187
10-11-66
OCT 11 1966

NAA-SR-11906

COPY

MASTER

SNAPTRAN 10A/2 KINETICS
TESTING AND DESTRUCT
REACTOR EXPERIMENTS

AEC Research and Development Report

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of 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. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

CESHI PRICE

H.C. \$ 4.00; MN 75

SNAPTRAN 10A/2 KINETICS
TESTING AND DESTRUCT
REACTOR EXPERIMENTS

BY

R. P. JOHNSON

RELEASED FOR ANNOUNCEMENT

IN NUCLEAR SCIENCE ABSTRACTS

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

CONTRACT: AT(11-1)-GEN-8

ISSUED: JUL 15 1966

ACKNOWLEDGMENT

The author wishes to express his appreciation to J. F. Jackson, L. I. Moss, W. A. Rhoades, and J. D. Rochfort of Atomics International for their technical assistance throughout the experimental program and to acknowledge the Phillips Petroleum Co. 's STEP Experimental and Operational staff for their cooperation while performing the experimental program.

DISTRIBUTION

This report has been distributed according to the category "Aerospace Safety," as given in the Standard Distribution for Unclassified Scientific and Technical Reports, TID-4500.

ABSTRACT

In a series of nondestructive tests and a destructive test conducted for the Aerospace Nuclear Safety Program, the nuclear safety of a SNAP 10A/2 type reactor was investigated. These tests were performed at the National Reactor Test Station by the Atomic Energy Division of Phillips Petroleum Co., using the Atomics International designed and fabricated SNAPTRAN-1 and -2 reactors.

The transient tests performed on the SNAPTRAN-1 reactor provided information which led to a better understanding of the inherent reactivity feedback characteristics of this and similar reactors. Step and impulse insertions introduced nondestructive reactivities up to \$4.15 during the transient series.

A destruct test, designated as the SNAPTRAN-2, was conducted to measure the reactivity feedback effects, including those of rapid mechanical expansion. The reactivity input during the destruct test was \$5.06. The radiological effects during and after the excursion were determined.

CONTENTS

	Page
I. Summary	1
II. Introduction	3
A. Objectives	3
B. Summary of Experiments	3
1. Reactor Checkout	3
2. Reactor Startup and Evaluation	3
3. SNAPTRAN Instrumentation	4
4. SNAPTRAN-1 Transient Series	4
5. SNAPTRAN-2 Destruct Test	5
III. Description	6
A. Facility	6
B. Reactor Assembly	9
1. SNAPTRAN-1 Reactor	9
2. SNAPTRAN-2 Reactor	15
IV. Mechanical Reactor Checkout	20
A. Stepper Drive Mechanisms	20
B. Impulse Drive Mechanisms	21
C. Destruct Impulse Drive Mechanisms	25
D. Auxiliary Components	26
V. Physics Parameters of the SNAPTRAN-1 and -2 Reactors . . .	28
A. Critical Assembly	28
1. SNAPTRAN-1	28
2. SNAPTRAN-2	31
B. Control Drum Calibration	34
1. SNAPTRAN-1 and -2 Drum Calibrations	34
2. SNAPTRAN-1 Drum Interaction Effects	39
C. Power Calibration	41
D. β/l * Measurements	42
VI. Safety and Experimental Instrumentation	43
A. SNAPTRAN Safety Instrumentation	43
B. SNAPTRAN Experimental Instrumentation	44
1. Nuclear Measurements	44

CONTENTS

	Page
2. Temperature Measurements	47
3. Mechanical Measurements	54
4. Destruct Test Motion Measurements	55
5. Destruct Test Photography Measurements	56
6. Summary of SNAPTRAN-1 and -2 Experimental Instrumentation	56
VII. SNAPTRAN-1 Transient Test Series	57
A. Step Transients Initiated from Ambient Temperatures . . .	57
B. Step Transients Initiated from Elevated Temperatures . . .	63
C. Single-Drum Impulse Transient Series	67
D. Coupled-Drum Impulse Test Series	69
E. Summary of SNAPTRAN-1 Non-destructive Transients . . .	72
VIII. SNAPTRAN-2 Destruct Test	74
A. Preliminary Calibrations	74
1. Static Physics Measurements	75
2. Pretransient Calibration Tests	75
B. Destruct Test	76
IX. References	82
X. Appendices	
Appendix A. SNAPTRAN Inhour Tables	A-1
Appendix B. SNAPTRAN-1 and -2 Diagnostic Instrumentation	B-1
Appendix C. SNAPTRAN-1 Transient Data Summary	C-1
Appendix D. SNAPTRAN Calculations	D-1

TABLES

	Page
1. SNAPTRAN-1 Initial Stepper Scram Time Data	21
2. SNAPTRAN-1 and -2 Stepper Assembly Design and Acceptance Test Comparison	22
3. SNAPTRAN-1 and -2 Impulse Assembly Scram Time Design and Acceptance Test Comparison	22
4. SNAPTRAN-1 Impulse Assembly Impulse Design and Acceptance Test Comparison	23
5. SNAPTRAN-2 Impulse Assembly Impulse Design and Acceptance Test Comparison	26
6. SNAPTRAN-1 Loading Schedule	30
7. SNAPTRAN-1 Super Critical Loadings	31
8. SNAPTRAN-2 Loading Schedule	33
9. Energy Probe Characteristics	53
10. SNAPTRAN-2 Static Physics Measurements Summary	75
11. Preliminary Data of the SNAPTRAN-2 Calibrational Step Transients	76
B-1. SNAPTRAN-1 Nuclear Instrumentation	B-1
B-2. SNAPTRAN-1 Thermocouple Instrumentation	B-2
B-3. SNAPTRAN-1 Energy Probe Instrumentation	B-3
B-4. SNAPTRAN-1 Pressure Instrumentation	B-5
B-5. SNAPTRAN-1 Strain Gage Instrumentation	B-5
B-6. SNAPTRAN-2 Nuclear Instrumentation	B-6
B-7. SNAPTRAN-2 Thermocouple Instrumentation	B-8
B-8. SNAPTRAN-2 Energy Probe Instrumentation	B-9
B-9. SNAPTRAN-2 Strain Gage Instrumentation	B-10
B-10. SNAPTRAN-2 Radial and Axial Motion Detectors	B-11
B-11. SNAPTRAN-2 Acoustical Measurement Detectors	B-11
B-12. SNAPTRAN-2 Photography Coverage	B-12
C-1. SNAPTRAN-1 Transient Data Summary	C-2

FIGURES

	Page
1. IET Facility, TAN	7
2. SNAPTRAN-1 Reactor on Test Dolly at IET Facility	8
3. Operational Mode of the Stepper and Impulse Drums	11
4. Stepper Drive Assembly	12
5. Impulse Drive Assembly	14
6. Typical Drum Shaft and Tower Assembly	15
7. Rotated Cubical Structure	16
8. SNAPTRAN-2 Reactor on Test Dolly at IET Facility	18
9. SNAPTRAN-2 Impulse Destruct Mechanisms Components	19
10. SNAPTRAN-2 Impulse Destruct Mechanism	24
11. Typical SNAPTRAN Core Layout	32
12. SNAPTRAN-1 Step Transient "B or C" Drum Worth	36
13. SNAPTRAN-1 Impulse Transient "A" Drum Worth	37
14. SNAPTRAN-1 Impulse Transient "A or D" Drum Worth	38
15. SNAPTRAN-1 "B and D" Drum Worth	39
16. SNAPTRAN-2 "A and D" Drum Worth	40
17. Transient and Destruct Series Nuclear Detector Range	46
18. SNAPTRAN-1 Diaphragm-ended Thermocouples	48
19. SNAPTRAN-1 Spot-welded Thermocouples	50
20. SNAPTRAN-1 Cladding and Grid Plate Thermocouples	51
21. SNAPTRAN Energy Probes	52
22. Preliminary Peak Power, Energy Release, Temperature Rise Plots of the SNAPTRAN-1 Ambient Temperature Step Tests	60
23. Preliminary Total Energy Release and Maximum Temperature Plots for the SNAPTRAN-1 Ambient Temperature Step Tests. . .	60
24. Preliminary Fuel Element Pressure and Strain Plots of the SNAPTRAN-1 Ambient Temperature Step Tests	62
25. Preliminary Inhour Plot of the SNAPTRAN-1 Ambient Temperature Step Tests	62
26. Cascade Step Test Series No. 5	64
27. Preliminary Peak Power, Energy Release and Temperature Rise at Peak Power of the SNAPTRAN-1 Elevated Temperature Step Tests	65

FIGURES

		Page
28.	Preliminary Peak Power and Maximum Temperature Versus Total Energy Release of the SNAPTRAN-1 Elevated Temperature Step Tests	66
29.	Preliminary Peak Power Versus Programmed Reactivity of the SNAPTRAN-1 Single-drum Impulse Tests	70
30.	Preliminary Reactor Power Ratio, Energy Release and Temperature Rise Data of the SNAPTRAN-1 Single-drum Impulse Tests	70
31.	Preliminary Peak Power Versus Power Ratio and Programmed Reactivity of the SNAPTRAN-1 Coupled-drum Impulse Test	71
32.	Preliminary Power Ratio and Energy Release Versus Reciprocal Period of the SNAPTRAN-1 Coupled-drum Impulse Tests	73
33.	Preliminary Peak Power, Power Ratio, Energy Release, and Temperature Rise Data to Maximum of the SNAPTRAN-1 Coupled-drum Impulse Tests	73
34.	SNAPTRAN-2 Destruct Test Sequence	79
A-1.	SNAPTRAN Inhour Plot	A-2

I. SUMMARY

The nuclear safety of a SNAP 10A/2 type reactor was investigated in a series of nondestructive tests and a destructive test conducted for the Aerospace Nuclear Safety Program at the National Reactor Test Station (NRTS). Atomics International (AI) designed, fabricated, and functionally tested the specialized test reactors used during this program. The transient nuclear tests performed on these reactors, designated the SNAPTRAN reactors, were conducted by the Atomic Energy Division of Phillips Petroleum Co. (PPCo).

After installation of the SNAPTRAN-1 reactor at the NRTS, static reactor physics measurements were performed. These measurements were followed by transient tests initiated either by step or impulse reactivity additions. Performed with reactivity inputs up to \$4.20 (based on static drum calibrations), these tests provided information which led to a better understanding of the inherent reactivity feedback characteristics of this and similar reactors.

A destruct test, designated the SNAPTRAN-2, was conducted for the purpose of measuring the reactivity feedback effects, including those of rapid mechanical expansion, as well as the radiological effects during and after an extreme nuclear excursion. The excess reactivity of the SNAPTRAN-2 reactor during the destruct test, \$5.06, was greater than that obtainable during any conceivable SNAP reactor accident. In the test, the reactivity was introduced into the reactor in a two-phase step mode in which all control drums were rapidly inserted to the most reactive position.

In this report, the preliminary results of these tests are discussed as well as the testing, calibration, and the transient operation of the SNAPTRAN-1 and -2 reactors. The detailed analysis of the SNAPTRAN-1 and -2 transient data is presented in References 1 and 2. References 3, 4, 5, and 6 contain further information of interest.

BLANK

II. INTRODUCTION

The objectives of the SNAPTRAN experiment and a summary of experiments follows.

A. OBJECTIVES

The SNAPTRAN experimental program was performed to provide information related to the safety of SNAP 10A/2 type reactors. The specific program objectives were:

- 1) To determine those dynamic characteristics of the SNAP 10A/2 reactor which are important for an evaluation of nuclear safety.
- 2) To provide physics and engineering data to aid in the understanding of the self-limiting characteristics of the reactor.
- 3) To demonstrate the mechanical and radiological consequences of a transient more extreme than any which could occur in an accident.

B. SUMMARY OF EXPERIMENTS

SNAPTRAN-1 and -2 were duplicate reactors, except that impulse capabilities on the SNAPTRAN-2 reactor were restricted to the insertion mode. The discussion herein encompasses both experiments.

1. Reactor Checkout

Complete mechanical checkout of the SNAPTRAN-1 and -2 reactors was made prior to installation at the NRTS. Performance of the fast-reactivity insertion drive mechanisms and associated components, either in the normal, step, or impulse mode, met or exceeded design specifications. Design specifications for drum insertion in the above modes were $1^\circ/\text{sec}$ for normal drum insertion, 60 msec for stepper drum insertion ($+45^\circ$ to 0°), and 30 msec for the significant reactivity cycle (-135° to 0° to $+135^\circ$) on impulse drum insertion.

2. Reactor Startup and Evaluation

Critical configurations on the SNAPTRAN-1 and -2 reactors were determined with full core loadings, 37 standard or instrumented fuel elements. Control drum shimming configurations were adjusted to obtain desired

controllable excess reactivities, and the respective control drum worths for the step, impulse, and destruct test configurations were determined within an accuracy of 5%, using differential period calibration techniques. The specific power calibration of each reactor was obtained with in-core fission foil irradiations. Specific power tolerances were determined by PPCo within an accuracy of 10% and 8% on the SNAPTRAN-1 and -2, respectively.⁽⁵⁾

3. SNAPTRAN Instrumentation

The transient-testing SNAPTRAN-1 reactor and destruct test SNAPTRAN-2 reactor were instrumented with neutron, temperature, and strain gage detectors. Neutron and gamma ionization and scintillation detectors were used to assess the power burst, energy deposition, period and reactivity feedback mechanisms resulting from various reactivity input step and impulse transients. These detectors were calibrated within an accuracy of 10% during the specific power calibration and initial transient tests. The temperature response during transient tests and energy deposition values were determined with thermocouples and by applying known heat capacity values to the energy probe temperature data. Mechanical effects due to thermal expansion and fuel element hydrogen release were determined by means of strategically located strain gages.

4. SNAPTRAN-1 Transient Series

The nondestructive transient series was performed over a reactivity input range of \$0.27 to \$4.15, either with a step or impulse mode of reactivity insertion. The maximum amount of reactivity introduced in a step mode was \$1.70. The resulting preliminary hot-spot temperature, period, peak power, and energy release values were 1704°F, 1.18 msec, 3.45×10^3 Mw, and 16.97 Mw-sec, respectively. Maximum peak power, temperatures, and energy releases observed during the coupled-drum impulse series were obtained from a \$3.90 transient initiated from 1.67 watts, where 6.28×10^3 Mw, 1565°F, and 13.3 Mw-sec were obtained. Lesser values were obtained on the maximum reactivity transient, as the starting power level was only 0.001 watt.

5. SNAPTRAN-2 Destruct Test

The preliminary step transients performed on the SNAPTRAN-2 reactor provided inter-calibration data to correlate the transient testing series results with the destruct test. When the preliminary physics tests and the transient tests were completed, a series of full-scale, dry-run countdown tests was conducted in preparation for the destruct test. The neutronic, mechanical, and fission product behavior of a SNAP 10A/2 reactor resulting from a reactivity insertion of \$5 were determined. Preliminary estimates of the peak power, period, and energy release were 71×10^3 Mw, 206 μ sec, and 55 Mw-sec, respectively.

III. DESCRIPTION

A. FACILITY

The SNAPTRAN 10A/2 Kinetics Testing Program was conducted at the NRTS at the Test Area North (TAN) facilities. All transient tests performed on the SNAPTRAN reactors were performed in the Initial Engineering Test (IET) facility located one mile north of the Technical Support Facilities (TSF). Figure 1 shows the TAN facilities.

The IET facility is located within a security area restricted to authorized personnel. Within the IET facility are the test cell, where the SNAPTRAN reactors were located, the control and equipment building, from where the operations were conducted, and several other facilities. Personnel access to the IET is provided either through the inner control gate during non-testing periods or through the outer control gate, located at TSF, during testing periods. As shown in Figure 1, a four-track railroad spur connects the TSF area with other TAN facilities, including the IET. The SNAPTRAN reactors were assembled on a four-track test dolly at TSF and transferred to the IET via this railroad spur. The locomotive which serviced the area was also used to remove and replace the IET building during the destruct test period. Figure 2 shows the uninstrumented SNAPTRAN-1 reactor on the test dolly at the IET.

The IET control and equipment building which services the test cell and dolly is located below grade. The control room and test cell are separated by approximately 15 ft of compacted earth fill and concrete building structure. All electrical control and detector lead wires associated with the test dolly penetrate the test cell building through the dolly locating-snout; quick-disconnect coupling is made to permanent installations within the coupling station. Reactor control lead wires are then routed to a master relay rack and to the control console. The control console and the static and transient instrumentation are located within the control room of the control and equipment building.

The instrumentation to monitor reactor operation during steady-state and transient tests is located within the IET control room. The control console was designed to give reactor operations personnel visual access of: the nuclear startup count-rate, linear, log N, and reactor period channels;

NAA-SR-11906
7

4-29-66

Figure 1. IET Facility-Test Area North

7611-1031

NAA-SR-11906

8

Figure 2. SNAPTRAN-1 Reactor on Test Dolly at IET Facility

reactor power recorders; events recorders; and closed-circuit TV receivers. All reactor control functions are actuated from panels in the center of the control console. These controls include actuating switches for normal and transient operating modes. (See Section VI.)

All SNAPTRAN transient experiments were performed under semi or full meteorological restrictions. Local weather data were collected at the IET and factored into the transient testing schedule. The SNAPTRAN-2 destruct test was performed under restricted wind speed, wind direction, lapse and precipitation conditions. The NRTS weather bureau collected weather data from both the TAN and central facilities to predict conditions on the scheduled destruct data. Additional meteorological and geographical data are presented in the SNAPTRAN Safety Analysis Report.⁽⁷⁾

B. REACTOR ASSEMBLY

1. SNAPTRAN-1 Reactor

The reactor which was used to perform the kinetics experiments has been designated the SNAPTRAN-1 reactor. The SNAPTRAN-1 reactor consists of a standard SNAP 10A/2 core and reflector with modified control drum drive systems and modified upper and lower vessel head assemblies to facilitate the variety of experiments run.^(8,9)

The reactor vessel consists of a standard 37-fuel element core with 6-internal beryllium reflectors to fill the hexagon lattice to that of the cylindrical vessel. Although the reactor vessel maintained standard SNAP 10A/2 dimensions within the core region, the upper and lower vessel head assemblies were modified. The upper vessel head and nitrogen exhaust tube assembly was modified to provide access to instrumentation lead wires which penetrated the reactor core through the upper grid plate. The head was split into halves making it easily removable. The lower vessel head, which is an integral part of the reactor vessel, was modified to house instrumentation lead wires penetrating the core through the lower grid plate. This tube, or nitrogen inlet tube assembly, also indexes the reactor vessel within the cubical structure. A standard SNAP 10A/2 flight reflector with a thickness of 1.875 in. surrounded the reactor vessel. This reflector was modified only to the extent

of providing axial instrumentation slots; otherwise, standard dimensions were maintained.

Two modes of reactor control were provided on the SNAPTRAN-1 reactor: variable-drive motors, which inserted reactivity at nominal rates for normal reactor operation; and high reactivity insertion drive mechanisms. Of the four control drums in the reactor, alternate pairs were capable of inserting reactivities at high rates. The stepper drums (drums B and C) were capable of inserting reactivity in a "step" mode at the average rate of \$34/sec. The impulse drums (drums A and D) were capable of inserting reactivity in an "impulse" mode at the average rate of \$370/sec. Both the stepper and impulse drums were equipped with variable-speed drive motors for reactivity insertions in the "normal" mode. These drive motors, when operated through a 120,000:1 reduction gear train, rotated the control drums at angular speeds up to 1°/sec. In the maximum differential worth region of each control drum, this angular speed corresponds to a reactivity insertion rate of approximately \$0.06/sec. (A detailed description of the operational characteristics of the stepper and impulse drive mechanisms, including the operational modes, is given below (Figure 3).) The stepper drums are restricted to "positive" sector movement only, 180° to 0°, whereas the impulse drums are capable of 450° rotation, 225° in the "negative" sector and 225° in the "positive" sector. The "positive" sector is designated as the sector in which reactivity insertion is clockwise from +180° to 0°. Reactivity can also be inserted in the "negative" sector, resulting from counter-clockwise motion of the impulse drums from -180° to 0°. The stepper drums are capable of initiating a "step" transient by rapid insertion of either a single drum or coupled-alternate drums from the arming position, 45° to 0°. Contrary to the step transient, the impulse transient results from complete rotation of a single drum or coupled-alternate drums from the arming position -225°, through the least reactive position, -180°, through the most reactive position and stopping in the positive sector, +180°. Impulse motion is counter-clockwise.

Figure 3. Operational Mode of the Stepper and Impulse Drums

"Step" reactivity insertion (mode of drums B and C) is accomplished by pneumatically driving a rack coupled to the respective control drum through a pinion gear. The stepper drive and damper piston is an integral component with the drive rack which acts within the drive cylinder and damper cylinder. The drive and damper cylinders are integral components. The damper piston and cylinder is double acting to provide a dampening effect at either end of the piston's stroke (at the "out" position upon scram conditions and at the "in" position for step dampening). Stepper dampening is accomplished pneumatically with 1000 psig nitrogen gas applied to the damper cylinder. Stepping motion is accomplished when the drive cylinder is filled with 350 psig nitrogen gas and the respective tooth clutch is opened to allow the drive piston to act on the control drum assembly. During the stepper drive cylinder charging process, the electromagnetic tooth-clutch on the respective drive unit is energized. The tooth clutch is de-energized when the fire signal is initiated. This allows the stepper drum to be accelerated by the driving pressure of the compressed nitrogen, rotating the stepper control drum into the most reactive position, 0°. To reverse drum travel after a step, the drive cylinder is vented, allowing the

stepper scram spring to return the control drum to the least reactive position. Figure 4 shows the details of a stepper drive assembly.

During the normal operating mode, the "stepper" control drums may be operated in any sequence with the remaining control drums. As previously mentioned, drive motion is applied to the stepper drums via a variable-speed drive motor and a gear reduction system. Drive speeds, either insertion or withdrawal of reactivity, are controlled by the reactor operator. The variable speed drive motors are connected to the control drum assembly through an electromagnetic clutch, to provide scrambling capabilities when the tooth clutch is disengaged, the stepper scram spring acts on the drive piston/rack assembly which returns the stepper control drum from any position to the

Figure 4. Stepper Drive Assembly

least reactive position, + 180°. The stepper scram spring is an integral part of the stepper drive assembly and provides continuous scram capability. Stepper scram motion is counter-clockwise in the positive sector.

The "impulse" mode of reactivity insertion accelerates a control drum from a least reactive position, rapidly rotating the drum through its most reactive position, then decelerates the drum, and motion is arrested at the least reactive position. This is accomplished by driving a rack and piston assembly pneumatically and converting linear motion of the rack assembly to angular motion of the drum assembly through a pinion gear. The impulse drum is manually driven to the "arming" position where the respective electromagnetic clutch remains engaged. When the proper interlocks are satisfied the impulse drive cylinder is filled with 1000 psig nitrogen gas. To "fire" the impulse drum, the electromagnetic tooth clutch is disengaged, allowing the compressed nitrogen to accelerate the drive piston. The drive piston is accelerated continuously until the control drum reaches the most reactive position. Then the nitrogen is allowed to bypass the drive piston and flow into the dampening cylinder (opposite end of the drive cylinder) where the gas is trapped and compressed by the forward moving drive piston. The drive piston and control drum assembly is then decelerated until forward motion is arrested. The control drum is at the least reactive position in the positive sector when the impulse is completed. Positive assurance is provided to restrict reverse movement of the drive piston and drum assembly. A "Sprag" clutch unit which is designed to permit rotational movement in the counter-clockwise direction but resists clockwise motion, is chain-coupled to each drum shaft assembly and is actuated during an impulse test. A second motion-restricting device is also mounted directly on the end of the impulse rack assembly. This hydraulic backstop permits fluid to flow through an orifice during an impulse and restricts reverse flow (and rack movement) by closing the orifice with a spring-actuated conical plug. A typical impulse drive assembly is shown in Figure 5.

"Scramming" capabilities on an impulse drum are more intricate as the impulse mode must be performed without the restricting action of a scram spring. As the normal operation mode necessitates positive scram capabilities, proper provisions were included. The impulse drive rack is constructed with a raised section on either side; this section is sloped to provide the action of a

5-6-66

7611-4009A

Figure 5. Impulse Drive Assembly

cam. Rollers which ride on the impulse rack cam are connected through a double-linked toggle assembly to a compression scram-spring. Action of the compression spring on the rollers (which may be positioned on either the "positive" or "negative" slope) provides scrambling capabilities through linear motion of the rack and drum assembly into either the "positive" or "negative" sectors. The force of the scram spring may be counteracted by pressurizing the scram lockout cylinder. Actuation of the scram lockout system raises the cam rollers off the impulse rack and thus disables scram capabilities. This step is performed only in conjunction with an impulse test.

Each stepper and impulse drum assembly is connected to an instrumentation tower. The instrumentation towers include digital and analog position indicators and drum end-of-limit and arming indicator switches. Limit switches for corresponding drive mechanism positions are located on the stepper and impulse drive assemblies. Figure 6 shows a typical stepper or impulse drum shaft and tower assembly.

The stepper and impulse drum shaft and tower assemblies, and respective drive mechanisms are capable of being removed from the cubical structure directly or remotely. Special locking locator-pins are installed on each assembly. These locks may be unpinned, opened, and the respective assembly removed with overhead cranes. The disassembly process of a SNAPTRAN reactor involves: (1) disconnecting all electrical plugs and pressure lines; (2) removing the stepper and impulse drum shaft and tower assemblies; (3) rotating the cubical structure 180° from its normal upright position; (4) removing the stepper and impulse drive assemblies in that order; (5) returning the cubical structure to the upright position; and (6) removing the core vessel locking pins, permitting vertical removal of the reactor vessel assembly. The SNAPTRAN-1 reactor is shown in the rotated position in Figure 7.

2. SNAPTRAN-2 Reactor

SNAPTRAN-2 (Figure 8) was the same as the SNAPTRAN-1 reactor except that the impulse stroke stopped in the most reactive region at the completion of an impulse test. The lower head of the reactor vessel assembly was also modified to facilitate additional experiments during the destruct test.

5-6-66

7611-18216A

Figure 6. Drum Shaft and Tower Assembly

Figure 7. Rotated Cubicle Structure

The criteria used to establish the destruct test configuration required that a large amount of reactivity be inserted into the SNAPTRAN-2 reactor in a minimum time period. A special design high-capacity shock absorber was placed in the open end of each impulse drive cylinder. The shock absorber was positioned such that the drive piston, accelerated by normal drive pressures, struck the shock absorber at an equivalent drum position of -30° . The piston was then decelerated and forward motion stopped when the control drum reached 0° to $+30^\circ$. Due to the higher deceleration forces involved, the impulse drum shaft and control drum mounting brackets were strengthened for the SNAPTRAN-2 reactor. The layout of the SNAPTRAN-2 destruct mechanism is shown in Figure 9.

As stated in the previous section, the impulse destruct mechanisms restricted the use of the impulse assemblies to that of the negative sector. As a result, impulse drum scram capabilities were considerably slower due to the slight negative slope on the rack assembly on which the scram cam-rollers acted. Precautions had to be taken to restrict manual impulse drum operation in the region from -30° to $+30^\circ$ as shock absorbers impeded the inserting motion of the variable speed drive motors and sufficient forces could be developed to momentarily separate the tooth clutches.

The SNAPTRAN-2 reactor vessel was modified by opening the lower vessel head and providing a vessel extension such that a parabolic mirror could be mounted directly underneath the reactor core. This mirror was used to project light through the core to aid in high speed interstitial-photography measurements taken during the destruct test by Edgerton, Germeshausen and Grier (EG&G).⁽⁶⁾

4-29-66

7611-01240A

Figure 8. SNAPTRAN-2 Reactor on Test Dolly at IET Facility

5-19-66

7611-18215A

Figure 9. SNAPTRAN-2 Impulse Destruct Mechanism Components

NAA-SR-11906

IV. MECHANICAL REACTOR CHECKOUT

A thorough mechanical checkout on the SNAPTRAN 10A/2-1 and -2 reactors was performed to verify that design criteria was met. Pre-operational checkouts performed on the stepper and impulse drive assemblies were conducted during the fabrication phases of the SNAPTRAN-1 and -2 reactors. Additional assembly and system checkouts were made on the reactors upon installation at the National Reactor Test Station. A description of this checkout phase follows.

A. STEPPER DRIVE MECHANISMS

The initial mechanical checkout of the stepper drive mechanisms was performed in the R & D shops at Atomics International Headquarters (Canoga Park, Calif.) facility. The first step of the checkout phase consisted of mating the respective stepper drum shaft with the instrumentation tower assembly and adjusting the drum-in and -out limit switches and the digital position indicators to the proper position. The drum shaft and tower assembly and stepper drive mechanisms were then mounted on the cubical structure, and a continuity check was made on the associated stepper drive actuating circuits. These continuity checks were made using the SNAPTRAN operating console. When all the drive actuating circuits were functioning properly, the stepper damper system was pressurized in increments. Scram checks at various drum positions were performed at selected damper pressure settings. Scram time data were accumulated until the rated damper pressure was reached. At this point, the stepper damper cylinder was pressure checked to approximately 120% of the rated value, 1000 psig. Table 1 lists the stepper scram times with 985 psig damper pressure.

The performance of the stepper mode was checked at the completion of the scram checks. This involved positioning the stepper drum at the arming position, 45°, and actuating the required charge and fire circuits to initiate a step. To determine the minimum drive pressures required to override the action of the stepper scram spring, the pressure in the stepper drive cylinder was slowly increased until the drive piston moved away from the full out position, 180°, toward the most reactive position, 0°. This check established the minimum stepper drive pressure to be used when initiating a step test from

TABLE 1
SNAPTRAN -1 INITIAL STEPPER SCRAM
TIME DATA (Stepper Unit B)

Stepper Drum Position	Final Drum Position	Scram Time*
135°	187° 15'	---
90°	187° 8'	150 ms
60°	187° 12'	167 ms
30°	187° 17'	185 ms
0°	187° 49'	185 ms

*Scram times given are the times for the drum to travel from the initial position to the final position.

the arming position. The stepper drive pressure was then increased in increments from the minimum value above, to that pressure which resulted in acceptable step input times.

A detailed description of stepper drive operation appears in Ref. 5; Table 2 lists the acceptance test results observed during the initial checkout of the SNAPTRAN-1 reactor. Similar acceptance checks were made on the SNAPTRAN-2 reactor and the respective scram and step times are also shown in Table 2.

B. IMPULSE DRIVE MECHANISMS

The impulse mode of transient operation was performed only during the SNAPTRAN-1 testing series. Initial checkout of the impulse drive units (A and D) was performed during the fabrication of the SNAPTRAN-1 reactor. During this checkout period, drum and rack limit switches, drum position indicators, and the operating sequence circuitry were adjusted and checked for proper operation.

As the impulse mechanisms were provided with scram capabilities in both the positive and negative sectors (0° to +180° and -22° to -180°, respectively), the scram times were determined for each case. Typical scram times in the positive and negative sectors for each impulse drum are given in Table 3.

TABLE 2
SNAPTRAN-1 AND -2 STEPPER ASSEMBLY DESIGN
AND ACCEPTANCE COMPARISON

Unit	Step Time (45° to 0°) Pressure (psig)		Scram Time (0° to 135°) Damper Pressure 1000 psig	Comments
	Drive 350	Damper 1000		
-1 Stepper B	0.060* 0.069+ 0.067+		0.150* 0.136+	*Denotes design requirements.
-1 Stepper C	0.060* 0.065+ 0.067+†		0.150* 0.124+†	+Denotes single drum (B or C) step tests.
-2 Stepper B	0.060* 0.066+†		0.150* 0.110+†	Denotes coupled drum (B and C) step tests.
-2 Stepper C	0.060* 0.061+†		0.150* 0.100+†	

TABLE 3
SNAPTRAN-1 AND -2 IMPULSE ASSEMBLY SCRAM TIME DESIGN
AND ACCEPTANCE TEST COMPARISON

Unit	Negative Sector Scram Time (-22° to -180°)	Positive Sector Scram Time (0° to +180°)	Comments
-1 Impulse A	No time specified*	150 msec*	*Design requirements.
-1 Impulse A	125 msec	170 msec	
-1 Impulse D	No time specified*	150 msec*	†Scram times determined prior to installation of the destruct mechanism.
-1 Impulse D	113 msec	169 msec	
-2 Impulse A	No time specified*	150 msec*	
-2 Impulse A	125 msec	114 msec†	
-2 Impulse D	No time specified*	150 msec†	
-2 Impulse D	113 msec	108 msec†	

As noted in the impulse drum description of Reference 8, the reverse motion of the impulse rack and associated drum assembly was arrested by a Sprag clutch. After modification of the Sprag clutch assemblies, each unit performed satisfactorily at the completion of the checkout tests. At this time, a redundant backstop device, or load cell, was also included on each impulse drive mechanism. This backstop device used the principle of non-compressible hydraulic fluid flow through an orifice which is closed by a spring-acting cone in the event of reverse flow. The load cell required a working stroke of approximately 0.5 in. before becoming completely effective in retarding reverse movement and, therefore, was only effective when reverse movement of the impulse rack was permitted by slippage of the Sprag clutch.

Final acceptance testing on the SNAPTRAN-1 impulse drive assemblies was performed with the reactor assemblies installed at the NRTS. The tests were conducted by PPCo's Nuclear Test Section personnel using previously accepted AI test procedures. During the acceptance testing of the SNAPTRAN-1 impulse units, the pulse width -135° to 0° and 0° to $+135^{\circ}$, was accurately determined as a function of impulse drive pressure. When the designed impulse drive pressure (1000 psig) was reached, a series of tests was run to determine operation consistency. The impulse pulse-width was determined for each impulse drive assembly in the single-drum operating mode and for the coupled-drum operating mode. A summary of impulse pulse-width acceptance data is presented in Table 4.

TABLE 4
SNAPTRAN-1 IMPULSE ASSEMBLY DESIGN AND
ACCEPTANCE TEST COMPARISON

Units	Insertion Time (-135° to $+135^{\circ}$)	Comments
-1 Impulse A	30 msec*	* Design
-1 Impulse A	28.5 msec	** Impulse drums coupled
-1 Impulse D	30 msec*	
-1 Impulse D	26.0 msec	
-1 Impulse A-D**	29.0 msec

5-19-66

7611-2501

Figure 10. SNAPTRAN-2 Impulse Destruct Mechanism

C. DESTRUCT IMPULSE DRIVE MECHANISMS

The destruct impulse drive mechanisms designed for the SNAPTRAN-2 reactor were the same as the SNAPTRAN-1 impulse drive units, but with linear cushion units installed on the respective drive cylinders (Figure 10). The linear cushion positioned in the drive cylinder started a snubbing action on the impulse drive piston when the control drum reached -30° , and was completely stopped when the control drum reached 0° to $+30^{\circ}$. The advantages of this design were: (1) having a recoverable system, allowing the destruct mode of operation to be repeated during the mechanical checkout phase, and (2) positive assurance of the respective control drums being at the most reactive position during the destruct test.

Acceptance testing of the destruct impulse drive mechanisms was performed at the NRTS. The impulse drive units and the drum and tower assemblies were mounted on the SNAPTRAN-2 structure assembly. Necessary functional checks were made on the system to check out the normal operational drive mode. All limit switch settings and drum alignments were made in this configuration. To determine impulse drum input times and the linear cushion characteristics, uncoupled impulses were run at increasing drive pressure increments. The first test on each impulse drum was run with 250 psig nitrogen pressure applied to the drive cylinders. Successive impulse tests were run with higher drive pressures until the rated drive pressure of 1000 psig was reached. Only a limited number of 1000 psig impulse tests were run during the system checkout phase.

Final acceptance tests were run on the destruct impulse drive units after the reactor assembly was completed. The final tests were performed to determine the degree of synchronization of the impulse drums during a coupled mode. As the magnetic characteristics of each impulse tooth clutch differed slightly, the respective release times of the tooth clutches varied as much as 20 msec under full drive pressure conditions. An adjustable electronic delay circuit was placed in series with the faster-releasing tooth clutch which allowed fine adjustments to be made on the respective impulse tooth clutch. This technique was satisfactory, but reproducibility of tooth clutch release time could only be maintained within 5 msec (See Section IV-D). A secondary method was used which enabled the impulse drums to be operated either in the single or coupled mode. This required the use of a "Marmon" clamp on the impulse coupling clutch. The

Marmon clamp increased the torque rating of the coupling clutch from 350 ft lb, to approximately 1000 ft lb. The coupling chain which made the final coupling between the impulse drum assemblies was rated at approximately 1200 ft lb. Employing the above modifications, synchronization of the impulse drums during the destruct test could be assured within 1 to 2 msec.

Table 5 lists the respective impulse times obtained during the destruct impulse drive mechanism acceptance testing.

TABLE 5
SNAPTRAN-2 IMPULSE ASSEMBLY IMPULSE DESIGN
AND ACCEPTANCE TEST COMPARISON

Unit	Insertion Time (-135° to 0°) Drive Pressure 1000 psig	Comments
-2 Impulse A	12.0 msec	* Impulse drums coupled.
-2 Impulse D	12.0 msec	
-2 Impulse A-D*	12.0 msec	
-2 Impulse Design	15 msec	

D. AUXILIARY COMPONENTS

Prior to conducting the coupled drum impulse test series on the SNAPTRAN-1 reactor, calculations were made showing the effect of reactivity pulse broadening due to low drive pressures or asynchronous drum insertion. Results of the study indicated that the power burst would be damped or lowered in the case of asynchronous drum insertion, but would be increased in the case of pulse broadening. Precautions were taken to prevent initiating a transient with low drive pressure. Redundant switch-actuating pressure sensors were placed on the stepper and impulse drive cylinders during fabrication. To determine the magnitude of drum asynchronization as a function of drum position, several subcritical coupled-drum impulse tests were run. These tests showed that asynchronization times varying from 0 to 30 msec (measured at the impulse drums most reactive position, 0°) and were dependent on: (1) reference voltage applied to the impulse tooth clutches; (2) the orientation of the moving section of the tooth clutches relative to the static section; and (3) the tooth clutch release

characteristics. These effects which caused impulse drum asynchronization could not be cancelled with the aid of the impulse drum coupling mechanism. The coupling clutch had a 350 ft-lb torque rating and was designed to slip if opposing forces exceeded this value.

Extensive tests were performed in attempts to minimize the above variables so that synchronization of the impulse drums could be obtained. The reference dc voltage supply used for reactor control functions was obtained from a large bank of batteries. To minimize the voltage drop which occurred in the transmission lines and across the respective tooth clutches, additional large-gauge carrier-wires were installed from the control relays to the impulse tooth clutches. To observe the effect tooth clutch position has on the respective release time, circuits were developed to monitor: (1) the impulse fire relay dropout time; (2) the respective impulse tooth clutch magnetic field decay; and (3) the tooth clutch separation times. With the above monitoring circuits, a common position was picked on the fixed portion of each of the impulse tooth clutches and the resulting tooth clutch dropout characteristics determined as a function of angular position of the rotating portion of the clutch. It was observed that the relative dropout times could be varied as much as 25 msec depending on the orientation of the tooth clutch. Thus, proper tooth-to-tooth alignment would produce reasonable synchronization of the impulse drums through their impulse cycle. Further refinements were made when an electronic delay circuit was placed in series with the faster releasing impulse tooth clutch. As this delay circuit was adjustable, pre-transient checks could be made to determine tooth clutch dropout time asynchronization and appropriate delay adjustments made. By controlling the forementioned variables, synchronous impulse drum movement was obtained within 2 msec during the coupled-drum impulse test series.

V. PHYSICS PARAMETERS OF THE SNAPTRAN-1 AND -2 REACTORS

A thorough understanding of the reactor characteristics associated with the SNAPTRAN-1 and -2 reactors was obtained by measuring the following physics parameters: critical mass and excess reactivity, control drum worths, specific power, and the mean prompt-neutron lifetime. A description of the experiments which determined these parameters follows.

A. CRITICAL ASSEMBLY

1. SNAPTRAN-1

Loading to a full core configuration, to meet transient testing requirements on the SNAPTRAN-1 reactor, was performed in two stages. The first approach to criticality and full core loading was to determine the resulting in-core tolerances and to verify clearance for scheduled in-core instrumentation. The second core loading was made while simultaneously inserting the scheduled instrumentation. Access to the reactor core for the in-core instrumentation was through the nitrogen inlet assembly and lower grid plate, and through the nitrogen exhaust assembly and upper grid plate (Section VI-B).

The initial critical assembly and loading to a full core configuration, 37 fuel elements, was made in a conservative manner. A total of 37 hollow-aluminum dummy elements were placed in the reactor while an aluminum upper grid plate maintained radial geometry. The loading schedule then required the addition of fuel elements using a center-hexagon loading array in a 4, 6, 5, 4, 1, ..., sequence until criticality was achieved. During the loading sequence, when the inner-three fuel rings were completely filled, a single lucite dummy element was placed in the respective position allocated for the succeeding fuel element, and its incremental worth, as compared to a hollow-dummy element and a fuel element, was determined. This dummy element substitution was used throughout the remainder of the critical assembly.

After the addition of a loading step, subcritical multiplication measurements were taken with five control drum configurations. These configurations were: (1) drums ABCD full out, 180°; (2) drum A in, 0°, and BCD out, 180°; (3) drums AB in, 0°, and drums CD out, 180°; (4) drums ABC in, 0°, and drum D out, 180°; and (5) drums ABCD in, 0°. To determine the multiplication at each drum and

loading configuration, data from five startup channels were obtained. These startup channels included four proportional B¹⁰ chambers and count-rate circuits, and one uncompensated ionization chamber and ammeter readout. These detectors were located next to the fixed beryllium reflector. Extrapolations to the minimum critical mass were determined by plotting inverse-multiplication data with the drums in configuration (5), drums ABCD at 0°.

During the initial loading of the SNAPTRAN-1 reactor, the loading sequence progressed smoothly until the 23rd fuel element was placed into position 20. The fuel element could not be positioned between the internal beryllium reflector and the adjacent fuel elements. The reactor core was then unloaded and examined. Indentations were found just above and below the lower and upper grid-plate locations. When repair of the vessel was completed, the loading to criticality and full core configuration continued. Criticality was achieved upon the addition of the 34th fuel element. The reactor was then loaded to a full core configuration to verify that no interferences were present.

The uninstrumented core assembly was then unloaded and the in-core transient instrumentation installed. The second approach to criticality and full core loading was made using the aforementioned center-hexagon loading array and outer ring lucite-dummy replacement technique, but using a different loading sequence, namely, 2, 10, 5, 5, 5, 1, ... Table 6 lists the loading schedule of the SNAPTRAN-1 reactor. The first loading step was made with the two externally-instrumented fuel elements, as the detector lead wires penetrated the lower grid plate. Criticality was reached upon the addition of the 35th fuel element and extrapolation of the inverse multiplication plot showed a critical mass equivalent to 34.2 fuel elements. Table 7 lists the super-critical loadings. Figure 11 represents a typical SNAPTRAN core with the respective fuel element positions numbered.

The last fuel element loading to the SNAPTRAN-1 reactor involved removing four un-instrumented fuel elements and replacing them with four internally instrumented elements which were attached to the upper grid plate (see Table 7 loading number 18).

Using the drum worth data (Section V-B) and the critical positions noted in Table 7, the excess reactivity and shutdown reactivity values were \$4.85 and \$4.15, respectively.

TABLE 6
SNAPTRAN-1 LOADING SCHEDULE (Instrumented Core)

Loading Number	Core Position	Loading Sequence	Fuel Element Number*	Minimum Extrapolated Critical Mass
1	7	1	E-123	
1	18	2	E-125	
2	1	3	E-217	
2	3	4	E-239	
2	5	5	E-245	
2	2	6	E-244	
2	4	7	E-208	
2	6	8	E-246	
2	11	9	E-283	
2	17	10	E-237	
2	9	11	E-242	
2	15	12	E-255	
3	19	13	E-258	
3	13	14	E-249	
3	12	15	E-248	
3	10	16	E-260	
3	16	17	E-237	32.5
4	8	18	E-222	
4	14	19	E-233	
4	29	20	E-234	
4	33	21	E-118	
4	24	22	E-261	39.5
5	20	23	E-219	
5	35	24	E-226	
5	26	25	E-227	
5	37	26	E-271	
5	28	27	E-218	40
6	34	28	E-254	33.7
7	25	29	E-215	36.7
8	22	30	E-232	33.8
9	31	31	E-221	34.8
10	21	32	E-257	34.5
11	27	33	E-216	34.3
12	36	34	E-120	34.2

*SNAPTRAN-1 fuel composition listed in Reference 14.

TABLE 7
SNAPTRAN-1 SUPER CRITICAL LOADINGS

Loading Number	Core Position	Loading Sequence	Fuel Element Number	Critical Positions			
				Drum A	B	C	D
13	30	35	E-262	0°	0°	0°	85°1'
14	23	36	E-256	0°	0°	46°10'	180°
15	32	37	E-250	54°22'	0°	180°	180° (1)
				59°25'	0°	180°	180° (2)
16	11	38	E-240	(3)			
17	15	39	E-252	(3)			
18	1	40	E-192	(4)			
18	3	41	E-211	(4)			
18	16	42	E-212	(4)			
18	37	43	E-214	(4)			

Comments: (1) Critical with aluminum grid plate.
 (2) Critical with SNAPTRAN grid plate.
 (3) PPCo externally instrumented fuel elements.
 (4) AI internally instrumented fuel elements.

2. SNAPTRAN-2

The loading of the SNAPTRAN-2 reactor progressed in a similar manner to the previous critical assemblies. Again, a center-hexagon loading schedule was used. Initially, the reactor core was loaded with 19 hollow-aluminum dummy elements in positions 1 through 19, and lucite dummy elements in the remaining 18 positions. The startup instrumentation consisted of four proportional B¹⁰ chambers and associated count-rate circuits, and an operational uncompensated ionization chamber with ammeter readout. These neutron detectors were mounted near the fixed beryllium reflector.

During the loading sequence, fuel elements were put into the reactor core one at a time. After each fuel element addition, multiplication data were determined with all the control drums in the least reactive position, 180°. These data were compared with the all-drums-out data obtained during the SNAPTRAN-1 critical assembly. Table 8 lists by loading order the fuel elements loaded and the respective fuel element positions. Figure 11 also illustrates the SNAPTRAN-2 core layout schedule.

5-19-66

7611-1030A

Figure 11. SNAPTRAN Core Layout

NAA-SR-11960

TABLE 8
SNAPTRAN-2 LOADING SCHEDULE

Loading Order	Core Location	Fuel Rod Number*
1	1	E-104
2	4	E-64
3	2	E-101
4	6	E-45
5	3	E-283
6	7	E-121
7	5	E-117
8	11	E-10
9	17	E-102
10	9	E-17
11	15	E-32
12	19	E-50
13	13	E-100
14	12	E-263
15	18	E-31
16	10	E-42
17	16	E-97
18	8	E-38
19	14	E-54
20	25	E-95
21	34	E-13
22	21	E-105
23	30	E-96
24	22	E-79
25	31	E-93
26	26	E-119
27	27	E-48
28	36	E-43
29	35	E-34
30	24	E-8
31	33	E-98
32	37	E-44
33	28	E-99
34	23	E-61
35	32	E-103
36	20	E-49
37	29	E-94

*SNAPTRAN-2 fuel composition listed in Reference 14.

When all 37 fuel elements were loaded into the reactor core, a banked critical position was determined. (To determine a banked critical position, each of the control drums was placed at the same angular position in the "positive" or "negative" sector). The initial banked critical position observed on the SNAPTRAN-2 reactor was $61^{\circ}10'$ on drums B and C and $289^{\circ}50'$ ($-61^{\circ}10'$) on drums A and D. The control drum shimming configuration was altered from that used during the critical assembly to the final configuration used during the destruct test (Section V-B-2). The clean excess and shutdown reactivity values obtained from final drum calibrations on the SNAPTRAN-2 reactor were $\$4.85$ and $\$4.43$, respectively.

B. CONTROL DRUM CALIBRATION

1. SNAPTRAN-1 and -2 Drum Calibrations

The transient series conducted on the SNAPTRAN-1 and -2 reactor required a thorough knowledge of control drum worth and the respective interaction effects. The success and safety of each transient series was thus based on accurate control drum worths experimentally determined during the static physics measurements made on each reactor. Control drum worth determinations were made for each shimming configuration during the transient series.⁽¹⁰⁾ For this report the control drum shimming configurations used during the SNAPTRAN-1 step transient and single drum impulse transient test series will be designated as "Configuration A." The respective drum worths and shimming configuration used during the coupled-drum impulse test series will be designated as "Configuration B," and that configuration used during the SNAPTRAN-2 destruct test will be "Configuration C."

The method used to calibrate the SNAPTRAN-1 and -2 control drums is the accepted "differential period" technique. For example, to calibrate alternate drums, one drum was positioned at the most reactive position, 0° , the other drum positioned, at the least reactive position, 180° , while the remaining control drums were used to adjust the reactor to criticality. From this initial configuration, the least reactive drum was inserted to establish a relatively short reactor period (approximately 20 sec.) Upon accurately measuring the reactor period, the first control drum was withdrawn to decrease reactor power, and subsequently repositioned so that a relatively long reactor period (approximately 60

sec.) was established. The equivalent reactivity value associated with the short reactor period was plotted as the differential worth of that drum at the average drum position. The reactivity difference between the two observed reactor periods was that differential worth value for the second drum movement. This technique was repeated until each drum had reversed end positions. Appendix A lists the SNAPTRAN in-hour plot used during the static drum calibration measurements.

The stepper drums, drums B and C, were initially calibrated versus the impulse drums, drums A and D. The shimming configuration used was "Configuration A." The stepper drums or impulse drums were held at the same angular position for each differential worth measurement and were moved in synchronization over the range in which they were calibrated. Figure 12 shows the differential and integral worth of a single stepper drum, B or C, as determined in the BC versus AD drum calibration tests. The integrated worth of drums B or C was determined to be \$2.18.

The single drum impulse test series was performed using impulse drum A to initiate the transient. To determine the differential and integral worth of drum A, differential period measurements were made as drum A traversed from least reactive position to the most reactive position. Drums B, C, and D were held at the same angular position for each measurement and were withdrawn to a less reactive position during the tests. The shimming configuration of drum A was again "Configuration A." Figure 13 shows the differential and integral worth of Drum A as determined during the A versus BCD calibration tests. The total integrated worth of drum A was determined to be \$2.37.

The coupled-drum impulse test series was performed with the drum shimming configuration changed to "B". This change was made so that continuous reactivity insertions could be made, while progressing through the single-drum and coupled-drum transient series. The impulse drums were calibrated in the same manner as the coupled stepper drum calibrations; namely, maintaining uniform A-D and B-C angular positions throughout the calibration tests. Figure 14 shows the worth of a single impulse drum as calibrated in the A-D versus B-C mode. The worth of a single impulse drum was determined to be \$2.17 and \$4.34 for the total A-D drum worth.

Figure 12. SNAPTRAN-1 Step Transient "B or C" Drum Worth

5-19-66

Figure 13. SNAPTRAN-1 Impulse Transient "A" Drum Worth

7611-2519

Figure 14. SNAPTRAN-1 Step Transient "A or D" Drum Worth

Calibration of the SNAPTRAN-2 control drums was performed in a like manner as that described above, and the final shimming configuration was experimentally determined so that a maximum reactivity test could be made in a modified impulse mode. The final destruct test control drum shimming configuration is that of "Configuration C." The resulting drum worths for the stepper and impulse drums are shown in Figures 15 and 16. The combined stepper drum worths were found to be \$4.63, while both impulse drums were worth \$4.62 in "Configuration C."

2. SNAPTRAN-1 Drum Interaction Effects

A series of experiments was performed on the SNAPTRAN-1 reactor to determine the interaction effects of adjacent and opposite control drum movement on the observed drum calibrations.⁽¹¹⁾ The magnitude of the resulting interaction effects enabled the reactivity prediction (based on control drum calibrations) of the high reactivity SNAPTRAN-1 transients and -2 destruct test to be made with higher confidence. Drum interaction effects were determined for the flux-tilting caused by inserting opposite and adjacent control drums, and for the scattering due to moving a control drum toward a flat of the hexagonal core lattice.

Figure 15. SNAPTRAN-1 "B and C" Drum Worth

Figure 16. SNAPTRAN-2 "A and D" Drum Worth

In the flux tilting case, the relative worths of the drums were determined by observing the reactor periods while: (1) drums A and D were at their most reactive position, slightly supercritical, and (2) drums B and C were at their most reactive position. These data were compared with reactor period measurements obtained while A and C were at their previous positions and while B and D were at their previous positions. Comparison of these data indicated that a 3% interaction effect results when the control drums are positioned to obtain maximum flux tilting.

During the drum scattering interaction experiment, both impulse drums were positioned toward a fully inserted stepper drum, drum C, and adjusted equally to obtain criticality. The stepper drum positions were then reversed; i. e., full in to full out. The reactivity differences observed in this configuration were compared to the reactivity differences observed when the impulse drums were positioned to face drum B and reversing stepper drum positions. Slight interaction effects were observed during this experiment, but were less than that observed during the flux-tilting experiment.

In conclusion, the reference material notes that the overall drum interaction effects are less than the control drum calibration error (5%) and the resulting magnitude of the interaction effects has little effect on the interpretability of SNAPTRAN data. Also, the magnitude of the interaction effects observed on the SNAPTRAN-1 reactor is within that observed on the SNAP 10A critical assembly.¹²

C. POWER CALIBRATION

The specific power calibrations made on the SNAPTRAN-1 and -2 reactors were determined by irradiating a series of U^{235} and threshold detector foils in the reactor. These irradiations were made while the reactor operated at an arbitrary steady state power level for a sufficient length of time to activate the foils.

Flux wires were placed in the reactor core on a radial and axial array, to determine the specific power of the SNAPTRAN-1 reactor. These detectors filled 14 of the available 25 interstices in a wedge of the hexagonal lattice. Three types of materials were used to make up the flux detectors: (1) 10% U^{235} aluminum wire; (2) 1% gold-copper alloy; and (3) zinc. These wires were encapsulated in aluminum containers. Foils were used in addition to the wires. These foils were alloys of copper-aluminum, antimony-aluminum, gold-copper and tungsten-aluminum. The above flux wires and foils were irradiated for a period of 1.0 hr at an approximate power level of 100 watts. The induced activity of each foil was determined using standard gamma-spectroscopy techniques. This activity was then expressed in terms of neutron flux, n/cm^2 -sec. Volume weighting factors and standard power conversion factors were used to determine the power level at which the irradiation was made. Using the operational linear micro-microammeter (the direct readout of the operational uncompensated ionization chamber, see Section VI-A) as a standard instrument, the specific power of the SNAPTRAN-1 reactor was determined to be 8.2×10^{-9} amperes/watt.

Similar flux measurements were made in the SNAPTRAN-2 reactor. The flux detectors were positioned in the inner nine interstices of a typical wedge of the hexagonal core. Each flux detector consisted of five U^{235} foils spaced at three-inch axial intervals, the center foil being placed on the reactor

centerline. After determining the flux density and calculating the respective power at which the irradiation was made, the specific power was found to be 7.25×10^{-9} amperes/watt, again using the operational linear micro-microammeter as a standard power channel.

D. β / ℓ^* MEASUREMENTS

The mean prompt neutron lifetime, ℓ^* , was measured in the SNAPTRAN-1 reactor by experimentally approximating the time constant of the prompt neutron chain, ℓ^* / β ,⁽¹³⁾ where β is the effective delayed neutron fraction. Noise analysis techniques were used to determine the magnitude of the reactor transfer function over the frequency range of 10 to 80,000 cps.

The reactor transfer function was measured while the SNAPTRAN-1 reactor was operated in a low power, source free, critical mode. To monitor the neutron count rates, four scintillation detectors were positioned on the exposed upper grid plate of the reactor. The scintillation detectors were electronically coupled in parallel; the resulting pulses were combined in a cathode follower mixer, amplified and coupled to fast count-rate circuits. Signal fluctuations from the count-rate circuit were then amplified, filtered and recorded in three modes on analog tape (frequency modulated at 7.5 ips and 60 ips, and direct at 60 ips).

The raw data recorded on analog tape were played back and fed directly to a wave analyzer system. Preliminary power spectral density measurements were obtained from this system. Normalization and frequency response corrections were then applied to the data to obtain the power spectral density function. From analysis of this function, the reflector and core lifetime, abundance of effective reflector neutrons, and the mean prompt neutron lifetime were determined. While assuming the effective delayed neutron fraction to be 0.008, a mean prompt neutron lifetime of 6.25μ sec was calculated, using the fore-mentioned noise analyzer technique. The prompt neutron lifetime was also determined during the transient test series and is discussed in Appendix D.

VI. SAFETY AND EXPERIMENTAL INSTRUMENTATION

During the normal operation mode of the SNAPTRAN-1 and -2 reactors, operational instrumentation was provided to insure reactor safety during reactor startup and steady state operation. Additional instrumentation was provided to monitor the kinetics behavior of each reactor during the transient test series. A description of the above instrumentation and the respective detectors is presented in this section.

A. SNAPTRAN SAFETY INSTRUMENTATION

The reactor operators were provided with diagnostic instrumentation to monitor the nuclear status of the SNAPTRAN reactor, auxiliary components and facility communications at all times. Nuclear behavior of the reactor during startup and steady state conditions were monitored with four channels of pulse neutron count-rate circuits, a linear power channel, and three logarithmic power channels.

The pulse neutron count-rate circuits consisted of four B^{10} proportional pulse chambers strategically located near the SNAPTRAN reactor to provide over-lapping coverage of neutron detection from source level to approximately 100 watts. The respective channel amplifiers and high voltage sources were located in the control room and the counting instruments located either on the control console or nearby instrument racks. Count-rate readout was also provided and was monitored directly by the reactor operator.

The linear power channel and associated recorder were also under direct surveillance of the reactor operator. The uncompensated ionization chamber was located directly on the cubical structure approximately 3 ft from the reactor core and was sufficiently sensitive to monitor reactor power from source level to approximately 1 Mw.

The log power channel provided both a visual indication of reactor power over an eight decade range to approximately 10 Mw, and a recorded history of reactor operation. The uncompensated ionization chamber for the operational log power channel was located directly on the cubicle structure of the reactor package.

Two additional compensated ionization chambers located on the cubicle structure supplied reactor power level signals to the Log N safety channels. The safety channels provided high power level scrams and short period scram capabilities which were operational until manually by-passed during transient set-up procedures. The normal scram points on the power channels were set at 1 kw, and the normal short period scram point was 10 sec.

Calibration of the nuclear startup, operational, and safety channel detectors was performed in two phases. Each detector was initially calibrated in the PPCo Materials Testing Reactor (MTR) thermal flux calibration facility where detector outputs were determined for various known thermal flux levels. After the specific power calibration of each SNAPTRAN reactor was made (Section V-C) a calibration sensitivity, neutron count-rate or detector current output per watt value was determined. Only the linear and log power channels were used as standard power channels.

Further surveillance of reactor and facility status was maintained through an audible count-rate circuit and two closed-circuit TV systems. The audible count-rate circuit distributed an audible signal from selected neutron count-rate startup channels throughout the IET facility. Two closed-circuit TV cameras, one located on the IET weather tower and the second in the IET test cell, provided visual surveillance of the facility and the SNAPTRAN test dolly. The closed-circuit TV receivers were located at the control console.

B. SNAPTRAN EXPERIMENTAL INSTRUMENTATION

Many diagnostic measurements were made on the SNAPTRAN-1 and -2 reactors to determine the kinetic effects during transient conditions. This section includes a detailed description of nuclear, temperature, strain, acoustic and other measurements made during the transient series performed on the SNAPTRAN-1 and -2 reactors and the SNAPTRAN-2 destruct test.

1. Nuclear Measurements

During each transient, gamma and neutron detectors were used to assess the nuclear power burst, reactor period, energy release, compensated reactivity shape and in-core flux distributions. The sensitivities of the external ionization and scintillation detectors were attenuated with distance and shielding material

to monitor reactor powers from 1 to 10^{12} watts. Figure 17 indicates the range detected by each power detector during the transient and destruct series (Section VI-B-b).

The sensitivity of each of the above power detectors, in terms of count-rate or current per thermal watt, was determined at the PPCO's MTR canal calibration facility. A second calibration, or normalization of detector sensitivities, was made when the detectors were positioned in the respective locations required for transient testing. This calibration involved operating the SNAPTRAN reactor at known steady-state power level to determine the corresponding detector count-rate or current output at that point. As each detector output was very small during this calibration run, the respective linear amplifier gains were adjusted to the most sensitive range. Inter-detector calibrations were made for those detectors with sensitivity too slight to give deflecting signals during the reactor calibration run. During the transient series, the inter-detector calibrations were made when significant output signals were obtained from these high-range nuclear detectors. The referenced voltage output for an uncalibrated high-range detector was compared with calibrated detectors and a corresponding sensitivity determined.

Each nuclear detector output signal was coupled either to a linear or log amplifying stage, through an electrical patch panel, and recorded on either oscillographic recorders or on analog tape recorders. The linear amplifiers used to amplify the nuclear detector output signals were quite versatile in that six precision gain selections could be made. From the amplifier output, a voltage divider circuit provided 100%, 10% and 2% taps which could be selected and recorded on analog recorders. Thus, a wide range of reactor power could be monitored with proper gain selections. During the transient series, it was noted that some linearity differences occurred between the various tap settings on a respective gain setting. This effect was overcome by trimming internal amplifier components to match the output of different amplifier taps.

Oscillographic traces of reactor power were analyzed to obtain preliminary data on reactor period, energy release, reactor power and the magnitude of compensated reactivity. These data were used during the step and impulse transient series to provide preliminary information on the kinetic effects which were characteristic to the SNAPTRAN-1 reactor. A thorough examination of

Figure 17. Transient and Destruct Series Nuclear Detector Range

the kinetic effects observed on each transient was performed by computer analysis. The results of each transient series were compared to the theoretical model, COMPOST, and the model fitted to the experimental data.⁽¹⁾ To perform this computer analysis, the analog data recorded during each transient test were screened, digitized and transmitted to AI (Canoga Park). PPCo also analyzed the digitized transient data and compared these with a similar theoretical model.⁽³⁾

2. Temperature Measurements

During the non-destructive kinetics tests and the destruct test performed on the SNAPTRAN 10A/2 reactors, the system heating response was monitored at many points within the reactor structure. Radial and axial temperature measurements were made in the fixed beryllium reflector and in the reactor core. Also, radial temperature measurements were made on the upper and lower grid plates. Three types of temperature sensing detectors were used throughout the testing series; namely, diaphragm-ended chromel-alumel thermocouples, spot-welded chromel-alumel thermocouples and energy probes. Monitoring of these temperature sensors during the testing series provided information on radial and axial temperature distributions, thermal effects on heat capacity, and energy deposition rates.

The diaphragm-ended thermocouples were constructed as an integral part of four SNAPTRAN fuel elements. Each fuel element contained three thermocouples on a fixed radial and axial array. The lower portion of these fuel elements included a compression spring which maintained positive pressure of the fuel material on the fixed thermocouples, thus insuring positive thermocouple-to-fuel contact. Response time of the diaphragm-ended thermocouples was measured during the initial sub-prompt critical step transients and found to be approximately 700 msec. Accurate radial and axial temperature profiles were determined during the power burst of each of the sub-prompt critical transients where the heating rate of the reactor did not exceed the thermocouple time response value. Of those transients ranging from slightly below prompt critical and up, the diaphragm-ended thermocouples were used only to record long-term temperature effects resulting from the transient. Figure 18 shows the construction and location of the diaphragm-ended thermocouples. (See Section VI-B-6.)

5-19-66

7611-1030B

Figure 18. SNAPTRAN-1 Diaphragm-ended Thermocouples

Modifications were made to the upper grid plate such that the fuel elements in locations 2 and 36 could easily be removed or replaced during the SNAPTRAN-1 transient series. The fuel element cladding was stripped from each of these removable fuel elements at three interstice locations at the axial centerline and two inches from the top of the fuel element. In all, twelve 10-mil thermocouples were spot welded to these exposed areas. The spot-welded thermocouples were used to monitor the fuel element surface temperature from slightly sub-prompt critical transients through \$2.3 input transients. As the inherent time constant of the spot-welded thermocouples was estimated to be approximately 500 μ sec, temperature data were assumed to be valid on transients with reactivity inputs less than \$1.5. The temperature data indicated by the spot-welded thermocouples on sub-prompt critical transients lagged that temperature indicated by the diaphragm-ended thermocouple, since the cladding provided a heat sink on the fuel surface during the long-term transient. The locations of the spot-welded thermocouples is shown on Figure 19. (Section VI-B-6.)

Additional diaphragm-ended and spot-welded thermocouples were used to monitor fuel element cladding and upper and lower grid plate temperatures. These measurements showed the heat transfer characteristics present during the long-term sub-prompt critical transients. These temperature data were also used to correlate in-core temperatures during the sub-prompt critical transient tests. Placement of the aforementioned thermocouples is shown in Figure 20. (See Section VI-B-5.)

A series of high-response temperature sensing energy probes were placed radially and axially in interstices of the SNAPTRAN-1 and -2 reactors in order to provide a means of assessing energy deposition during an excursion. Probes, consisting of a small piece of fuel material to which 0.5 mil thermocouple lead wires were attached, were placed directly in the reactor core. The active portion of the energy probe is then centered in a magnesium-oxide insulating material and stainless steel sheath covered. An electrical ground is provided from the fuel to the stainless steel sheath. The chromel-alumel thermocouple lead wires are also magnesium-oxide insulated and stainless steel sheathed. Figure 21 shows the details and location of energy probes used in the SNAPTRAN-1 and -2 reactors.

5-19-66

7611-1030C

Figure 19. SNAPTRAN-1 Spot-welded Thermocouples

NAA-SR-11906

5-19-66

7611-1030D

Figure 20. SNAPTRAN-1 Cladding and Grid Plate Thermocouples

NAA-SR-11906

5-19-66

7611-1030E

Figure 21. SNAPTRAN-1 Energy Probes

NAA-SR-11906

The composition of the fuel material used in a given energy probe, and the respective fuel material heat capacity, determined the energy deposition rate within the energy probe. As the majority of energy probes used in the SNAP-TRAN transient tests employed the same fuel material as the fuel elements, direct energy depositions during a transient could be determined. Energy probes of which the fuel material differed from that above yielded energy deposition values differing only by the heat capacities and fissionable material concentration. Table 9 lists the types of energy probes used during the non-destructive and destructive transient tests. Also listed on the table are the respective heat capacity values used to determine equivalent energy deposition during a transient.

TABLE 9
ENERGY PROBE CHARACTERISTICS

Energy Probe Type	Degree of Hydriding (10^{22} atoms/cc)	Fuel Alloy (w/o U^{235})	Heat Capacity (cal/gm°C)
1. ZrHU ₁₀	6.5	10	$0.0898 + 8.44 \times 10^{-5}T$
2. ZrHU ₅	6.5	5	$0.0898 + 8.44 \times 10^{-5}T$
3. ZrU ₁₀	0	10	$0.0732 + 1.39 \times 10^{-5}T$
4. ZrU ₅	0	5	$0.0757 + 1.31 \times 10^{-5}T$
5. ZrU _{2.5}	0	2.5	$0.0770 + 1.27 \times 10^{-5}T$

Cross-calibration of energy probes to nuclear detectors was made throughout the transient series. The energy probe calibration is based on prompt sensible heat release, approximately 180 Mev/fission, while the nuclear detector calibration is based on total heat release, 204 Mev/fission. A calibration factor, P_{cal} , the energy release ratio between that energy derived from the nuclear detectors and that energy obtained from the energy probes was calculated as a function of time for each transient. This calibration factor was used to show response linearity of the energy probes during the transient series.⁽¹⁾

Linear amplifiers were used to condition the thermocouple and energy probe output signals prior to display or analog recording. These amplifiers were capable of amplifying the respective signal retaining readout sensitivity from ambient to 3000°F. To further increase the sensitivity of each amplification stage, the resulting signal was split into two ranges, 100% and 10%. The gain settings and selected output taps were adjusted during the transient series to monitor maximum temperatures on the most sensitive range (Section VI-B-6).

3. Mechanical Measurements

Two types of detectors were used to monitor hydrogen release from the zirconium-uranium-hydride lattice and expansion of the fuel elements and reactor vessel from thermal and pressure buildup effects. Pressure transducers directly monitored the internal fuel element pressures during a transient. Strain gages monitored effects due to thermal expansion on fuel elements and the core vessel, and pressure buildup within specific fuel elements.

Six SNAPTRAN-1 fuel elements were modified to include either direct or remote coupled pressure transducers. These transducers, ranging from 50 to 3000 psi sensitivity, were used to monitor hydrogen release from the fuel. Reference or dummy transducers were placed in the same area as the active transducers to determine the magnitude of the radiation sensitivity. The pressure transducers were located: (1) on extension tubes connected to fuel elements in positions 1, 3, 16 and 37; and (2) directly on fuel elements located in positions 17 and 18 (Figure 17). The signals from these pressure transducers were amplified with linear amplifiers and recorded directly on analog tape or oscillographic recorders (Section VI-B-5).

To determine the fuel element cladding and reactor vessel strain during the transient series, both circumferential and axial strain gages were used. Axial and circumferential strain gages were installed on the two instrumented fuel elements located in core positions 7 and 18 (Figure 17). Dummy strain gages were mounted directly with the active gages to determine the radiation sensitivity at that point. The circumferential strain gages were mounted on the reactor vessel at the core centerline to measure the overall core expansion.

Axial, circumferential and compression strain gages were used to detect strain and expansion effects on the destruct reactor. These gages were placed at centerline and axial positions on a radial center-to-point array. The in-core axial and circumferential gages measured fuel element radial expansion and axial elongation. The compression strain gages, also placed on a radial center-to-point array, measured the expansion of three fuel elements into an interstice. Both 0-180° hoop and circumferential strain gages were mounted on the outer vessel wall to measure gross expansion of the reactor vessel.

The respective signals from the strain gages were conditioned using high gain linear amplifiers, and recorded on oscillographic or analog tape recorders (Section VI-B-6).

4. Destruct Test Motion Measurements

Direct motion of the upper grid plate, fuel elements, and fixed beryllium reflector assembly during the disassembly process on the SNAPTRAN-2 reactor was measured. These motion measurements were made with direct reading linear potentiometers and circuit closure devices. Axial movement was detected with the linear potentiometers positioned on upper grid plate and fuel element lifting pins and by the pin-cluster circuit closure devices. (The linear potentiometers were supplied by PPCo and the pin clusters by EG&G.) Radial movements of the fixed reflector were also measured with the linear potentiometers and the pin-clusters. These detectors were placed on all four flats of the reflector at centerline and other axial positions. Both oscillographic and analog recordings were made to record these data during the destruct test (Section VI-B-6).

5. Destruct Test Photography Measurements

Documentary coverage of the SNAPTRAN-2 destruct test was provided by color and infra-red photography. Four close-range camera stations housed cameras which viewed the reactor through telephoto lenses. The respective reactor image was reflected to each camera by a mirror. The overall destruct sequence was filmed on cameras with framing speeds of 20, 48, and 64 frames per second. The destructive process was filmed on high-speed cameras at

1000 and 2000 frames per second. One camera operating at 48 frames per second was located at a distance of one mile. Table 21 lists the camera stations, camera types, and locations of cameras provided by Phillips Petroleum Co.

The mode and rate of in-core disassembly was determined by ultra high-speed cameras operated by EG&G. Mirror arrangements reflected the SNAPTRAN-2 core image to remotely located cameras. The core image was backlighted by a convex mirror and lamp. The light reflected through open interstices was then recorded by framing cameras operating at 35000 frames per second. The results of the in-core photography measurements are reported by EG&G in Reference 6.

6. Summary of SNAPTRAN-1 and -2 Experimental Instrumentation

A complete listing of the nuclear, temperature, energy probe, strain, acoustical or photography instrumentation used during the SNAPTRAN-1 and -2 tests is presented in Appendix B, Tables B-1 through B-12.

VII. SNAPTRAN-1 TRANSIENT TEST SERIES

The non-destructive testing of the SNAPTRAN-1 reactor was conducted: (1) to accumulate temperature feedback information at various average core temperatures and various reactivity input rates; (2) to determine the kinetic behavior of a SNAP 10A/2 reactor resulting from short period conditions; and (3) to refine the theoretical model used to predict the kinetic behavior of SNAP 10A/2 reactors. A series of step and impulse transients was performed with reactivity inputs up to the threshold of reactor damage. This section discusses the criteria under which the ambient and elevated step transients and the impulse transients were conducted. Also presented are the operational limits which were used to extend the transient series to the maximum non-destructive limit, as well as the preliminary results obtained during each transient series. The results quoted in this section represent only those obtained while performing the test series and do not encompass the computer-treated data.

A. STEP TRANSIENTS INITIATED FROM AMBIENT TEMPERATURES

During the initial step transient test series the reactivity input, as inserted by a step mode, ranged from a relatively low value which took the reactor slightly super-critical, to a value well in excess of prompt critical. This mode of reactivity insertion was used to increase the reactor temperature during the transient to allow the effects of the temperature feedback mechanisms to be observed and the respective value determined.

Maximum temperature, pressure and strain limits were imposed on the step transient test series to allow the damage threshold to be approached but not exceeded. The detectors used to monitor these variables were in-core thermocouples and energy probes, pressure transducers directly monitoring fuel element pressures, and circumferential and longitudinal strain gages attached to fuel elements. The test limits were: (1) hot-spot fuel element temperature, 1500°F; (2) fuel element pressure, 800 psig; and (3) 1.0% elongation of fuel elements (Sections VI-B and VII-E) and 0.1% circumferential vessel elongation. These test limits were increased during later step tests to 1700°F, 800 psig, and 0.5% and 1.2% for maximum hot-spot temperature fuel element pressure

circumferential strain on the reactor vessel and longitudinal strain on fuel elements, respectively. Hot-spot temperature, pressure, and strain relate to central fuel element measurements or data extrapolated to centerline values.

The operations required to initiate a step transient are given in the following sequence:

- 1) The equivalent stepper drum (drums B and C) position required for the scheduled reactivity insertion (see Figure 11 and Appendix A) is established.
- 2) With the stepper drums set at that position determined in 1), the reactor is brought to criticality by inserting the impulse drums (drums A and D).
- 3) The reactor is then made subcritical by withdrawing the stepper drums to the arming position (45°).
- 4) The proper time settings for tooth clutch clamp removal, fire, scram, and recorder start functions are determined and set on the sequence timer.
- 5) The stepper drums are armed by (a) maintaining a 45° stepper drum position, (b) energizing the stepper coupling clutch and tooth clutch clamps, and (c) actuating the stepper charge valves allowing proper drive pressure to be established in each drive cylinder.
- 6) The analog and oscillographic recorders are started.
- 7) The transient is initiated through the sequence timer. The sequence timer automatically starts and stops the drives of the oscillographic recorders, removes the tooth clutch clamps, fires the stepper drums, and actuates circuits to vent the stepper drive pressure and scram all control drums to terminate the transient.

As mentioned in the previous Section (VI-B), instrumentation for monitoring reactor power, fuel element temperature and pressure, and vessel and fuel element strain were recorded on analog and oscillographic recorders during each step transient. Preliminary reduction of the analog data was made by the STEP Nuclear Test and Experimental Sections of PPCo and by AI personnel. This initial data analysis included the determination of peak power, energy deposition (total and to peak power), hot-spot and average core temperatures at

peak power, maximum transient temperatures, and maximum pressure and strain values. These parameters were determined from reproduced recordings of the data recorded on the analog data transports. Three independent working plots of transient parameters were maintained by the above personnel and used to evaluate the status of the transient testing program.

The first transient of the ambient temperature step-test series required a step reactivity input of $\beta 0.27$. During this test and following tests where the reactor period was longer than 500 msec, the transient was terminated using a manual scram. The scram was initiated by PPCo operations personnel when it was observed that the temperature feedback mechanisms had sufficiently turned the power burst. When additional data were accumulated and the time function between fire and peak power determined, the terminating scram signal was programmed from the sequence timer. On transients where the reactor period was shorter than 500 msec the scram signal was programmed to start control drum movement after the power burst had been turned by an equivalent 1.5 to 3 front-side periods.

After the respective transient had been completed, the data recorded on the analog transports were reproduced for direct oscillographic recordings. From these data, the values of peak power, temperature at peak power, maximum core temperatures, maximum fuel element and vessel strain, and maximum fuel element internal pressure were determined. The stable reactor period was determined directly from those nuclear detectors with higher sensitivities. Values of peak power were obtained at maximum deflection on nuclear channels appropriately ranged. Energy release, both to peak power and total, was determined by integration of a power trace. This energy release was then normalized to that nuclear detector which described the average peak power value. The diaphragm-ended and the spot-welded thermocouples together with the radially and axially located energy probes were used to monitor temperatures through a transient. Appropriate normalization factors were used on the energy probe and spot-welded thermocouples when detector heat losses were observed (Section VI-B). Average core temperature at peak power was determined using volume-weighted axial and radial temperature profiles (Appendix D). The maximum values of fuel element pressure and axial strain were determined from the direct and remote pressure transducers and from axial strain gages mounted on fuel elements.

Figure 22. Preliminary Peak Power, Energy Release, Temperature Rise Plots of the SNAPTRAN-1 Ambient Temperature Step Tests

Figure 23. Preliminary Total Energy Release and Maximum Temperature Plots for the SNAPTRAN-1 Ambient Temperature Step Tests

The aforementioned variables were determined for each transient and plotted as a function of reciprocal period. These "working plots" were then used to predict results of succeeding transients. The increment of reactivity to be inserted over that of the previous transient was chosen by the STEP Experimental Physics Section. The expected results of the succeeding transient were then predicted independently and verification or recommendations made prior to the initiation of the transient. This type of prediction was made throughout the entire non-destructive transient series. By evaluating these preliminary results, a thorough understanding of reactor characteristics was made and the desired test limits approached safely.

A total of 25 ambient temperature step transients were run in the initial transient series, tests 0110 through 0159. During this test series the reactivity input range was from \$0.27 to \$1.50. The 13 ambient temperature step transients conducted under the higher test limits, tests 0200 through 0253, extended the reactivity range to \$1.70. Peak powers observed during this series ranged from 4.0×10^{-2} to 3.5×10^3 Mw, with corresponding maximum energy releases and temperatures of 0.4 to 17.0 Mw-sec and 270 to 1700°F, respectively. Minimum energy release and hotspot temperature values resulted from step transients at prompt critical. Plots of the preliminary transient results are presented to illustrate the progression of the ambient temperature step test series. As mentioned previously, the test results represent only preliminary analysis and specific values are subject to change pending computer treatment. Each of the variables monitored during the test series — peak power, energy release, temperature, pressure and strain — are plotted as a function of the reciprocal period. Figure 22 shows the relationship of peak power, energy release to peak power, and hot-spot temperature rise observed at peak power as a function of reciprocal period. This figure clearly shows the energy release and resulting temperature dependence on the prompt neutron precursor importance as reciprocal period values increase and pass through the prompt critical region. The maximum core temperature and energy release as a function of reciprocal period is shown on Figure 23. These values do not quite follow a defined function as each transient was not precisely terminated with a scram at the same peak power-to-power at-time-of-scram ratio. The respective fuel element pressure and axial strain values are noted on Figure 24. This

Figure 24. Preliminary Fuel Element Pressure and Strain Plots of the SNAPTRAN-1 Ambient Temperature Step Tests

Figure 25. Preliminary Inhour Plot of the SNAPTRAN-1 Ambient Temperature Step Tests

moderate hydrogen release value observed during the initial step test series provided the basis for extending the transient test limits to the higher values previously discussed. Figure 25 shows the inhour relationship obtained during the ambient temperature step test series.

B. STEP TRANSIENTS INITIATED FROM ELEVATED TEMPERATURES

During the ambient temperature step tests, the maximum average core temperature was raised to approximately 1300°F, with a reactivity input of \$1.70. As part of the SNAPTRAN objectives, it was desirable to be able to determine the magnitude of the temperature feedback mechanisms at as high an average core temperature as was obtainable. To accomplish this, series of transients were run where the average core temperature was raised significantly above ambient temperature using nuclear heat. These tests were termed the "cascade step-test series." The first transient of a cascade series used a high reactivity input, approximately \$1.50, to elevate the core temperatures. During the decay cycle, the strip heaters mounted in the thermal envelope doors were turned on to assist in the thermal equilibrating process. A second step transient with a lesser reactivity input was initiated while the reactor core and reflector temperatures were decaying but sufficiently equilibrated. As a result of the second step transient, the core temperatures were increased to approximately the same value as that obtained during the first transient, while the average core temperature at peak power and the maximum value were increased significantly over that obtained from a single-step transient. A total of five cascade step-test series was run and temperature feedback mechanisms and reactor characteristics determined over that elevated temperature range. Figure 26 shows a typical four-step cascade test series indicating average and peak temperatures obtained during the series.

Throughout the cascade step test series, working plots that were maintained included peak power, energy release, temperature, pressure, and strain values plotted as a function of reciprocal period. The variables of peak power and temperature rise were also plotted as a function of energy release. The aforementioned variables were determined again from oscillographic recordings of transient analog data. To determine the status of the reactor and associated components during the decay cycle, the temperature of fuel elements, the beryllium reflector, and control components were monitored.

Figure 26. Cascade Step Test
Series No. 5

These data were accumulated on strip chart recorders for direct evaluation. The thermocouples attached to the instrumentation towers and stepper and impulse drive mechanisms were monitored so that component temperature limits were not exceeded.

Three independent analyses were again made on the cascade step transient and decay data. The values of reactivity input, transient starting temperature, and expected transient results were determined independently, and the criteria under which the succeeding transient was to be run were verified or altered where necessary. This allowed a direct but safe approach to be made while establishing maximum elevated core temperatures during the test series. The respective values of peak power, energy release, and temperature rise to peak power are plotted as a function of reciprocal period in Figure 27. The function of peak power versus total energy release is shown in Figure 28.

Following each cascade transient, the radial and axial temperatures indicated by energy probes and diaphragm-ended and spot-welded thermocouples were recorded on a 15-channel sampling recorder. Each detector was recorded for one second on a 30 second cycle. These data indicated the effects of external heating and the general equilibrating process. The mean starting temperature

Figure 27. Preliminary Peak Power, Energy Release and Temperature Rise at Peak Power of the SNAPTRAN-1 Elevated Temperature Step Tests

Figure 28. Preliminary Peak Power and Maximum Temperature Versus Total Energy Release of the SNAPTRAN-1 Elevated Temperature Step Tests

was determined rapidly using these data while simultaneously preparing the reactor for the subsequent cascade transient. During the cascade test series the reactor core exhibited a fairly rapid equilibration process following a transient. The temperature sensors placed on an axial array indicated that a peak-to-average temperature ratio of one could be used without introducing significant error. A simple volume-weighted calculation was then used on the radially positioned temperature sensors to determine the overall average core temperature at the beginning of each transient (Appendix B).

The prompt temperature feedback mechanism and the transient behavior associated with the SNAPTRAN-1 reactor were determined with average starting temperatures as high as 1070°F and maximum average temperatures during a transient as high as 1390°F. This test series allowed these inherent characteristics to be determined from ambient starting temperatures to the highest attainable non-destructive average core temperature.

C. SINGLE-DRUM IMPULSE TRANSIENT SERIES

The single-drum impulse transient series extended the reactivity input from the maximum value obtained in the step transient series, \$1.70, to \$2.34. The impulse mode of reactivity insertion provides a well defined 28 msec reactivity pulse which was used to excite the reactor from subcritical conditions. Kinetic behavior of the reactor was determined using a constant reactivity insertion at various starting powers. As a result of increasing the starting power level and initiating a \$2.34 single-drum impulse transient, the effects on peak power, energy release, and temperature feedback mechanisms were determined. During this test series the results were compared with those predicted by the analytical model.

The mode of reactivity insertion during the single-drum impulse tests differed from that used in the step transient series in that the respective impulse drum (drum A) was positioned at the arming limit, -225° , armed, fired, and forward motion arrested in the positive sector at the end of a test, approximately $+180^\circ$. Approximately 60 msec were required to accelerate the drum and reach 0° ; likewise, approximately 75 msec were required for the drum to traverse from 0° to $+180^\circ$. The time required for the drum to traverse the reactivity region, -135° to 0° to $+135^\circ$, was 28 msec. When forward motion of the impulse drum was arrested in the positive sector, reverse motion was prevented by the Sprag clutch and hydraulic backstop devices. The operating sequence required to position, arm, and fire and impulse transient was as follows:

- 1) Position drum A in the negative sector for the desired reactivity to be inserted or at the arming position and obtain a three-drum, banked critical position with drums B, C and D.

- 2) Actuate the following interlocking relays to prepare the drive cylinder for charging:

- a) position the impulse drum at the arming position, -225° ,
- b) turn on the operational and analog recorders,
- c) check that B, C and D tooth clutches are not clamped,
- d) assure that all tooth clutches are engaged,
- e) clamp drum A tooth clutch,

- f) lock out drum A scram capabilities,
 - g) actuate drum A Sprag clutch,
 - h) actuate drum A load cell, and
 - i) open impulse drum A damper valve.
- 3) Charge the impulse drum drive cylinder to 1000 psig.
- 4) Actuate the sequence timer. Programmed on the sequence timer are the following functions;
- a) the chart drive of the operational and oscillographic recorders are turned on,
 - b) the impulse drum tooth clutch clamps are removed,
 - c) the impulse drum is fired by dropping out the tooth clutch holding current, and
 - d) the remaining three control drums are scrambled at a preset time.

Of the 27 single-drum impulse tests performed, the first eight tests were initiated from milliwatt starting power levels to increase the reactivity input from \$0.98 to the maximum single-drum reactivity input value. Reactivity inputs used during the first eight tests include \$0.98, \$1.51, \$1.95, \$2.16 and \$2.33. Four tests were run with a reactivity input of \$2.16, and the response function of the peak power to starting power ratio as a function of starting power was determined. These tests placed higher confidence on being able to perform similar transients with maximum reactivity inputs and significantly higher starting power levels. The remaining 19 transients were performed with a \$2.33 or \$2.34 reactivity input. During this latter sequence, the starting power level was increased in a stepwise fashion, from 10 milliwatts to 260 watts.

The general working plots used during the step transient test series—peak power, energy release, and temperature versus reciprocal period—were expanded to include such variables as the ratio of peak power to starting power, energy release, and temperature rise as a function of starting power. (These variables were determined at a constant reactivity input.) Again, transient data recorded on analog and oscillographic recorders were independently analyzed to determine preliminary results. On single-drum impulse transients, where the reactivity

input was varied, or on constant reactivity input transients, where the starting power level was varied, the predicted results for a specific transient were independently predicted. The predicted results were compared and input parameters were brought into agreement prior to conducting the transient.

Figure 29 represents the preliminary values of peak power and energy release (normalized to a 0.010 watt starting power level) as a function of inserted reactivity. The reactor power ratio, energy release and temperature rise (at constant reactivity input) as a function of starting power are shown in Figure 30. Reactor response to \$2.33 reactivity inputs was sufficiently fast that the starting power increased from 0.01 watts to approximately 1.0 watts before significant temperature rises resulted, as shown from Figure 30. Prompt neutron lifetime calculations were also made during the single-drum impulse test series (Appendix D).

D. COUPLED-DRUM IMPULSE TEST SERIES

A series of transients was performed using the highest reactivity insertion mode of the testing series. Reactivities ranging from \$2.00 to \$4.15 were inserted by means of coupled-drum impulse tests. The influence of the reflector neutron delay on the dynamic behavior was observed and the prompt temperature coefficient of reactivity was measured on transients where significant nuclear heat was developed.

Prior to initiating the coupled-drum impulse test series, it was determined that two adverse conditions would exist during the test series. The first condition would result from extreme drum asynchronization, where one impulse drum would lag the other during the impulse cycle, yet maintain a uniform pulse width, 28 msec. The analytical model predicted that the asynchronization effect would tend to suppress the resulting peak power and energy release as compared to a normal transient with synchronous drum insertion. Although this effect yields conservative results for a specific transient, working plots constructed under these conditions would predict low peak power, energy release, and temperature rise values. Hence, under maximum reactivity insertion conditions, the predetermined safe limits would be exceeded and damage would occur to the reactor core. Precautions were taken during the coupled-drum transient series to assure synchronization of the drums during an impulse.

Figure 29. Preliminary Peak Power Versus Programmed Reactivity of the SNAPTRAN-1 Single-drum Impulse Tests

An adjustable time delay circuit was incorporated into each tooth clutch current-holding circuit, to provide synchronized tooth clutch release times.

The second adverse condition would be the effect on peak power, energy release, and temperature rise resulting from an abnormally wide reactivity pulse introduced during the transient. Again the analytical model predicted that abnormally high peak power, energy releases, and temperature rise would result if the reactivity pulse width was increased in excess of 30 msec. This condition would be obtained if a lesser drive pressure were used in the impulse drive units or if the impulse drum coupling chain and clutch were to foul during operation. Extensive precautions were taken to assure proper impulse drive pressure by monitoring drive cylinder and supply pressures during the period from initial charging

Figure 30. Preliminary Reactor Power Ratio, Energy Release and Temperature Rise Data of the SNAPTRAN-1 Single-drum Impulse Tests

until just prior to impulse firing. The synchronization precautions taken above also reduced the possibility of reducing the impulse cycle time due to mechanical interferences.

The initial coupled-drum impulse transients encompassed the maximum reactivity insertion values obtained during the single-drum impulse transients. The reactivity input was then increased from \$2.00 to \$3.00 in a stepwise fashion to establish the initial effects of coupled-drum reactivity insertions. Plots of peak power versus the peak-power-to-starting-power ratio and reactivity were determined during this initial series. The corresponding peak power and required starting power for succeeding higher reactivity inputs were determined by direct extrapolation of these plots. Figure 31 illustrates these peak power and power ratio results obtained in the initial and subsequent transients. To make these plots meaningful, the starting power on each test was normalized to 1 milliwatt.

Following the initial coupled-drum impulse series, the reactivity input was increased in small increments until the resulting energy release limits established for the test series were approached. The maximum reactivity input limit was reached at \$4.15. During this sequence, predicted results were based

Figure 31. Preliminary Peak Power Versus Power Ratio and Programmed Reactivity of the SNAPTRAN-1 Coupled-drum Impulse Test

on direct extrapolation of peak power, reactor power ratio, energy release, and temperature rise plots. The preliminary peak power and power ratio data are summarized in Figure 31. Energy release and power ratio data are plotted as a function of reciprocal period on Figure 32.

A final coupled-drum impulse test series was conducted to increase the average and maximum core temperatures observed in the preceding series to the maximum hotspot temperature limit, 1500°F. This was accomplished by using a constant reactivity input, \$3.90, and increasing the starting power level to obtain successively higher peak powers, energy releases, and temperatures. The expected results of each transient were predicted from direct extrapolation of the above working plots and energy release, peak power, and maximum temperature rise data were plotted as a function of starting power, Figure 33. Maximum hotspot temperature rise observed during this series was 1485°F, which resulted from a \$3.90 transient initiated from a 1.67-watt starting power level and an initial starting temperature of 80°F.

E. SUMMARY OF SNAPTRAN-1 NON-DESTRUCTIVE TRANSIENTS

During the SNAPTRAN-1 kinetics testing series, non-destructive transients were performed over a continuous reactivity input range from \$0.27 to \$4.15. Resulting reactor hotspot temperatures were increased from ambient to approximately 1700°F during the ambient step test, and to 1500°F during the elevated step test and single and coupled-drum impulse test series. The overall response of the SNAP 10A/2 reactor was determined over this reactivity and temperature range and for each reactivity insertion mode. A continuous function of the temperature feedback mechanism, core lifetime values, reflector delayed neutron effects, and inhour relationships was made, (reference 1). The analytical model developed for the SNAP 10A/2 reactors was improved continuously throughout the transient series, although comparison of transient results and the model showed close agreement.

A summary of transient results is presented in Appendix C.

Figure 32. Preliminary Power Ratio and Energy Release Versus Reciprocal Period of the SNAPTRAN-1 Coupled-down Impulse Tests

Figure 33. Preliminary Peak Power, Power Ratio, Energy Release and Temperature Rise Data at Constant Reactivity SNAPTRAN-1 Coupled-down Impulse Tests

VIII. SNAPTRAN-2 DESTRUCT TEST

The analytical model which was refined during the non-destructive SNAPTRAN-1 tests was used to predict the results of the planned SNAPTRAN-2 destruct test. Input parameters to the analytical model were based on the stepper and impulse drive mechanism capabilities. It was desired to insert a maximum amount of reactivity in a stepwise fashion within a time period that would not cause significant temperature rises to occur. The mode of reactivity insertion for the destruct test was: (1) to insert as much reactivity as possible with the stepper drums, bringing the reactor slightly super critical, then (2) to insert the remaining reactivity with the impulse drums. The majority of the controllable reactivity was inserted with the stepper drums, as the resulting impulse reactivity pulse half-width was sensitive to added controllable reactivity; i. e., increasing the impulse drum controllable reactivity initiated the power burst earlier in time and, consequently, temperature increases would be observed prior to complete reactivity insertion. These reactivity values were programmed into the analytical model and were computer analyzed. Analysis showed that the SNAPTRAN-2 reactor would undergo complete destruction with a stepwise reactivity insertion of approximately \$5. By performing a destructive transient of this magnitude, the knowledge of neutronic behavior of the reactor could be extended from that range observed during the non-destructive transients. Also the mechanical and fission product release behavior of this type of reactor would be determined. The above results and consequences were then factored into the analytical model for accurate determinations of maximum reactivity accidents resulting from SNAP 10A/2 reactors.

A. PRELIMINARY CALIBRATIONS

A series of static-physics tests and prompt-critical step transients was performed on the SNAPTRAN-2 reactor to compare characteristics with that determined on the SNAPTRAN-1 reactor. The static physics measurements included only drum calibrations (Section V-B-2) and the specific power determination (Section V-C-2). Coupled-drum step transients with reactivity inputs ranging from \$1.03 to \$1.05 were performed to determine the reactor response characteristics and temperature feedback mechanisms. These parameters agreed well with those determined during the SNAPTRAN-1 ambient-temperature step-transient test series.

1. Static Physics Measurements

As the SNAPTRAN-2 physics measurements were discussed in detail in Section V, only a summary of these measurements is presented in the following table.

TABLE 10

SNAPTRAN-2 STATIC PHYSICS MEASUREMENTS SUMMARY

Excess Reactivity, including system perturbations	\$5.05
Single Impulse-Drum Worth, A or D	\$2.32
Coupled Impulse-Drum Worth, A and D	\$4.63
Single Stepper-Drum Worth, B or C	\$2.31
Coupled Stepper-Drum Worth, B and C	\$4.62
Shutdown Margin	-\$4.20
Specific Power Calibration, Linear Ammeter	7.25×10^{-9} amp/watt

2. Pretransient Calibration Tests

Destruct test prerequisites required that several operational events be performed in sequence. The time of this sequence of events approaching the final test is termed the countdown period. Several completely successful dry-run countdown sequences were performed prior to the destruct test. The countdown procedure used during the dry-run tests is the same as that presented in the following section, except that a low reactivity insertion step transient was initiated at the completion of the countdown. A total of five partial or full-scale dry-run countdown tests was successfully completed prior to conducting the destruct test.

The five calibrational step transients were performed after the SNAPTRAN-2 reactor was completely loaded and instrumented. The reactivity inputs for the scheduled step transients ranged from \$1.03 to \$1.05. This reactivity input range was used as minimum temperature rise and energy releases result, and many of the in-core detectors were temperature limited. The dynamic range

of the linear amplifiers was adjusted to monitor the expected values of reactor power and temperature during each step transient. The respective gain adjustments were desensitized for the destruct test, to provide maximum coverage of the test.

During the calibrational step-transients, the power burst, energy release, and in-core temperatures were monitored. Evaluation of these parameters allowed direct comparison of the SNAPTRAN-1 and -2 reactors. A summary of preliminary peak power, reactor period, energy release and temperature rise data obtained on these calibrational step transients is presented in Table 11.

TABLE 11
PRELIMINARY DATA OF THE SNAPTRAN-2 CALIBRATIONAL
STEP-TRANSIENTS

Test No.	Starting Temperature (°F)	Reactivity Inserted (\$)	Peak Power (Mw)	Energy Release (Mw-sec)	Maximum Temperature Rise (°F)	Reactor Period (msec)
329	69	1.03	3.2	0.18*	84	23.3
330	70	1.037	12.0	1.0	134	19.3
332	91	1.03	10.6	1.07	190	22.4
334	50	1.036	13.0	1.54	260	18.9
340	82	1.056	26.1	3.0	347	13.4

*Minimum energy release resulted from premature scrambling of control drums during the transient.

Although the reactor fuel material and reflector shimming configuration was slightly different from that used in the SNAPTRAN-1 reactor, the neutronic behavior of the SNAPTRAN-2 reactor was quite comparable. The preliminary values of peak power, reactor period, energy deposition, and temperature rise to peak power agreed with those values observed on the SNAPTRAN-1 reactor for the same reactivity input range.

B. DESTRUCT TEST

The SNAPTRAN-2 destruct test was scheduled only after three successful dry-run countdown tests had been made. By satisfying the requirement of

performing successful dry-run countdown tests, the final full-scale countdown was performed efficiently. During the dry-run countdown tests, the nuclear, temperature, and mechanical detectors were recorded on analog recorders either in a more sensitive mode to monitor step transient behavior, or on the last countdown tests when a step transient was not scheduled, in a least sensitive mode. Inter- and intra-channel correlations were made to determine the magnitude of inherent noise being recorded on the data transports. At the completion of the dry-run tests, all 156 channels of analog data were essentially free of inherent or induced noise.

The destruct test was to be performed under full meteorological restrictions. Under full meteorological restrictions, lapse, wind direction and speed, and precipitation conditions were carefully predicted and monitored during the final countdown test. To conduct the destruct test, full lapse conditions at the IET facility had to be present and maintained for a predicted period of three hours. The wind prior to the test, and predicted to persist for a three hour period, had to be at a minimum speed of 10 mph and not exceeding 30 mph and had to be coming out of the 180° to 240° sector and having minor direction fluctuations not exceeding 20° from either side of this sector. Due north is 0° on the IET grid network. Finally, no precipitation conditions could exist during or for a period of three hours immediately after the destruct test. During the SNAPTRAN-2 destruct test, the following weather conditions prevailed:

Lapse condition - Full
Wind speed - 10 mph
Wind direction - 250° (SW)
Precipitation - None

The events that occurred during the final countdown are enumerated in the following sequence. A thorough checkout of the reactor system was made by performing scram checks on each of the control drums, determining a banked-drum critical position and performing a subcritical coupled-drum impulse test to determine the degree of drum synchronization. A detailed calibration was made on all operational and transient instrumentation. All remote photography stations were checked for operation and loaded with film. The test cell and weather station closed-circuit TV systems were checked for operation.

Calibration and final adjustments were made on the auxiliary instrumentation provided by EG&G and the Los Alamos Scientific Laboratory (LASL). (EG&G provided in-core photography coverage and mechanical displacement instrumentation, while LASL included several energy deposition experiments during the destruct test.) The IET test cell building was removed for the destruct test. Final reactor checkouts were made, to determine the pre-transient critical position and make final impulse drum synchronization adjustments. Throughout the above sequences, the U. S. weather bureau personnel were monitoring weather conditions for general, NRTS site, and TAN site locations and providing periodic wind, lapse, and precipitation information to the operations personnel. During the last hour of the countdown sequence, final adjustments were made on photography equipment, the remote air-sampling stations located on the meteorological grid were activated, and a final check was made on all transient instrumentation. The stepper and impulse drums were brought to the respective arming position, and a final check was made to verify that all instrumentation and recording systems and all auxiliary systems were functioning properly. When all of the above requirements were satisfied, the stepper and impulse drive cylinders were charged with 350 and 1000 psig nitrogen, respectively; all tooth clutches were clamped; the stepper and impulse drums were coupled; and the sequence timer was activated. The sequence timer started the events, and CEC recorders, removed the tooth clutch clamps from the stepper tooth clutches, fired the stepper drums, removed the tooth clutch clamps from the impulse tooth clutches, and fired the impulse drums.

Figure 34 illustrates the SNAPTRAN-2 destruct test sequence. The top and bottom photos were taken before and after the destruct test to show the damage incurred during the test. The center photo sequence was taken by a 20 frame/sec Hulcher camera positioned 500 ft from the reactor. These photos show the progressive effect of the mechanical disassembly process. Immediately following the destruct test, the area was surveyed with remotely controlled TV monitors. After the airborne cloud had moved from the area, many localized fires were observed in and around the cubical structure and in the test cell area. These fires were ignited from hot fuel debris. The first visual assessment of damage was obtained from these TV monitors. Initial views showed that the cubical structure, void of reactor core and reflector, was completely intact.

$T_0 + 0.00 \text{ sec}$

$T_0 + 0.10 \text{ sec}$

$T_0 + 0.60 \text{ sec}$

$T_0 + 0.85 \text{ sec}$

$T_0 + 1.10 \text{ sec}$

$T_0 + 1.85 \text{ sec}$

SNAPTRAN-2 PREDESTRUCT

- A. CUBICAL STRUCTURE DRIVE MOTOR
- B. SUPERSTRUCTURE
- C. TOWER ASSEMBLY
- D. OPERATIONAL POWER CHAMBER
- E. REFLECTOR
- F. DRUM ASSEMBLY
- G. CUBICAL STRUCTURE
- H. STEPPER DRIVE ASSEMBLY

- A. SUPERSTRUCTURE
- B. OPERATIONAL POWER CHAMBER
- C. TOWER ASSEMBLY
- D. CUBICAL STRUCTURE
- E. CUBICAL STRUCTURE DRIVE MOTOR
- F. STEPPER DRIVE ASSEMBLY
- G. IMPULSE DRIVE ASSEMBLY

SNAPTRAN-2 POST DESTRUCT

6-28-66

7611-2517

Figure 34. SNAPTRAN-2 Destruct Test Sequence

NAA-SR-11906

BLANK

The drum shaft and tower assemblies were severely damaged. Each drum shaft assembly was severed from the respective tower assembly. The tower assemblies were found either on or in the cubical structure or, as in the case of one tower assembly, propelled away from the reactor structure. The stepper and impulse drive mechanisms remained intact and mounted on the cubical structure. Only the coupling assembly, which connects the pinion to the drum shaft assembly, appeared to be damaged.

Post-destruct entry was made immediately following the test to observe the reactor area. Although access was limited due to high radiation and contamination levels, further damage assessments were made. Pieces of beryllium reflector, varying from fragments to 1 x 2 in., in size were found within the 100-meter arc. Beryllium shim fragments were also found in a direct line from the respective drum positions. Fuel fragments were found throughout the area with sizes ranging from minute particles to approximately 3/4 in. These larger fuel fragments were found at distances up to 100 meters. The smaller fuel fragments were retained within the 10- to 15-meter arc. Pieces of fuel element cladding were also found within the 15-meter arc, all of which were severely mangled. The upper grid plate was found approximately 20 meters from the reactor. The drum shafts which were not visible during the TV survey were found, severely damaged, on the test cell floor beside the test dolly.

The cleanup process, which required approximately three months, recovered all of the debris resulting from the destruct test. A general map was prepared indicating the location of fuel and beryllium fragments and other components. Analysis of the fuel material was made and results are reported in Reference 4.

Oscillographic recordings were made of the data recorded on analog data transports which were on-line during the destruct test. Although a thorough treatise of the destruct test data is being made^(2,4), preliminary analysis of the oscillographic data indicates that an asymptotic period of 206 μ sec, a peak power of 71×10^3 Mw, and an energy release of 33 Mw-sec (to peak power) and 54 Mw-sec (total) resulted from the \$5.06 destruct transient. The energy release values are based on direct integration of the nuclear detectors which were calibrated on the basis of total fission energy (204 Mev/fission).

IX. REFERENCES

1. J. F. Jackson and W. A. Rhoades, "Analysis of the Nondestructive Kinetics Tests of the SNAPTRAN 10A/2-1 Reactor," NAA-SR-11850.
2. J. F. Jackson and W. A. Rhoades, "Analysis of the SNAPTRAN 10A/2-2 Reactor Destruct Test," NAA-SR-11851.
3. W. E. Kessler, et al, "SNAPTRAN Kinetics Test Results, Summary Report," IDO-(to be published).
4. W. E. Kessler, et al, "SNAPTRAN-2 Destruct Test Results," IDO-(to be published).
5. V. T. Berta, "SNAPTRAN Experimental Measurements and Instrumentation," IDO-(to be published).
6. H. Smith, "SNAPTRAN 10A/2-2 Test Report," EG&G-AEC-1183-1229.
7. J. M. Waage, "Safety Analysis Report - SNAPTRAN 10A/2 Safety Tests," IDO-16825.
8. "SNAP Reactor Transient Testing Machine," California: ASME, 1965, 65-WA/SAF-1.
9. "High Rate Reactivity Insertion Device for SNAP 10A Reactor Testing," California: ASME, 1965 (no number).
10. J. F. Jackson, "Control Drum Calibrations for the SNAPTRAN Experiments," NAA-SR-MEMO-11771 (February 15, 1966) (CRD).
11. W. A. Rhoades, "Experimental Evaluation of the Control Drum Interaction in SNAPTRAN 10A/2-1," NAA-SR-MEMO-11774 (December 20, 1965).
12. D. W. Clifford, "Interim Report on the SNAP Critical Assembly (SCA-4A) Experimental Results," NAA-SR-10245 (March 20, 1965) (CRD).
13. R. L. Randall and G. R. Grayban, "Measurement of SNAP 10A SNAPTRAN Kinetics Parameters by Reactor Noise Techniques," NAA-SR-MEMO-9160 (November 11, 1963).
14. W. R. Castle, "SNAPTRAN Core Reactivities," NAA-SR-MEMO-9453 (January 23, 1964) (CRD).

X. APPENDICES

APPENDIX A
SNAPTRAN INHOUR TABLES

Parameters Used in Following Inhour Data:

Lifetime = 6.000E-06 Beta = 8.0000E-03

<u>A</u>	<u>Lambda</u>
3.30000E-02	1.24000E-02
2.19000E-01	3.05000E-02
1.96000E-01	1.11000E-01
3.95000E-01	3.01000E-01
1.15000E-01	1.13000E-00
4.20000E-02	3.00000E-00

Figure A-1. SNAPTRAN Inhour Plot

APPENDIX B
SNAPTRAN-1 AND -2 DIAGNOSTIC INSTRUMENTATION

TABLE B-1
SNAPTRAN-1 NUCLEAR INSTRUMENTATION

Detector	Model	Location and Detection	Type	Maximum Power Range
N-1	WL-8105	10' from reactor on flatcar	(FN)	1.1×10^9 watts
N-2	RSN-76A	7' from reactor on structure	(FN)	3.0×10^8 watts
N-3	RSN-76A	10' from reactor on flatcar	(FN)	3.5×10^9 watts
N-4	RSN-76A	10' from reactor on flatcar	(FN)	1.6×10^{10} watts
N-5	G-11	14' from reactor on test cell floor	(FN)	3.5×10^9 watts
N-6	20th Cent.	7' from reactor on structure	(FN)	7.0×10^9 watts
N-7	WL-8105	10' from reactor on flatcar	(FN)	9.0×10^8 watts
N-8	20th Cent.	10' from reactor on flatcar	(FN)	4.5×10^{10} watts
N-9	GE-22	7' from reactor on flatcar	(γ)	1.5×10^{11} watts
N-10	GE-22	10' from reactor on flatcar	(γ)	4.0×10^{11} watts
N-11	GE-12	7' from reactor on flatcar	(γ)	1.0×10^{10} watts
N-12	GE-Mini	In-core	(TN)	1.5×10^{11} watts
N-13	GE-Mini	In-core	(TN)	1.1×10^{11} watts
N-14	GE-Mini	In-core	(TN)	1.2×10^{11} watts
N-15	NaI Scint.	14' from reactor under flatcar	(FN)	2.2×10^{11} watts
N-16	NaI Scint.	14' from reactor under flatcar	(FN)	3.0×10^{11} watts
N-17	RSN-76A	30" from reactor on structure	(TN)	1.1×10^{11} watts
N-18	GE-Mini	In-core	(TN)	1.5×10^{11} watts
N-19	GE-Mini	In-core	(TN)	1.2×10^{11} watts
N-20	GE-Mini	In-core	(TN)	1.5×10^{11} watts

Note:

WL - Westinghouse
RSN-Reuter Stokes
G, GE - General Electric
FN - Fast neutron
TN - Thermal neutron
 γ - Gamma

TABLE B-2
SNAPTRAN-1 THERMOCOUPLE INSTRUMENTATION

Gage No.	Type	Position	Interstice	Elevation
TC-1	C-A 10 mil Spot Welded	Top Grid	12-4, 13-4	
TC-2	C-A 10 Mil Spot Welded	Top Grid	10-4, 11-4	
TC-3	C-A 10 mil Spot Welded	Top Grid	8-4, 9-4	
TC-4	C-A 10 mil Spot Welded	Top Grid	4-3, 5-2	
TC-5	C-A AI Diaphragm	Lower Grid	14-3, 13-4	Upper Part of Grid
TC-6	C-A 10 mil Spot Welded	Lower Grid	14-3	Lower Part of Grid
TC-7	C-A AI Diaphragm	Lower Grid	11-4	Upper Part of Grid
TC-8	C-A AI Diaphragm	Lower Grid	11-4	Lower Part of Grid
TC-9	C-A 10 mil Spot Welded	Lower Grid	10-3	Upper Part of Grid
TC-10	C-A 10 mil Spot Welded	Lower Grid	10-3	Lower Part of Grid
TC-11	C-A 10 mil Spot Welded	Lower Grid	9-4, 8-3	Upper Part of Grid
TC-12	C-A 10 mil Spot Welded	Lower Grid	9-4, 8-3	Lower Part of Grid
TC-13	C-A 10 mil Spot Welded	Lower Grid	14-3	Upper Part of Grid
TC-14	C-A 10 mil Spot Welded	Vessel Wall		Centerline
TC-15	C-A 10 mil Spot Welded	Vessel Wall		Centerline
TC-22	C-A 10 mil Spot Welded	11	12-2	+ 4 inches
TC-25	C-A 10 mil Spot Welded	15	4-5	+ 4 inches
TC-26	C-A 10 mil Spot Welded	11	13-3	Centerline
TC-30	C-A AI Diaphragm	1		+ 5 inches
TC-31	C-A AI Diaphragm	1		+ 3 inches
TC-32	C-A AI Diaphragm	1		Centerline
TC-33	C-A AI Diaphragm	3		+ 5 inches
TC-34	C-A AI Diaphragm	3		+ 3 inches
TC-35	C-A AI Diaphragm	3		Centerline
TC-36	C-A AI Diaphragm	16		+ 5 inches
TC-37	C-A AI Diaphragm	16		+ 3 inches
TC-38	C-A AI Diaphragm	16		Centerline
TC-39	C-A AI Diaphragm	37		+ 5 inches
TC-40	C-A AI Diaphragm	37		+ 3 inches
TC-51	C-A 10 mil Spot Welded	36	2-1	Centerline
TC-52	C-A 10 mil Spot Welded	36	5-1	Centerline
TC-53	C-A 10 mil Spot Welded	36	4-1	Centerline
TC-54	C-A 10 mil Spot Welded		8-4	Centerline
TC-59	C-A 2 mil Spot Welded	8	9-2	Centerline
TC-1A	C-A 10 mil Spot Welded	On Coupon	12-3	+ 1-1/2 inches
TC-2A	C-A 10 mil Spot Welded	On Coupon	10-3	Centerline

Note: 1. C-A type indicates chromel vs alumel thermocouples
2. TC-1A and TC-2A are installed on dummy coupons for radiation test.

TABLE B-3
SNAPTRAN-1 ENERGY PROBES

Probe No.	Serial No.	Interstice	Elevation
* EP-1	78-6.5-10H	9-4	Centerline
3	104-6.5-10H	7-3	Centerline
4	40-6.5-5H	11-4	Centerline
5	41-6.5-5H	10-2	Centerline
* 6	105-6.5-10H	9-3	Centerline
7	106-6.5-10H	8-2	Centerline
8A	M-2-5N	8-5	+ 6 inches
8B	M-2-5N	8-5	+ 4 inches
8C	M-2-5N	8-5	+ 2 inches
8D	M-2-5N	8-5	Centerline
* 9A	M-1-5N	10-4	+ 6 inches
9B	M-1-5N	10-4	+ 4 inches
9C	M-1-5N	10-4	+ 2 inches
9D	M-1-5N	10-4	Centerline
10	43-6.5-5H	5-3	+ 1.5 inches
* 12	71-6.5-0H	7-5	Centerline
13	107-6.5-10H	13-4	Centerline
14	1-6.5-10H	12-2	Centerline
16	47-6.5-5H	11-2	Centerline
17	108-6.5-10H	10-1	Centerline
18	121-5N	6-2	Centerline
19	190-5N	10-5	Centerline
20A	M-3-5N	2-2	+ 6 inches
20B	M-3-5N	2-2	+ 4 inches
20C	M-3-5N	2-2	+ 2 inches
20D	M-3-5N	2-2	Centerline
21	84-6.5-5H	2-3	Centerline
22A	M-5-5N	7-5	+ 6 inches
22B	M-5-5H	7-5	+ 4 inches
* 22C	M-5-5N	7-5	+ 2 inches

TABLE B-3
SNAPTRAN-1 ENERGY PROBES (Cont)

Probe No.	Serial No.	Interstice	Elevation
22D	M-5-10H	7-5	Centerline
23	109-6.5-10H	11-5	Centerline
24	85-6.5-5H	14-3	Centerline
25	110-6.5-5H	11-1	Centerline
* 26A	M-4-5N	11-6	+ 6 inches
26B	M-4-2.5N	11-6	+ 4 inches
26C	M-4-5N	11-6	+ 2 inches
26D	M-4-10N	11-6	Centerline
27	123-6.5-10N	1-1	Centerline
* 28	111-6.5-5H	1-2	Centerline
* 29	112-6.5-5H	1-3	Centerline
30	113-6.5-5H	2-5	Centerline
* 31	2-6.5-10H	6-7	Centerline
32	5-6.5-10H	13-5	Centerline
34	45-6.5-5H	Be 0.5	Centerline
* 35	46-6.5-5H	Be 1.0	Centerline
36	10-6.5-10H	8-3	Centerline
37	37-6.5-5H	8-3	+ 2.4 inches
38	11-6.5-0H	7-4	Centerline
39			Centerline
40			Centerline
41A	M-13-5H	9-5	+ 6 inches
41B	M-13-5H	9-5	+ 4 inches
41C	M-13-5H	9-5	+ 2 inches
41D	M-13-5H	9-5	Centerline
43	145-6.5-10H	14-1	Centerline
47	151-0-10N	6-5	Centerline
49	146-6.5-10H	4-2	Centerline

*Denotes energy probes which became inoperative during the test series.

TABLE B-4
SNAPTRAN-1 PRESSURE INSTRUMENTATION

Gage No.	Type	Location
P-1	Statham 3000 psi	Position 1
P-2	Statham 3000 psi	Position 3
P-3	Statham 3000 psi	Position 16
P-4	Statham 3000 psi	Position 37
P-7	CEC 300 psi	Position 15
P-8	CEC 300 psi	Position 11
P-9	CEC 2500 psi	Top Grid (radiation test)
P-10	CEC 2500 psi	Top Grid (radiation test)
P-11	CEC 250 psi	Position 1
P-12	CEC 150 psi	Position 3
P-13	CEC 150 psi	Position 16
P-14	CEC 50 psi	Position 37

TABLE B-5
SNAPTRAN-1 STRAIN GAGE INSTRUMENTATION

Gage No.	Type	Position	Interstice	Elevation
SG-1	Axial A-D	Vessel Wall		Centerline
SG-2	Axial A-D	Vessel Wall		Centerline
SG-3	Hoop	Vessel Wall		Centerline
SG-4	Axial A-D	7	4-3	Centerline
SG-5	Axial A-D	7	6-3	Centerline
SG-8	Axial A-D	18	3-1	Centerline
SG-10	Axial A-D	18	5-2	Centerline
SG-11	Axial A-D	18	3-2	Centerline
SG-13	Axial A-D	11	13-3	Centerline
SG-14	Axial A-D	11	12-3	+ 4 inches
SG-17	Axial A	On Coupon	5-4	Centerline
SG-1A	Axial A-D	On Coupon	12-3	+ 1-1/2 inches
SG-2A	Axial A-D	On Coupon	6-3	+ 1-1/2 inches
SG-4A	Axial A	On Coupon	11-3	Centerline

- Note:
1. A-D type indicates an active and dummy gage installation.
 2. A type indicates an active gage installation.
 3. SG-17, SG-1A, SG-2A, and SG-4A are dummy gage installations for radiation test.

TABLE B-6
SNAPTRAN-2 NUCLEAR INSTRUMENTATION

Detector	Type	Location	Sensitivity (watts/ analog volt)
N-1	WL-8105 (FN)	Enclosure 2	3.2×10^7
N-2	RSN-76A (FN)	Z = +5 in. R = 1 ft	3.7×10^4
N-3	RSN-76A (FN)	Enclosure 3	1.1×10^{11}
N-6	20th Cent. (FN)	Enclosure 3	6.4×10^{11}
N-8	20th Cent. (FN)	Enclosure 2	3.3×10^9
N-9	GE - gamma	Z = -3.5 ft R = 7 ft	2.4×10^7
N-10	GE - gamma	Enclosure 1	7.0×10^9
N-11	GE - gamma	Z = +5 in. R = 1 ft	9.7×10^4
N-12	GE - (FN)	Enclosure 6	5.7×10^{11}
N-16	Scint. (FN)	Enclosure 5	6.2×10^{11}
N-18	Scint. (FN)	Enclosure 7	3.1×10^5
N-20	Scint. (FN)	Enclosure 2	1.2×10^4
N-22	Scint. (FN)	Enclosure 7	1.9×10^6
N-23	Scint. (FN)	Enclosure 1	2.1×10^8
N-25	Scint. (FN)	Enclosure 4	1.5×10^{12}
N-26	GE - gamma	Z = 40 ft between 3 & 4	3.4×10^{12}
N-27	GE - gamma	Enclosure 4	1.6×10^{13}
N-30	Scint. (FN)	Enclosure 7	5.1×10^{10}
N-32	GE - mini (TN)	In-core 6-7 Z=0	2.0×10^9
N-33	GE - mini (TN)	In-core 6-5 Z= +3.1 in.	1.1×10^9
N-34	GE - mini (TN)	In-core 6-6 Z=0	2.7×10^9
N-35	GE - mini (TN)	In-core 9-5 Z=0	3.0×10^9
N-43	Scint. (FN)	Enclosure 5	1.3×10^{10}

NOTES ON NUCLEAR DETECTOR ENCLOSURES AND ENCLOSURE LOCATIONS

1. R and Z are measured from the center of the reactor core. Z is positive upward.
2. Enclosure 1 is a 2-in. Pb enclosure placed on the flatcar on 0.02-in. Cd. The enclosure is also covered with 0.02-in. Cd. Approximate R and Z are $R = 9$ ft; $Z = -8$ ft.
3. Enclosure 3 is a detector enclosure built of 4-in. Pb, 0.02-in. Cd, 8-in. wax in that order looking out of the enclosure. The enclosure is placed on the ground immediately outside the test cell. The base of the enclosure is 0.02-in. Cd and 2-in. Pb. Approximate R is $R = 40$ ft.
4. Enclosure 4 is an 8-in. Pb enclosure placed next to enclosure 3. The base is the same as that for enclosure 3.
5. Enclosure 5 is a 2-in. Pb enclosure situated on the test cell floor directly under the reactor. $R = Z \cong -14$ ft.
6. Enclosure 2 is a detector enclosure built of 2-in. Pb, 0.02-in. Cd, and 4-in. wax in that order looking out of the enclosure. The enclosure is placed on the north end of the flatcar on 0.02-in. Cd. Approximate R and Z are $R = 11$ ft - $Z = -8$ ft.
7. Enclosure 7 is a 2-in. Pb enclosure with a 0.02-in. Cd cover. The enclosure is situated on the test cell floor ($Z = -14$ ft) at a distance $R = 20$ ft from the reactor. The enclosure is placed on 0.02-in. Cd.
8. Enclosure 6 is located in the coupling station. Approximate R and Z are $R = 20$ ft - $Z = -15$ ft. The enclosure is made from polyethylene-borated-lead brick covered with 0.02-in. Cd. The enclosure is placed on 0.02-in. Cd.

TABLE B-7
SNAPTRAN-2 THERMOCOUPLE INSTRUMENTATION

Detector	Type	Location	Sensitivity (°F/ analog volt)
TC-1	Nanmac Cu-C	Edge of core Z = 15-7/8 in. = 0°	2400
TC-2	Nanmac Cu-C	Edge of core Z = 23-7/8 in. = 0°	2400
TC-3	Nanmac Cu-C	Edge of core Z = 31-7/8 in. = 0°	2400
TC-4	Nanmac Cu-C	Edge of core Z = 39-7/8 in. = 0°	2400
TC-5	Chromel-alumel	Top grid plate	2200
TC-6	Chromel-alumel	Top grid plate	2200
TC-7	Chromel-alumel	7-4 Z = 2 in.	880
TC-8	Chromel-alumel	7-5 Z = -2 in.	880

TABLE B-8
SNAPTRAN-2 ENERGY PROBE INSTRUMENTATION

Detector	Type	Location	Sensitivity (°F/analog volt)
EP-147	ZrH	10-4 Z = 0	441
EP-149	ZrH	8-4 Z = 0	441
EP-150	ZrH	12-4 Z = 0	441
EP-153	ZrHU ₁₀	8-4 Z = 0	2200
EP-154	ZrHU ₁₀	10-4 Z = 0	2200
EP-155	ZrHU ₁₀	12-4 Z = 0	2200
M6-1	ZrU _{2.5}	9-4 Z = +6 in.	441
M6-2	ZrU _{2.5}	9-4 Z = 4 in.	877
M6-3	ZrU _{2.5}	9-4 Z = 2 in.	1761
M6-4	ZrU _{2.5}	9-4 Z = 0 in.	2200
M8-1	ZrU _{2.5}	11-4 Z = 6 in.	441
M8-2	ZrU _{2.5}	11-4 Z = 4	877
M8-3	ZrU _{2.5}	11-4 Z = 2	1761
M8-4	ZrU _{2.5}	11-4 Z = 0	2200
M9-1	ZrU _{2.5}	13-4 Z = 6	441
M9-2	ZrU _{2.5}	13-4 Z = 4	877
M9-3	ZrU _{2.5}	13-4 Z = 2	1761
M9-4	ZrU _{2.5}	13-4 Z = 0	2200
M10-1	ZrU _{2.5}	14-3 Z = 6	441
M10-2	ZrU _{2.5}	14-3 Z = 4	877
M10-3	ZrU _{2.5}	14-3 Z = 2	1761
M10-4	ZrU _{2.5}	14-3 Z = 0	2200
M11-1	ZrU _{2.5}	13-3 Z = 6	441
M11-2	ZrU _{2.5}	13-3 Z = 4	877
M11-3	ZrU _{2.5}	13-3 Z = 2	1761
M11-4	ZrU _{2.5}	13-3 Z = 0	2200
M14-1	ZrU ₅	$\theta = 60^\circ$ Z = 6 in.	441
M14-2	ZrU _{2.5}	$\theta = 60^\circ$ Z = 4	441
M14-3	ZrU _{2.5}	$\theta = 60^\circ$ Z = 2	877
M14-4	ZrU _{2.5}	$\theta = 60^\circ$ Z = 0	877
M-15-1	ZrU ₅	$\theta = 60^\circ$ Z = 6 in.	877
M-15-2	ZrU ₅	$\theta = 60^\circ$ Z = 4	877
M-15-3	ZrU _{2.5}	$\theta = 60^\circ$ Z = 2	877
M-15-4	ZrU _{2.5}	$\theta = 60^\circ$ Z = 0	1100
M-16-1	ZrU ₅	$\theta = 60^\circ$ Z = 6 in.	877
M-16-2	ZrU ₅	$\theta = 60^\circ$ Z = 4	877
M-16-3	ZrU ₅	$\theta = 60^\circ$ Z = 2	877
M-16-4	ZrU ₅	$\theta = 60^\circ$ Z = 0	877

TABLE B-9
SNAPTRAN-2 STRAIN GAGE INSTRUMENTATION

Detector	Type	Location	Sensitivity (in./in./analog volt)
SG-1	Axial A-D	7-4 Z = -2 in.	3.5×10^4
SG-2	Axial A-D	7-5 Z = -2 in.	3.5×10^4
SG-4	Axial A-D	8-5 Z = -2 in.	3.5×10^4
SG-7	Axial A-D	13-3 Z = -2 in.	3.5×10^4
SG-8	Axial A-D	14-2 Z = -2 in.	3.5×10^4
SG-11	Circ. A-D	7-6 Z = -2 in.	3.5×10^4
SG-13	Circ. A-D	13-3 Z = -2 in.	3.5×10^4
SG-14	Circ. A-D	Vessel Z = 0 = 0°	3.5×10^4
SG-15	Circ. A-D	Vessel Z = 0 = 180°	3.5×10^4
SG-16	Hoop 180°	Vessel Z = -0.5 in. = 0 to 180°	8.0×10^4
SG-17	Hoop 180°	Vessel Z = -0.5 in. = 180 to 360°	8.0×10^4
SG-18	Dummy	Next to reactor	3.4×10^4
ICD-1S	Compression	7-4 Z = 0	1.9×10^4
ICD-2S	Compression	6-5 Z = 1 in.	1.9×10^4
ICD-3S	Compression	7-5 Z = 0 in.	1.9×10^4
ICD-4S	Compression	7-6 Z = 0 in.	1.9×10^4
ICD-5S	Compression	5-5 Z = 0 in.	1.9×10^4
ICD-7S	Compression	9-3 Z = 0 in.	1.9×10^4
ICD-8S	Compression	10-1 Z = 0 in.	1.9×10^4
ICD-9S	Compression	7-1 Z = 0 in.	3.8×10^4
ICD-10S	Compression	Vessel Z = 0°	1.9×10^4
AC-1	4-arm strain	Element position 1	12600 g/v
AC-2	4-arm strain	Element position 20	11300 g/v
AC-3	4-arm strain	Be reflector = 270°	12800 g/v
AC-4	4-arm strain	Be reflector = 270°	11760 g/v
ICD-1M	Magneto-strictive	7-4 Z = 0	---
ICD-3M	Magneto-strictive	7-5 Z = 0	---
ICD-4M	Magneto-strictive	7-6 Z = 0	---
ICD-9M	Magneto-strictive	7-1 Z = 0	---
ICD-10M	Magneto-strictive	Vessel Z = 0	---
MA-1	Magneto-strictive	Vessel Z = 0 = 0°	
MA-2	Magneto-strictive	Vessel Z = 0 = 90°	
MA-3	Magneto-strictive	Vessel Z = 0 = 180°	
MA-4	Magneto-strictive	Vessel Z = 0 = 270°	

TABLE B-10
SNAPTRAN-2 RADIAL AND AXIAL MOTION DETECTORS

Detector	Type	Location	Sensitivity (in./analog volt)
DT-1	Linear Motion Pot.	Top of element position 5	1.6
DT-2	Linear Motion Pot.	Top of element position 14	1.6
DT-3	Linear Motion Pot.	Top of element position 29	1.6
DT-4	Linear Motion Pot.	Top grid plate 7-4	1.6
DT-5	Linear Motion Pot.	Top grid plate 7-5	1.6
DT-6	Linear Motion Pot.	Top grid plate 7-6	1.6
DT-7	Linear Motion Pot.	Be reflector Z = 0 = 0°	1.6
DT-8	Linear Motion Pot.	Be reflector Z = 0 = 90°	1.6
DT-9	Linear Motion Pot.	Be reflector Z = 0 = 180°	1.6
DT-10	Linear Motion Pot.	Be reflector Z = 0 = 270°	1.6
DT-11	Linear Motion Pot.	Under dolly	4.0
DT-12	Linear Motion Pot.	Top of element position 7	0.18
DT-13	Linear Motion Pot.	Be reflector Z = 0 = 0°	0.18
DT-14	Linear Motion Pot.	Be reflector Z = 0 = 270°	0.18

TABLE B-11
SNAPTRAN-2 ACOUSTIC DETECTORS

Detector	Type	Location	Sensitivity (psi/analog volt)
P-1	Kaman AC Bridge	R = 10 core dia., side-on	3.1×10^3
P-2	Kaman AC Bridge	R = 10 core dia., face-on	6.8×10^3
P-3	Kaman AC Bridge	R = 30 core dia., side-on	2.6×10^3
P-4	Kaman AC Bridge	R = 30 core dia., face-on	3.8×10^3
P-5	Kaman AC Bridge	Z = 30 ft radiological tower, side-on	6.0×10^2
P-6	Kaman AC Bridge	Z = 30 ft radiological tower, face-on	4.2×10^1
P-7	B & K Microphone	R = 100 M	4.7×10^{-2} Bar/V
P-8	B & K Microphone	R = 300 M	4.9×10^{-3} Bar/V

TABLE B-12

SNAPTRAN-2 PHOTOGRAPHY COVERAGE

Camera Type	Camera Station	Distance from Reactor (ft)	Frames per Second
Bell and Howell	E	500	64
Bell and Howell	E	500	48
Bell and Howell	C	110	64
Arriflex	-	5280	48
Infra Red	C	110	1000
Photo Sonic	E	500	1000
Photo Sonic	A	130	1000
Photo Sonic	C	110	1000
Photo Sonic	E	500	1000
Photo Sonic	E	500	1000
Photo Sonic	D	125	1000
Waddell	A	130	2000
Waddell	D	125	2000
Waddell	C	110	2000
Hulcher	D	125	20
Hulcher	E	500	20

APPENDIX C
SNAPTRAN-1 TRANSIENT DATA SUMMARY

TABLE C-1
SNAPTRAN-1 TRANSIENT DATA SUMMARY

Test No.	Reactivity Input (\$)	Starting Power (w)	Starting Temperature (°F)	Peak Power (Mw)	Energy Release (Mw-sec)	Maximum Temperature (°F)	Period (msec)
Ambient Temperature Step Tests							
0110	0.27		69.0	0.04	2.16	450	21000
0111	0.47		71.5	0.17	5.91	720	6800
0112	0.66		70.0	0.47	8.55	936	2500
0113	0.80		60.0	1.39	4.36	577	950
0115	0.90		65.0	1.84	6.25	807	344
0116	0.95		63.0	2.26	3.75	805	154
0119	1.001		82.0	3.89	4.35	576	47.5
0121	1.03		79.0	9.55	1.14	268	20.9
0124	1.03		62.7	9.23	1.67	328	22.7
0126	1.07		77.0	33.6	2.60	403	11.5
0128	1.09		78.0	61.0	2.47	482	8.84
0131	1.16		73.0	167.0	3.83	649	5.30
0133	1.27		81.0	390.0	5.00	928	3.23
0136	1.35		71.0	690.0	7.14	1073	2.46
0138	1.36		66.0	830.0	8.24	1117	2.38
0140	1.43		68.0	1018.0	8.61	1232	1.96
0142	1.50		54.8	1286.0	9.52	1335	1.71
0144	1.48		64.0	1330	9.55	1282	1.77
0146	1.02		71.2	8.32	1.59	235	26600
0148	1.01		84.7	5.97	0.99	200	33100
0151	1.04		71.5	15.6	1.34	250	16700
0153	-		82.5	-	-	-	20600
0155	0.29		74.0	0.04	-	404	22000
0157	0.78		78.8	0.66	-	619	1510
0159	1.33		82.5	680.0	7.30	1043	2.60
0200	1.37		65.0	650	7.21	840	2.32
0201	1.48		69.0	1440	9.86	1312	1.82
0202	1.50		56.6	1600	11.10	1398	1.74
0203	1.51		71.0	1620	9.93	1357	1.72
0204	1.52		76.0	1600	10.92	1365	1.67
0205	1.55		74.0	1730	10.25	1409	1.58
0206	1.58		49.5	2200	12.29	1446	1.50
0207	1.60		56.0	2250	12.37	1486	1.46
0209	1.49		62.0	1490	10.40	1245	1.79
0211	1.54		82.5	1720	8.94	1481	1.61
0246	1.47		75.5	1620	11.44	1365	1.75

TABLE C-1
(Sheet 2 of 4)

Test No.	Reactivity Input (\$)	Starting Power (w)	Starting Temperature (°F)	Peak Power (Mw)	Energy Release (Mw-sec)	Maximum Temperature (°F)	Period (msec)
0249	1.49		231.0	1780	12.38	1467	1.67
0253	1.70		93.0	3590	16.97	1704	1.18
Elevated Temperature Step Tests							
0209	1.49		62.0	1490	10.40	1245	1.79
0210	1.09		432.1	66	1.77	728	9.60
0211	1.54		82.5	1720	8.94	1481	1.61
0212	1.10		696.5	25	0.80	788	8.11
0213	1.37		630.2	830	9.50	1447	2.32
0246	1.47		75.5	1620	11.44	1365	1.75
0247	1.41		598.8	1300	11.00	1501	1.98
0248	1.19		900.0	359	6.42	1387	4.35
0249	1.49		231.0	1780	12.38	1467	1.67
0250	1.36		693.0	1040	9.99	1514	2.26
0251	1.20		911.0	574	7.18	1428	4.04
0252	1.16		1072.0	246	5.24	1490	4.99
0253	1.70		93.0	3590	16.97	1704	1.18
0254	1.34		642.0	966	9.75	1492	2.38
0255	1.19		900.0	334	5.67	1438	4.32
0256	1.15		1061.0	227	5.02	1462	5.39
Single-Drum Impulse Tests							
0163	0.98	0.014	89	9.00×10^{-8}	-	-	-
0164	1.51	0.042	94	1.50×10^{-5}	-	-	-
0165	1.96	0.0032	97	1.80×10^{-4}	-	-	-
0166	2.16	0.0035	88	8.48×10^{-3}	1.81×10^{-4}	-	0.723
0167	2.16	0.0053	88	1.77×10^{-2}	3.88×10^{-4}	-	0.723
0168	2.16	0.0016	88	1.30×10^{-2}	-	-	-
0169	2.16	0.0023	88	8.21×10^{-3}	1.69×10^{-4}	-	-
0170	2.33	0.0060	91	4.60×10^{-1}	1.70×10^{-3}	-	6.17
0171	2.33	0.010	93	7.31×10^{-1}	3.00×10^{-3}	94	0.646
0173	2.33	0.90	75	38.4	1.55×10^{-1}	105	0.630
0174	2.33	6.90	87	504	1.96	339	0.613
0175	2.33	12.0	183	738	2.77	516	0.643
0176	2.33	17.1	82	1030	3.77	666	0.637
0177	2.33	30.0	98	1540	5.27	858	0.636
0178	2.33	40.7	71	2120	6.96	981	0.640
0215	2.33	9.5	70	811	2.84	429	0.612
0217	2.33	9.7	62	1130	3.22	667	0.607
0218	2.33	10.4	176	1070	3.22	667	0.617

TABLE C-1
(Sheet 3 of 4)

Test No.	Reactivity Input (\$)	Starting Power (w)	Starting Temperature (°F)	Peak Power (Mw)	Energy Release (Mw-sec)	Maximum Temperature (°F)	Period (msec)
0219	2.34	20.0	73	1510	5.19	677	0.615
0220	2.34	29.5	62	2520	7.02	920	0.625
0221	2.34	38.4	83	1680	5.92	886	0.610
0222	2.34	49.6	79	2550	8.02	1040	0.615
0223	2.34	63.8	81	2580	9.60	1133	0.615
0224	2.34	82.3	120	2780	9.80	1166	0.613
0225	2.34	139.5	87	3520	11.20	1287	0.620
0226	2.34	194.6	120	3970	12.50	1393	0.615
0227	2.34	260.0	106	4860	14.30	1466	0.616
Coupled-Drum Impulse Tests							
0180	2.00	0.0257	103	1.14×10^{-5}			0.866
0181	2.40	0.0017	102	2.30×10^{-6}			
0182	2.70	0.00049	100	5.40×10^{-6}			
0183	3.00	0.00037	102	1.29×10^{-4}			0.509
0184	2.00	0.128	92	4.05×10^{-5}			0.918
0185	2.00	0.158	89	8.30×10^{-5}			0.943
0186	2.40	0.134	89	6.83×10^{-4}	1.70×10^{-6}		0.625
0187	2.70	0.00079	89	1.39×10^{-5}			0.750
0188	3.00	0.0585	89	3.04×10^{-2}	1.28×10^{-4}		0.478
0189	3.25	0.010	92	6.50×10^{-2}	1.91×10^{-4}		0.387
0190	3.45	0.00976	92	3.23×10^{-1}	1.59×10^{-3}		0.353
0191	3.60	0.00024	96	5.60×10^{-2}	5.61×10^{-5}		0.373
0192	3.70	0.00122	100	1.33	1.13×10^{-2}		0.313
0193	3.80	0.00195	92	4.42	1.14×10^{-2}	95	0.317
0194	3.90	0.00185	91	15.6	4.15×10^{-2}	97	0.312
0195	4.00	0.00183	93	50.0	2.71×10^{-1}	119	0.290
0196	4.10	0.0055	86	770	1.05×10^{-1}	337	0.270
0197	4.00	0.00037	62	13.1	3.03×10^{-2}	68	0.282
0198	4.20	0.00215	63	518	1.14	335	0.267
0229	3.80	0.0013	73	3.92	1.30×10^{-2}	75	0.300
0230	3.90	0.0012	75	6.29	1.84×10^{-2}	78	0.248
0231	4.00	0.0015	73	72.0	2.46×10^{-1}	110	0.279
0232	4.15	0.0011	71	150	5.28×10^{-1}	153	0.261
0233	3.90	0.054	72	478	2.00	292	0.293
0234	3.90	0.106	73	864	2.34	426	0.302
0235	3.90	0.141	76	1380	3.64	584	0.298
0236	3.90	0.386	90	1630	4.27	645	0.306

TABLE C-1
(Sheet 4 of 4)

Test No.	Reactivity Input (\$)	Starting Power (w)	Starting Temperature (°F)	Peak Power (Mw)	Energy Release (Mw-sec)	Maximum Temperature (°F)	Period (msec)
0237	3.90	0.387	82	2360	5.56	807	0.306
0238	3.90	0.607	104	2280	5.39	774	0.316
0240	3.90	0.645	85	3330	7.78	1027	0.315
0241	3.90	0.896	88	3900	8.92	1155	0.304
0242	3.90	1.240	106	3770	8.41	1152	0.321
0243	3.90	1.220	80	4310	9.60	1262	0.315
0244	3.90	1.670	80	6280	13.30	1565	0.309

APPENDIX D

SNAPTRAN CALCULATIONS

Following is a description of the analysis used to obtain the preliminary results reported in the non-destructive transient series and the destruct test sections of this report.

1. PEAK POWER

Peak power values were determined on each nuclear detector which was ranged to record the maximum power burst. Neutron and gamma ionization and scintillation detectors, predominantly N-1, N-8, N-9, N-10, N-15, and N-16, were ranged to record peak power during the non-destructive transient series. The composite error associated with the resulting peak power values obtained was $\pm 13\%$, 10% due to detector calibration and 3% due to oscillographic record readability.

2. ENERGY RELEASE

All energy release values reported were determined from direct integration of power channels which deflected sufficiently during a transient. Total energy release values and energy to peak power were normalized to that average peak power obtained for a respective transient. Thus, all energy release values quoted are based on total energy release, 204 mev/fission, and not prompt energy deposition, 180 mev/fission.

3. REACTOR PERIOD

Again, the sensitivity ranges of neutron and gamma ionization and scintillation detectors were scaled sufficiently low during each transient to determine the rate of reactor power rise. The respective stable or asymptotic period was determined from deflection versus time plots of these sensitive nuclear detectors.

4. TEMPERATURE

During each transient, respective radial and axial temperature data were determined at peak power and at maximum energy release from diaphragm-ended and spot-welded thermocouples and from the array of energy probes.

Using appropriate radial and axial correction factors, the maximum (hotspot) temperature was determined for each transient. The average core temperature was also determined for each transient, but at only one point in time, peak power.

The axial temperature profile was determined from the axially placed energy probes and thermocouples, and was found to be constant throughout the non-destructive transient series. The peak-to-average-temperature ratio, $T/\bar{T}$, was determined at various radial positions from the "piggy-back" energy probes. These data were volumetrically weighted over the radius of the core, to determine the overall axial peak-to-average ratio. A four-concentric-cylinder array was chosen to calculate the overall ratio by:

$$T/\bar{T}_A = \sum_{i=1}^4 f(w)_i T/\bar{T}_R \quad \dots (1)$$

where

$T/\bar{T}_A$ = overall axial temperature distribution,

$f(w)_i$ = radial volumetric weighting factors,

$T/\bar{T}_R$ = peak-to-average temperature ratio calculated at R.

The mean axial peak-to-average temperature ratio was experimentally determined to be 1.36.

The average core temperature at peak power was calculated for each transient, in order to permit predicting of the maximum reactivity input transient during each test series. The average core temperature at peak power was calculated in terms of temperature rise $\overline{\Delta T}$ by the following equation;

$$\overline{\Delta T} = \overline{\Delta T}_R / T/\bar{T}_A \quad \dots (2)$$

where

$\overline{\Delta T}$ = average core temperature at peak power, °F,

$$\overline{\Delta T}_R = \sum_{i=1}^5 f(w)_r [\Delta T \cdot K] \quad \dots (3)$$

$f(w)_i$ = radial weighting factors determined from isotherm plots,

ΔT = radial center-line temperature rise, °F,

K = interstice flux depression factor, 1.04,

$T/\overline{T}_A$ = mean axial peak-to-average temperature ratio.

5. PROMPT TEMPERATURE COEFFICIENT

To determine the accuracy of this one-point average core temperature calculation, a one-point prompt temperature coefficient value was determined for each transient, this one-point calculation was made only at peak power as that point represents the reactivity compensated by the temperature feedback mechanism.

$$\frac{\Delta \rho}{\Delta T} = \frac{\rho - 1}{\Delta T} \quad \dots (4)$$

where

$\frac{\Delta \rho}{\Delta T}$ = prompt temperature coefficient, $\text{¢}/^\circ\text{F}$,

$\Delta \rho$ = compensated reactivity at peak power, ¢ ,

$\rho = \rho_i - \rho_d$,

ρ_i = reactivity inserted, ¢ ,

ρ_d = reactivity associated with the delayed neutron groups, 100 ¢ ,

$\overline{\Delta T}$ = average core temperature at peak power, °F.

Temperature coefficient values obtained from this calculation generally were within 50% of those values determined from multi-point computer calculation and were generally high due to the inaccuracy of the average core temperature calculation.

6. REACTOR LIFETIME

A rapid calculation of reactor lifetime was also made during the single- and coupled-drum impulse test series. The lifetime was determined by;

$$\ell^* = \frac{(\rho - 1) \beta}{\omega} , \quad \dots (5)$$

where

ℓ^* = average prompt neutron lifetime, μ sec,

ρ = reactivity inserted, based on drum calibrations, \$,

β = effective delayed neutron fraction, 0.008,

ω = reciprocal period, sec^{-1} .

7. EVALUATION OF EXPERIMENTAL TECHNIQUE

As computer analysis of the transient data accumulated during the SNAP-TRAN-1 and -2 testing programs was not performed simultaneously with the experiments, the preliminary calculations and results obtained throughout the test series are to be refined upon presentation of the final analysis. The overall evaluation of each specific test series, the prediction of expected results, and the agreement of transient results were made by three independent parties and agreed very well. Based on these preliminary results, the evaluation of a test series and the progression of the test sequence to maximum reactivity tests was made with a high degree of confidence.