 36.0$ msec	26
A20. Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 23.5$ msec	26
A21. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 22.0$ msec	27
A22. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 19.0$ msec	27
A23. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 16.0$ msec	28
A24. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 11.6$ msec	28
A25. Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 10.8$ msec	29
A26. Spert I B-24/32 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 10.3$ sec	29
A27. Spert I B-24/32 core transient, $\theta_i = 41^\circ\text{C}$, $\tau = 1.13$ sec	30
A28. Spert I B-24/32 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 286$ msec	30

A29. Spert I B-24/32 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 78.9 \text{ msec}$	31
A30. Spert I B-24/32 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 37.0 \text{ msec}$	31
A31. Spert I B-24/32 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 19.5 \text{ msec}$	32
A32. Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 11.1 \text{ sec}$	32
A33. Spert I B-24/32 core transient, $\theta_i = 58^\circ\text{C}$, $\tau = 726 \text{ msec}$	33
A34. Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 318 \text{ msec}$	33
A35. Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 95.2 \text{ msec}$	34
A36. Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 43.5 \text{ msec}$	34
A37. Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 21.5 \text{ msec}$	35
A38. Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 9.15 \text{ msec}$	35
A39. Spert I B-24/32 core transient, $\theta_i = 78^\circ\text{C}$, $\tau = 10.5 \text{ sec}$	36
A40. Spert I B-24/32 core transient, $\theta_i = 79^\circ\text{C}$, $\tau = 1.06 \text{ sec}$	36
A41. Spert I B-24/32 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 311 \text{ msec}$	37
A42. Spert I B-24/32 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 86.1 \text{ msec}$	37
A43. Spert I B-24/32 core transient, $\theta_i = 79^\circ\text{C}$, $\tau = 43.9 \text{ msec}$	38
A44. Spert I B-24/32 core transient, $\theta_i = 81^\circ\text{C}$, $\tau = 20.3 \text{ msec}$	38
A45. Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 10.6 \text{ sec}$	39
A46. Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 8.65 \text{ sec}$	39
A47. Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 1.11 \text{ sec}$	40
A48. Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 491 \text{ msec}$	40
A49. Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 140 \text{ msec}$	41
A50. Spert I B-24/32 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 43.0 \text{ msec}$	41
A51. Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 22.4 \text{ msec}$	42
B1. Spert I B-16/40 core transient, $\theta_i = 19^\circ\text{C}$, $\tau = 9.60 \text{ sec}$	45
B2. Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 5.18 \text{ sec}$	45
B3. Spert I B-16/40 core transient, $\theta_i = 21^\circ\text{C}$, $\tau = 2.61 \text{ sec}$	46
B4. Spert I B-16/40 core transient, $\theta_i = 22^\circ\text{C}$, $\tau = 1.15 \text{ sec}$	46

B5. Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 300$ msec	47
B6. Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 110$ msec	47
B7. Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 54.6$ msec	48
B8. Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 27.5$ msec	48
B9. Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 21.0$ msec	49
B10. Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 13.6$ msec	49
B11. Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 8.54$ sec	50
B12. Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 4.49$ sec	50
B13. Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 886$ msec	51
B14. Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 282$ msec	51
B15. Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 94.9$ msec	52
B16. Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 38.1$ msec	52
B17. Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 20.2$ msec	53
B18. Spert I B-16/40 core transient, $\theta_i = 79^\circ\text{C}$, $\tau = 1.02$ sec	53
B19. Spert I B-16/40 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 505$ msec	54
B20. Spert I B-16/40 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 147$ msec	54
B21. Spert I B-16/40 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 56.0$ msec	55
B22. Spert I B-16/40 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 31.7$ msec	55
B23. Spert I B-16/40 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 17.5$ msec	56
B24. Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 3.04$ sec	56
B25. Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 972$ msec	57
B26. Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 211$ msec	57
B27. Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 91.7$ msec	58
B28. Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 31.1$ msec	58
B29. Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 15.0$ msec	59
C1. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 9.15$ sec	63
C2. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 6.28$ sec	63

C3. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 2.20$ sec	64
C4. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 955$ msec	64
C5. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 461$ msec	65
C6. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 195$ msec	65
C7. Spert I B-12/64 core transient, $\theta_i = 21^\circ\text{C}$, $\tau = 125$ msec	66
C8. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 79.0$ msec	66
C9. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 46.0$ msec	67
C10. Spert I B-12/64 core transient, $\theta_i = 21^\circ\text{C}$, $\tau = 28.7$ msec	67
C11. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 19.9$ msec	68
C12. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 18.6$ msec	68
C13. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 15.0$ msec	69
C14. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 14.9$ msec	69
C15. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 14.4$ msec	70
C16. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 14.1$ msec	70
C17. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 11.7$ msec	71
C18. Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 9.40$ msec	71
C19. Spert I B-12/64 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 15.7$ msec	72
C20. Spert I B-12/64 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 14.2$ msec	72
C21. Spert I B-12/64 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 16.1$ msec	73
C22. Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 9.07$ sec	73
C23. Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 1.28$ sec	74
C24. Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 753$ msec	74
C25. Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 154$ msec	75
C26. Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 93.4$ msec	75
C27. Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 37.4$ msec	76
C28. Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 16.5$ msec	76
C29. Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 11.4$ msec	77

D1. Maximum reactor power vs reciprocal period, B-24/32 core	81
D2. Maximum reactor power vs reciprocal period, B-16/40 core	81
D3. Maximum reactor power vs reciprocal period, B-12/64 core	82
D4. Energy release to time of peak power vs reciprocal period, B-24/32 core	82
D5. Energy release to time of peak power vs reciprocal period, B-16/40 core	83
D6. Energy release to time of peak power vs reciprocal period, B-12/64 core	83
D7. Maximum fuel plate surface temperature vs reciprocal period, B-24/32 core	84
D8. Maximum fuel plate surface temperature vs reciprocal period, B-12/64 core	84
D9. Maximum fuel plate surface temperature vs reciprocal period, B-12/64 core	85
D10. Fuel plate surface temperature rise at time of peak power vs reciprocal period, B-24/32 core	85
D11. Fuel plate surface temperature rise at time of peak power vs reciprocal period, B-16/40 core	86
D12. Fuel plate surface temperature rise at time of peak power vs reciprocal period, B-12/64 core	86

TABLES

I. Characteristics of the Type B Fuel Plates	4
II. Physical Constants of the B-24/32, the B-16/40, and B-12/64 Cores	6
III. Nomenclature	11
IV. Experimental Data B-24/32 Core Test Series	89
V. Experimental Data B-16/40 Core Test Series	90
VI. Experimental Data B-12/64 Core Test Series	91

TRANSIENT TESTS OF THE FULLY ENRICHED, ALUMINUM PLATE-TYPE, B CORES IN THE SPERT I REACTOR:

DATA SUMMARY REPORT

I. INTRODUCTION

This report is a detailed summary of the experimental data obtained in the B-core transient test series performed in the Spert I reactor facility from December 1957, through May 1958. The principal objective of this test series was to determine the effect of changes in the void coefficient of reactivity upon the kinetic response of a highly enriched, aluminum plate-type, water-moderated and -reflected reactor to step-wise insertions of reactivity. Sizeable variations in the void coefficient were achieved through the use of assemblies with removable fuel plates. This permitted variation of the number of fuel plates per assembly and, consequently, of the water moderator channel thickness between the fuel plates as well as the number of fuel assemblies required for criticality.

The purposes of this report are (a) to present a complete set of graphs and tables of the experimental data taken in these tests, (b) to describe the methods used in processing the data, and (c) to provide information on the instrumentation used for the measurements of reactor power, temperature, and pressure.

The content and organization of the report are as follows: Section II consists of a general description of the Spert I facility applicable to the complete B-core test series, including brief descriptions of the reactor, fuel elements, and core configurations. Section III gives a description of the various tests performed. In Section IV, details of reactor power, temperature, and pressure measurements are discussed. Section V consists of a summary of the data processing procedures and the inherent errors contributed to the data by these procedures. Section VI consists of a discussion of the detailed data plots and tables presented in several appendices. Section VII is a list of references on the tests with the Spert I B cores.

II. REACTOR DESCRIPTION

The Spert I reactor [1, 2] is an open-pool-type, light-water-moderated reactor facility constructed for the purpose of performing basic reactor transient and safety studies. Such studies have been carried out in this facility using a variety of heterogeneous cores, including both highly enriched, aluminum or stainless steel, plate-type fuel elements [3, 4, 5], and low-enrichment uranium-oxide, rod-type fuel elements [6].

The cores used in the test series summarized in this report were composed of aluminum-clad, plate-type, highly enriched fuel assemblies. The cores were submerged in a pool of light water contained in an open vessel four feet in diameter and fifteen feet high. The vessel was filled with water to a height of two feet above the core during all transient test operations described in this report. There was no special provision for heat removal. Coolant circulation, other than by natural convection, was effected only by the use of a motorized stirrer. A cutaway view of the Spert I reactor for this test series is shown in Figure 1.

Shutdown and control of the reactor was obtained through the use of four ganged control rods and one centrally located transient rod operated by means of motor-drive systems suspended on a bridge above the core. Each control rod consisted of a pair of vertical blades. Each blade was made upon a 26 inches long, 3.75 inches wide, and 0.020 inch thick cadmium sheet centered in a flattened aluminum tube, 57 inches long, 4 inches wide, and 0.27 inch thick. The transient rod was made up of a 26 inches long, 3.75 inches wide, and 0.020 inch thick cadmium sheet centered in a flattened aluminum tube, 57 inches long, 4.75 inches wide, and 0.27 inch thick.

The fuel plates were mounted in 38-inch-long aluminum cans of square cross section, approximately three inches on a side. The cans were constructed in such a way as to allow variation of the fuel plate spacing. A pair of grooved side plates was permanently brazed into each can to provide guides for the fuel plates. Four widely spaced fuel plates were permanently brazed into each can; the remaining twenty positions could be filled with removable fuel plates.

The characteristics of the fuel plates used in the cores for these tests are listed in Table I.

Since the fuel assemblies were constructed in such a way as to allow changes in the water moderator channel thickness between plates by removal of some of the plates, sizeable variations of the void coefficient of reactivity were possible in the B cores. The three fuel plate spacings used for transient testing in this test series, as shown in Figure 2, were as follows:

- (1) Twenty-four fuel plates per assembly, with 65-mil water channels (B-24/32 core).
- (2) Sixteen fuel plates per assembly, with alternate 190-mil and 65-mil water channels (B-16/40 core).
- (3) Twelve fuel plates per assembly, with 190-mil water channels (B-12/64, B-12/63, and B-12/70 cores).

Fig. 1 Spert I reactor-cutaway view.

TABLE I
CHARACTERISTICS OF THE TYPE B FUEL PLATES

Overall Length (in.)	25.125
Overall Width (in.)	2.724
Overall Thickness (in.)	0.060
Meat Length (in.) (nominal)	24.0
Meat Width (in.) (nominal)	2.505
Meat Thickness (in.) (nominal)	0.020
Clad Thickness (in.) (nominal)	0.020
Clad Material	Al (Type 6061)
Fuel	U-235 in U-Al Alloy
Enrichment - wt% U-235	93.5
Meat Composition - wt% U	11.7
U-235 / Plate g (nominal)	7.0

Fig. 2 B core fuel assemblies.

Most of the tests in the B-core series were performed on the B-24/32, the B-16/40, and the B-12/64 cores. (This method of core designation gives in sequence the core type, the number of fuel plates per assembly, and the number of assemblies in the operational core.) The geometrical core configurations of these three cores are illustrated in Figure 3. The basic physical characteristics of these cores are listed in Table II.

Also included in Figure 3 are the core configurations of the B-12/70 and the B-12/63 cores. The B-12/70 core was used for tests of a safety device designed by Atomics International. The B-12/63 core was used for a series of special tests conducted for the DuPont Company. Both cores were quite similar to the B-12/64 core. This test series and the results have been previously described [7, 8] and will not be discussed further in this report.

Fig. 3 Geometrical configurations of the B-12/64, the B-16/40, the B-24/32, the B-12/70, and the B-12/63 operational cores.

TABLE II

PHYSICAL CONSTANTS OF THE B-24/32, THE B-16/40, AND THE B-12/64 CORES

	B-12/64	B-16/40	B-24/32
No. of Assemblies	64	40	32
No. of Fuel Plates/Assembly	12	16	24
Clad	Al	Al	Al
Critical Mass (kg U-235)	4.3	3.6	4.3
Total Mass (kg U-235)	5.4	4.5	5.4
Metal-to-Water Ratio	0.46	0.63	1.14
Hydrogen-to-Uranium Ratio	759.0	540.0	270.0
Excess Reactivity (\$)	4.3	5.6	6.6
Temperature Defect 20 to 95°C (\$)	1.44	1.67	1.73
Temperature Coefficient 20°C (\$/°C)	-1.8×10^{-2}	-1.7×10^{-2}	-1.1×10^{-2}
Temperature Coefficient 95°C (\$/°C)	-2.0×10^{-2}	-3.4×10^{-2}	-3.4×10^{-2}
Average Void Coefficient (\$/cm ³)	-0.93×10^{-4}	-2.9×10^{-4}	-7.3×10^{-4}
Ratio of the prompt neutron lifetime to the effective delayed neutron fraction (Λ/β -sec)	0.011	0.010	0.007

III. TEST DESCRIPTION

The usual series of static measurements was first performed on each of the cores. These measurements included control rod calibrations, transient rod calibrations, temperature coefficient measurements, neutron-flux distribution measurements, and void coefficient measurements [9, 10, 11, 12]. Some of these results are listed in Table II.

The transient tests which followed were performed by imposing a known reactivity change on the reactor and observing the dynamic response of the system as measured by the time history of the power, pressure, temperature, etc.

The B-core tests included both step-transients and ramp-transient tests. In the step-transient tests the imposed reactivity variation was essentially in the form of a step change and was accomplished by the rapid ejection of the poison transient rod located in the center of the core. The test sequence was as follows: With the transient rod out of the core, the reactor was made critical by the partial removal of the four ganged poison control rods. The reactor was then made subcritical by pulling the transient rod into the core. The control rods were then further moved a certain distance so as to add a specified amount of reactivity to the system. The test was then initiated by the rapid ejection of the transient rod from the core, producing an exponential rise in the power level. The step-transients discussed in this report were all initiated at an initial power level of approximately five watts.

In the ramp tests, designed to simulate a "start-up accident", the reactivity change was imposed by the continuous withdrawal of the control rods at a constant rate, giving a reactivity variation which was essentially linear in time. (In this report only the data taken in the step-transient tests are presented. The ramp test results were presented in an earlier progress report [13].)

During testing of the B-24/32, the B-16/40, and the B-12/64 cores, step transients were performed with periods ranging from 10 sec to 10 msec [14, 15, 16]. The initial temperature of the reactor was usually about 20°C. However, in order to study the effect of initial temperature on the reactor response, some step transients were performed with initial reactor temperatures ranging to 96°C.

IV. INSTRUMENTATION

During the B-core test series, measurements were made of reactor power, plate-surface temperature, and pressure^[17,18,19]. The following is a description of the techniques used for measurement of these variables.

1. POWER MEASUREMENT

Power data were obtained by measurement of the neutron leakage from the core using five Spert-designed, boron-lined ionization chambers located at various positions outside the reactor vessel. Four of these chambers were connected to linear-amplifier circuits and one to a logarithmic-amplifier circuit. (All power data reported in this report are from the linear-amplifier circuits.) The data were transmitted from the amplifiers at the reactor to optical recording galvanometers half a mile away in the control center and then printed out on oscillograph charts.

The following is a description of the procedures that were used to obtain the calibration constants for the ion chamber circuits.

Each chamber and its associated circuitry was subjected to a three-stage calibration procedure. First, the chambers were placed in a high neutron-flux field in the thermal column of the Materials Testing Reactor. Measurements were made of the linearity of the chamber current as a function of neutron flux, the value of the current at a given neutron flux, and the operating voltage range for current saturation (ie, the domain where the current is independent of the applied voltage). Saturation currents of the order of 20×10^{-6} amps and operating voltages of approximately 1500 volts are representative of the ionization chambers used during this test series.

Second, the gain, linearity, and dynamic range of the electronic circuitry associated with each chamber were measured using a calibrated current source in place of the chamber. A relationship was then determined between the input current of the source and the magnitude of the resultant deflection of the galvanometer trace on the oscillograph record. This instrument calibration procedure was performed weekly in order to offset the effects of drift in the electronic amplifiers. The sensitivity or gain values obtained from the calibrations had a probable error of less than $\pm$ one percent. The dynamic range of the Spert boron-lined ion chambers as coupled with the linear amplifier circuits was determined to be approximately two decades.

Third, the reactor power corresponding to a given current output from each chamber was determined. With the reactor operating at some arbitrary power level, the rate of increase in the bulk system temperature was measured, along with the deflections of the galvanometers connected to the outputs of the ion chamber circuits. From this measured rate of temperature rise and a calculated value for the system heat capacity, the thermal power of the reactor was determined. The power, the deflections of the galvanometers connected to the outputs of the ion chamber circuits, and the results of the instrument calibration were then used to determine the chamber calibration constants in terms of power per unit current for each ion chamber (MW/ μ a).

2. TEMPERATURE MEASUREMENT

Fuel plate surface temperature was measured by the use of 10-mil diameter, chromel-alumel thermocouples, peened into the surface of the fuel plates. These thermocouples had a frequency response of approximately 25 cps. Calibration of the circuitry associated with the thermocouples was carried out in the same manner as for the ion chamber circuitry.

3. PRESSURE MEASUREMENT

The pressure transducers used in the B-core test series were primarily of the variable-reluctance magnetic type. One strain gauge-type pressure transducer also was used during the test series. The transducers were located in the lower end boxes of the fuel assemblies and gave an approximate measure of the average pressure developed within the water channels of the fuel assemblies. The pressure transducers used had ranges of 25, 100, 200, and 3000 psig. Calibration of the circuitry associated with the pressure transducers was carried out in the same manner as for the ion chamber circuitry. A more complete description of the pressure transducers used and an analysis of the pressure data obtained in the B-core test series has been published in a separate report [19].

4. SPECIFICATION OF TRANSDUCER LOCATION

The location of the in-core instrumentation involved a three-dimensional coordinate system as illustrated in Figure 4. The northwest corner of the reactor core was used as the point of origin of the coordinate system. The first coordinate given was the lattice position in the core (Figure 4a). The second coordinate was the plate position (Figure 4b). The third coordinate was the vertical distance in inches from the reactor core midplane (Figure 4c).

For example: (55 01B +3) indicates a transducer located in lattice position 55, on the south side of the first fuel plate, and three inches above the core midplane.

Fig. 4 B core coordinate system.

V. DATA PROCESSING PROCEDURES

The data collection method used in the Spert I B-core tests involved the use of high-speed optical recording galvanometers and photographic oscillographs. Signals from the transducer instrumentation at the reactor area (neutron-detecting ion chambers, pressure transducers, thermocouples, etc) were amplified and transmitted to the oscillograph recorders located 1/2 mile away in the control center. Data from 52 different channels were recorded on the oscillographs in analog form. Each of the 52 channels had a full scale deflection of approximately 76 mm without saturating the associated amplifiers.

The analog data recorded on the oscillograph records were processed through an analog-to-digital conversion system. The conversion system consisted of a manually operated analog curve follower with variable coordinates, coupled to an analog-to-digital converter with tabulated and punched card outputs. The converter was designed in such a way that appropriate scale factors could be incorporated in the system to yield the digital reduced data, not only in arbitrary units, but also in the desired engineering units. These reduced data were then plotted on a digital X-Y plotter to obtain individual curves representing the time variation of each of the test variables.

The errors introduced by the data processing procedures were as follows: The analog curve follower introduced an estimated error of $\pm 1/2$ mm (or about 0.7 percent of the full scale deflection of 76 mm) due to the parallax encountered by the operator in attempting to position the movable index precisely on a point of the analog curve being reduced. The estimated error introduced in the analog-to-digital conversion was $\pm$ one unit in the least significant digit of the converter's output which ranged from ± 000 to ± 999 . The estimated error introduced in setting the scale factors for the digital plotter was ± 0.02 inch (0.2 percent of the full scale deflection of 10 inches). There also was an inherent error of ± 0.015 inch (0.15 percent full scale) contributed by the servo-plotting mechanisms which locate the data points on the graph paper. All of these errors combine to give an overall error of less than five percent, provided the original deflection of the analog curve was approximately 10 mm or more. No data with peak deflections of less than 10 mm were used in this report.

VI. DISCUSSION OF TEST DATA

The step-transient test data from the Spert I B-core test series are presented in graphical and tabular form in the appendices.

Appendices A, B, and C, consist of graphs of the data taken during the B-24/32 core, the B-16/40 core, and the B-12/64 core test series, respectively. Each test is represented by a figure indexed according to both the initial asymptotic reactor period and the initial reactor temperature. The figure consists of curves showing a comparison between the time history of the reactor power and that of the hottest measured fuel plate surface thermocouple. These graphs generally portray the time history of the reactor power and temperature around the region of the initial power burst. Post-burst behavior is presented only in cases where the time history of the reactor power and temperature is of particular interest. The time of peak power and the saturation temperature also are indicated on each graph.

Appendix D consists of a set of correlative plots giving the variation, with the inverse asymptotic period, of the values at the time of peak power of (a) the power level, (b) the energy release, and (c) the surface temperature rise. Plots of the maximum fuel plate surface temperature as a function of the inverse asymptotic period also are given.

Appendix E consists of tables of the principal experimental test data taken with the B-24/32 core, the B-16/40 core, and the B-12/64 core, respectively. The tables are included as ready sources for comparison and reference of the experimental data. The tables give the transient number, the run type, the initial asymptotic reactor period, the inverse period, the peak power, the energy release at time of peak power, the initial reactor temperature, the maximum temperature, the temperature at time of peak power, and the location of the corresponding thermocouple. Table III gives the nomenclature used in the appendices.

TABLE III

NOMENCLATURE

Notation	Units	Definition
τ	msec or sec	Asymptotic Reactor Period
α	sec ⁻¹	Inverse Period
θ_i	°C	Initial Temperature
$\theta_{\max}$	°C	Maximum Temperature
θ_{tm}	°C	Temperature at Peak Power
ϕ_{tm}	MW	Peak Power
E_{tm}	MW-sec	Energy Release at Peak Power

In summary, the Spert I B-core test series demonstrated that variation of the void coefficient of reactivity had a significant effect upon the kinetic response of a highly enriched, aluminum plate-type, water-moderated and -reflected reactor to step insertions of reactivity. Examination of the tabular data and summary plots contained in the appendices indicates that the B-12/64 core, with the widest water channels and smallest magnitude for the void coefficient of reactivity, consistently attained the highest power levels, energy releases, and temperatures for a given period and initial temperature condition. Correspondingly, the B-24/32 core, with the narrowest water channels and the largest magnitude for the void coefficient, had the lowest power levels, energy releases, and temperatures for the same period and initial temperature condition. The B-16/40 core, which used alternate fuel plate spacings of 190 mils and 65 mils, in all cases reached power levels, energy releases, and temperatures intermediate between those attained with the other two cores.

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APPENDIX A

PLOTS OF B-24/32 CORE

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Fig. A1 Spert I B-24/32 core transient, $\theta_i = 22^\circ\text{C}$, $\tau = 13.2$ sec.

Fig. A2 Spert I B-24/32 core transient, $\theta_i = 21^\circ\text{C}$, $\tau = 11.0$ sec.

Fig. A3 Spert I B-24/32 core transient, $\theta_i = 22^\circ\text{C}$, $\tau = 5.11$ sec.

Fig. A4 Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 4.95$ sec.

Fig. A5 Spert I B-24/32 core transient, $\theta_i = 26^\circ\text{C}$, $\tau = 2.45$ sec.

Fig. A6 Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 1.34$ sec.

Fig. A7 Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 1.14 \text{ sec}$.

Fig. A8 Spert I B-24/32 core transient, $\theta_i = 27^\circ\text{C}$, $\tau = 626 \text{ msec}$.

Fig. A9 Spert I B-24/32 core transient, $\theta_i = 28^\circ\text{C}$, $\tau = 522$ msec.

Fig. A10 Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 212$ msec.

Fig. A11 Spert I B-24/32 core transient, $\theta_i = 28^\circ\text{C}$, $\tau = 151 \text{ msec}$.

Fig. A12 Spert I B-24/32 core transient, $\theta_i = 24^\circ\text{C}$, $\tau = 112 \text{ msec}$.

Fig. A13 Spert I B-24/32 core transient, $\theta_i = 22^\circ\text{C}$, $\tau = 96.7$ msec.

Fig. A14 Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 80.0$ msec.

Fig. A15 Spert I B-24/32 core transient, $\theta_i = 24^\circ\text{C}$, $\tau = 61.1 \text{ msec}$.

Fig. A16 Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 54.6 \text{ msec}$.

Fig. A17 Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 46.7$ msec.

Fig. A18 Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 37.4$ msec.

Fig. A19 Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 36.0$ msec.

Fig. A20 Spert I B-24/32 core transient, $\theta_i = 25^\circ\text{C}$, $\tau = 23.5$ msec.

Fig. A21 Spert I B-24/32 core transient, $\theta_i = 20^\circ \text{C}$, $\tau = 22.0 \text{ msec}$.

Fig. A22 Spert I B-24/32 core transient, $\theta_i = 20^\circ \text{C}$, $\tau = 19.0 \text{ msec}$.

Fig. A23 Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 16.0 \text{ msec}$.

Fig. A24 Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 11.6 \text{ msec}$.

Fig. A25 Spert I B-24/32 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 10.8 \text{ msec}$.

Fig. A26 Spert I B-24/32 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 10.3 \text{ sec}$.

Fig. A27 Spert I B-24/32 core transient, $\theta_i = 41^\circ\text{C}$, $\tau = 1.13$ sec.

Fig. A28 Spert I B-24/32 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 286$ msec.

Fig. A29 Spert I B-24/32 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 78.9$ msec.

Fig. A30 Spert I B-24/32 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 37.0$ msec.

Fig. A31 Spert I B-24/32 core transient, $\theta_1 = 40^\circ\text{C}$, $\tau = 19.5 \text{ msec}$.

Fig. A32 Spert I B-24/32 core transient, $\theta_1 = 60^\circ\text{C}$, $\tau = 11.1 \text{ sec}$.

Fig. A33 Spert I B-24/32 core transient, $\theta_i = 58^\circ \text{C}$, $\tau = 726$ msec.

Fig. A34 Spert I B-24/32 core transient, $\theta_i = 60^\circ \text{C}$, $\tau = 318$ msec.

Fig. A35 Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 95.2 \text{ msec}$.

Fig. A36 Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 43.5 \text{ msec}$.

Fig. A37 Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 21.5$ msec.

Fig. A38 Spert I B-24/32 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 9.15$ msec.

Fig. A39 Spert I B-24/32 core transient, $\theta_i = 78^\circ\text{C}$, $\tau = 10.5$ sec.

Fig. A40 Spert I B-24/32 core transient, $\theta_i = 79^\circ\text{C}$, $\tau = 1.06$ sec.

Fig. A41 Spert I B-24/32 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 311 \text{ msec}$.

Fig. A42 Spert I B-24/32 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 86.1 \text{ msec}$.

Fig. A43 Spert I B-24/32 core transient, $\theta_i = 79^\circ\text{C}$, $\tau = 43.9 \text{ msec}$.

Fig. A44 Spert I B-24/32 core transient, $\theta_i = 81^\circ\text{C}$, $\tau = 20.3 \text{ msec}$.

Fig. A45 Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 10.6$ sec.

Fig. A46 Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 8.65$ sec.

Fig. A47 Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 1.11 \text{ sec}$.

Fig. A48 Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 491 \text{ msec}$.

Fig. A49 Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 140 \text{ msec}$.

Fig. A50 Spert I B-24/32 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 43.0 \text{ msec}$.

Fig. A51 Spert I B-24/32 core transient, $\theta_i = 96^\circ\text{C}$, $\tau = 22.4 \text{ msec}$.

APPENDIX B

PLOTS OF B-16/ 40 CORE

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Fig. B1 Spert I B-16/40 core transient, $\theta_i = 19^\circ \text{C}$, $\tau = 9.60 \text{ sec}$.

Fig. B2 Spert I B-16/40 core transient, $\theta_i = 20^\circ \text{C}$, $\tau = 5.18 \text{ sec}$.

Fig. B3 Spert I B-16/40 core transient, $\theta_i = 21^\circ\text{C}$, $\tau = 2.61 \text{ sec}$.

Fig. B4 Spert I B-16/40 core transient, $\theta_i = 22^\circ\text{C}$, $\tau = 1.15 \text{ sec}$.

Fig. B5 Spert I B-16/40 core transient, $\theta_i = 20^\circ \text{C}$, $\tau = 300 \text{ msec}$.

Fig. B6 Spert I B-16/40 core transient, $\theta_i = 20^\circ \text{C}$, $\tau = 110 \text{ msec}$.

Fig. B7 Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 54.6 \text{ msec}$.

Fig. B8 Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 27.5 \text{ msec}$.

Fig. B9 Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 21.0$ msec.

Fig. B10 Spert I B-16/40 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 13.6$ msec.

Fig. B11 Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 8.54$ sec.

Fig. B12 Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 4.49$ sec.

Fig. B13 Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 886$ msec.

Fig. B14 Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 282$ msec.

Fig. B15 Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 94.9 \text{ msec}$.

Fig. B16 Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 38.1 \text{ msec}$.

Fig. B17 Spert I B-16/40 core transient, $\theta_i = 50^\circ\text{C}$, $\tau = 20.2 \text{ msec}$.

Fig. B18 Spert I B-16/40 core transient, $\theta_i = 79^\circ\text{C}$, $\tau = 1.02 \text{ sec}$.

Fig. B19 Spert I B-16/40 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 505 \text{ msec}$.

Fig. B20 Spert I B-16/40 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 147 \text{ msec}$.

Fig. B21 Spert I B-16/40 core transient, $\theta_i = 80^\circ \text{C}$, $\tau = 56.0 \text{ msec}$.

Fig. B22 Spert I B-16/40 core transient, $\theta_i = 80^\circ \text{C}$, $\tau = 31.7 \text{ msec}$.

Fig. B23 Spert I B-16/40 core transient, $\theta_i = 80^\circ \text{C}$, $\tau = 17.5 \text{ msec}$.

Fig. B24 Spert I B-16/40 core transient, $\theta_i = 95^\circ \text{C}$, $\tau = 3.04 \text{ sec}$.

Fig. B25 Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 972 \text{ msec}$.

Fig. B26 Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 211 \text{ msec}$.

Fig. B27 Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 91.7 \text{ msec}$.

Fig. B28 Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 31.1 \text{ msec}$.

Fig. B29 Spert I B-16/40 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 15.0$ msec.

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APPENDIX C

PLOTS OF B-12/64 CORE

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Fig. C1 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 9.15 \text{ sec}$.

Fig. C2 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 6.28 \text{ sec}$.

Fig. C3 Spert I B-12/64 core transient, $\theta_i = 20^\circ \text{C}$, $\tau = 2.20 \text{ sec}$.

Fig. C4 Spert I B-12/64 core transient, $\theta_i = 20^\circ \text{C}$, $\tau = 955 \text{ msec}$.

Fig. C5 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 461$ msec.

Fig. C6 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 195$ msec.

Fig. C7 Spert I B-12/64 core transient, $\theta_i = 21^\circ\text{C}$, $\tau = 125 \text{ msec}$.

Fig. C8 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 79.0 \text{ msec}$.

Fig. C9 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 46.0$ msec.

Fig. C10 Spert I B-12/64 core transient, $\theta_i = 21^\circ\text{C}$, $\tau = 28.7$ msec.

Fig. C11 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 19.9 \text{ msec}$.

Fig. C12 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 18.6 \text{ msec}$.

Fig. C13 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 15.0$ msec.

Fig. C14 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 14.9$ msec.

Fig. C15 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 14.4 \text{ msec}$.

Fig. C16 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 14.1 \text{ msec}$.

Fig. C17 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 11.7$ msec.

Fig. C18 Spert I B-12/64 core transient, $\theta_i = 20^\circ\text{C}$, $\tau = 9.40$ msec.

Fig. C19 Spert I B-12/64 core transient, $\theta_i = 40^\circ\text{C}$, $\tau = 15.7$ msec.

Fig. C20 Spert I B-12/64 core transient, $\theta_i = 60^\circ\text{C}$, $\tau = 14.2$ msec.

Fig. C21 Spert I B-12/64 core transient, $\theta_i = 80^\circ\text{C}$, $\tau = 16.1 \text{ msec}$.

Fig. C22 Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 9.07 \text{ sec}$.

Fig. C23 Spert I B-12/64 core transient, $\theta_1 = 95^\circ\text{C}$, $\tau = 1.28 \text{ sec}$.

Fig. C24 Spert I B-12/64 core transient, $\theta_1 = 95^\circ\text{C}$, $\tau = 753 \text{ msec}$.

Fig. C25 Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 154 \text{ msec}$.

Fig. C26. Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 93.4 \text{ msec}$.

Fig. C27 Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 37.4 \text{ msec}$.

Fig. C28 Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 16.5 \text{ msec}$.

Fig. C29 Spert I B-12/64 core transient, $\theta_i = 95^\circ\text{C}$, $\tau = 11.4$ msec.

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APPENDIX D

SUMMARY DATA PLOTS

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Fig. D1 Maximum reactor power vs reciprocal period, B-24/32 core.

Fig. D2 Maximum reactor power vs reciprocal period, B-16/40 core.

Fig. D3 Maximum reactor power vs reciprocal period, B-12/64 core.

Fig. D4 Energy release to time of peak power vs reciprocal period, B-24/32 core.

Fig. D5 Energy release to time of peak power vs reciprocal period, B-16/40 core.

Fig. D6 Energy release to time of peak power vs reciprocal period, B-12/64 core.

Fig. D7 Maximum fuel plate surface temperature vs reciprocal period, B-24/32 core.

Fig. D8 Maximum fuel plate surface temperature vs reciprocal period, B-12/64 core.

Fig. D9 Maximum fuel plate surface temperature vs reciprocal period, B-12/64 core.

Fig. D10 Fuel plate surface temperature rise at time of peak power vs reciprocal period, B-24/32 core.

Fig. D11 Fuel plate surface temperature rise at time of peak power vs reciprocal period, B-16/40 core.

Fig. D12 Fuel plate surface temperature rise at time of peak power vs reciprocal period, B-12/64 core.

APPENDIX E

SUMMARY TABLES OF EXPERIMENTAL DATA

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TABLE IV

EXPERIMENTAL DATA B-24/32 CORE TEST SERIES

Transient Number	τ (msec)	α (sec ⁻¹)	θ_i (°C)	ϕ_{tm} (MW)	E_{tm} (MW-sec)	θ_{tm} (°C)	θ_{max} (°C)	Thermocouple Location
5485	13200	0.076	22	0.110	2.78	28	50	55 24A +6
5613	11000	0.091	21	0.540 *	6.78 *	44 *	79 *	55 01B +6
5618	5110	0.196	22	0.580 *	7.02 *	46 *	80 *	55 01B -6
5506	4950	0.202	25	0.246	2.38	33	56	55 24A +6
5487	2450	0.408	26	0.443	2.37	35	65	55 24A +6
5608	1340	0.746	20	0.830	3.32	43	75	55 01B +6
5492	1140	0.877	20	0.984	2.29	38	67	55 24A +0
5490	626	1.60	27	1.42	2.11	39	80	55 01B +0
5494	522	1.92	28	2.06	2.05	41	80	55 24A +3
5502	212	4.72	25	3.82	1.77	41	87	55 24A +0
5496	151	6.62	28	5.60	1.70	45	77	55 01B +6
5508	112	8.93	24	9.99	2.06	35	88	55 24A +0
5615	96.7	10.4	22	15.2	2.57	60	88	55 01B +0
5696	80.0	12.5	20	22.2	2.73	68	103	55 01B -6
5511	61.1	16.4	24	25.9	3.13	83	109	55 01B -6
5630	54.6	18.3	20	49.2	4.19	89	123	55 01B +0
5633	46.7	21.4	20	72.3	5.40	102	137	55 01B +0
5695	37.4	26.7	25	85.6	6.02	140	147	55 01B +0
5514	36.0	27.8	25	131	7.46	146	180	55 24A +0
5517	23.5	42.6	25	207	8.59	150	163	55 01B +0
5636	22.0	45.5	20	210	9.98	144	152	55 01B +0
5691	19.0	52.6	20	292	9.88	162	169	55 01B +0
5693	16.0	62.5	20	429	10.3	174	187	55 01B +0
5701	11.6	86.2	20	635	12.3	194	207	55 01B +0
5703	10.8	92.6	20	849	13.6	208	228	55 01B +0
5819	10300	0.097	40	0.131	2.77	51	64	55 24A -6
5823	1130	0.877	41	1.20	2.45	61	83	55 01B +0
5825	286	3.50	40	2.95	1.63	53	86	55 01B +6
5826	78.9	12.7	40	16.0	2.40	61	95	55 01B -6
5828	37.0	27.0	40	78.0	4.88	112	137	55 01B -6
5830	19.5	51.3	40	290	7.96	152	165	55 01B -6
5832	11100	0.090	60	0.108	2.31	78	82	55 24A +3
5834	726	1.38	58	0.920	1.93	74	92	55 01B +0
5837	318	3.14	60	2.52	1.45	75	100	55 24A +3
5838	95.2	10.5	60	13.0	2.11	80	105	55 01B +0
5842	43.5	23.0	60	61.3	4.10	117	132	55 01B +0
5844	21.5	46.5	60	268	7.26	151	158	55 01B -6
5846	9.15	109	60	710	9.58	192	215	56 13A +0
6063	10500	0.095	78	0.133	2.74	88	102	55 01B +6
6065	1060	0.943	79	0.680	1.72	93	102	55 01B +0
6067	311	3.22	80	2.38	1.58	95	108	55 01B +0
6069	86.1	11.6	80	12.6	1.94	106	117	55 01B +0
6072	43.9	22.8	79	49.6	3.47	127	147	55 01B +0
6074	20.3	49.3	81	205	5.16	150	158	55 01B -6

*Stirrer on

TABLE IV (Continued)

Transient Number	τ (msec)	α (sec ⁻¹)	θ_1 (°C)	ϕ_{tm} (MW)	E_{tm} (MW-sec)	θ_{tm} (°C)	θ_{max} (°C)	Thermocouple Location
6170	10600	0.094	96	0.053	0.546	96	100	55 01B -6
6172	8650	0.115	96	0.058	0.583	96	100	55 01B +0
6174	1110	0.901	96	0.430	0.570	101	101	55 01B -6
6175	491	2.04	96	0.856	0.612	99	102	55 03B +0
6177	140	7.14	96	3.90	0.649	105	108	55 01B +0
6179	43.0	23.3	95	29.6	1.58	118	120	55 01B +0
6181	22.4	44.6	96	91.0	3.23	130	140	55 01B +0

TABLE V

EXPERIMENTAL DATA B-16/40 CORE TEST SERIES

Transient Number	τ (msec)	α (sec ⁻¹)	θ_1 (°C)	ϕ_{tm} (MW)	E_{tm} (MW-sec)	θ_{tm} (°C)	θ_{max} (°C)	Thermocouple Location
6523	9600	0.104	19	0.156	4.50	40	50	55 03B +0
6543	5180	0.193	20	0.341	3.88	42	55	55 03B +0
6541	2610	0.383	21	0.560	3.63	47	69	55 03B +0
6525	1150	0.870	22	1.25	2.60	48	85	55 03B +0
6527	300	3.33	20	3.10	2.40	50	88	55 03B +0
6529	110	9.09	20	15.4	2.76	63	109	55 03B +0
6531	54.6	18.3	20	49.0	4.80	96	140	55 03B +0
6533	27.5	36.4	20	212	7.80	158	170	55 03B +0
6536	21.0	47.6	20	313	9.10	186	192	55 03B +0
6545	13.6	73.5	20	680	12.1	148	241	55 03B +0
6632	8510	0.117	50	0.211	3.96	58	76	55 16A +0
6636	4490	0.223	50	0.320	3.81	65	85	55 03B +0
6634	886	1.13	50	1.30	2.98	54	88	55 03B +0
6638	282	3.55	50	3.75	2.36	78	98	55 03B +0
6640	94.9	10.5	50	18.8	3.04	92	117	55 03B +0
6641	38.1	26.2	50	90.0	5.32	123	128	55 03B +0
6643	20.2	49.5	50	273	7.45	168	174	55 03B +0
6644	1020	0.980	79	1.02 *	2.97 *	103 *	107 *	55 03B +0
6647	505	1.98	80	2.04 *	2.18 *	105 *	109 *	55 03B +0
6546	147	6.80	80	7.41	1.94	109	119	55 03B +0
6548	56.0	17.9	80	37.8	2.83	128	137	55 03B +0
6651	31.7	31.5	80	49.0	4.00	109	127	67 16A +0
6655	17.5	57.1	80	277	5.84	130	161	55 16A +0
6666	3040	0.329	95	0.183	0.658	100	103	55 03B +0
6658	972	1.03	95	0.500	0.589	102	105	55 03B +0
6660	211	4.79	95	2.20	0.558	102	108	55 03B +0
6662	91.7	10.9	95	9.50	1.18	105	111	55 03B +0
6664	31.1	32.2	95	64.6	2.37	112	138	55 03B +0
6665	15.0	66.7	95	218	4.00	147	169	55 03B +0

*Stirrer on

TABLE VI

EXPERIMENTAL DATA B-12/64 CORE TEST SERIES

Transient Number	τ (msec)	α (sec ⁻¹)	θ_1 (°C)	ϕ_{tm} (MW)	E_{tm} (MW-sec)	θ_{tm} (°C)	θ_{max} (°C)	Thermocouple Location
6887	9150	0.110	20	0.200	9.30	32	73	55 01B +0
6891	6280	0.160	20	0.550	7.66	55	83	55 01B +0
6978	2200	0.450	20	1.02	5.80	68	98	55 01B +0
6893	955	1.05	20	1.92	4.94	65	104	55 01B +0
6895	461	2.17	20	3.87	4.51	54	85	57 12A +0
6902	195	5.13	20	9.05	3.31	75	108	55 01B +0
6905	125	8.00	21	17.8	4.00	89	117	55 01B +0
6906	79.0	12.6	20	44.5	5.51	83	121	55 12A -6
7936	46.0	21.7	20	93.0	8.26	132	152	55 06B -6
6908	28.7	32.8	21	335	13.8	180	184	55 01B +0
7960	19.9	50.3	20	569	16.5	194	240	55 06B +0
6964	18.6	53.8	20	625	17.3	239	248	55 01B +0
7945	15.0	66.7	20	880	19.5	225	263	55 01B +0
7942	14.9	67.1	20	881	20.8	210	267	55 06B +0
7949	14.4	69.4	20	925	21.6	210	278	55 06B +0
7940	14.1	70.9	20	938	23.0	220	294	55 01B +0
6965	11.7	85.5	20	1360	24.2	330	354	55 01B -6
6976	9.40	106	20	2230	31.5	300	420	55 12A -9
7964	15.7	63.7	40	622	16.7	196	238	55 01B +0
7967	14.2	70.4	60	661	15.2	198	246	55 01B +0
7969	16.1	62.1	80	542	11.2	180	212	55 01B +0
7980	9070	0.110	95	0.100	2.15	98	108	66 06B +0
7981	1280	0.780	95	0.550	1.28	103	110	66 06B +0
7984	753	1.33	95	0.910	1.18	102	116	66 06B +0
7986	154	6.49	95	5.50	1.20	100	113	55 06B +0
7976	93.4	10.7	95	11.3	1.53	103	132	66 06B +0
7989	37.4	26.7	95	78.0	3.25	149	190	55 06B -6
7972	16.5	60.6	95	340	6.85	164	179	66 06B +0
7992	11.4	87.7	95	840	13.0	214	260	55 12A -3

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