THE UNIVERSITY OF WISCONSIN

CORE TEST PROGRAM

UWNR MIXED TRIGA-FLIP CORE

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CORE TEST PROGRAM--UWNR MIXED TRIGA-FLIP CORE

A. UNLOADING OF PREVIOUS CORE

Operation with standard core E30-R12 was terminated on 1 March 1974 after a total exposure of the TRIGA fuel of 4,807.5 critical hours and 3,479,002 kW hours. This core and the preceding TRIGA Core had been pulsed 941 times with reactivity insertions of up to 2.1% ρ . Core E30-R12 was unloaded on 7 March 1974.

B. CRITICAL EXPERIMENT--MIXED CORE

Loading of the mixed core began at 0900 on 8 March and continued on that date until 1624 without reaching critical. One thermocouple in element 7524 (Bundle F41) had indicated a low resistance after installation. The problem was investigated before resuming fuel loading. A short in the connector was corrected on 11 March and loading to critical resumed at 1040 on 12 March 1974.

Initial criticality on the mixed core was reached at 1545 on 12 March with loading F19-R10 (9 Flip and 10 standard bundles, 10 graphite reflectors) with the regulating blade fully withdrawn and remaining control elements at 15.19 inches (Excess reactivity 0.40% ρ). A rod-drop measurement of shutdown margin indicated 7.9% ρ subcritical with reg blade out and all other control elements full in.

C. LOADING TO OPERATIONAL CORE

On 13 March additional fuel was loaded (2 bundle increments), with excess reactivity estimated from rod bank position and shutdown margin measured by rod drop (regulating blade full out for shutdown measurements). Table 1 indicates data for each loading step.

Table 1				
Loading	Estimated Excess % ρ	Shutdown Margin % ρ	Change from previous loading, Bundles added	Worth of addition/ predicted % ρ
F19-R10	0.40	7.90		
F21-R10	2.30	6.30	E3,C7	0.95/1.05
F23-R10	3.26	5.06	B3,F7	0.50/0.63
F25-R10	4.43	4.87	B7,C3	0.55/0.63

Figure 1 is the core loading chart for F25-R10.

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Technical Specifications precluded additional measurements of reactivity worths of fuel bundles in other positions in the grid. The agreement of measured values vs predicted values as given in Table 1 was quite good.

D. OPERATIONAL CORE REACTIVITY MEASUREMENTS

Transient rod worth (6.15 inches to 20.71 inches) was measured to be 2.33% ρ (Note: The position indicator 0 reference is a plane 1.5 inches below the fuel meat.) The core was unloaded to a configuration subcritical with all control elements full out and the transient rod linkage was shortened by 2.5 inches to give a new in position of 8.65 inches. After reassembly and testing of the transient rod and drive, the core was reloaded (13 March).

On 14 and 15 March, calibration of control elements continued. Rising period and rod drop measurements of transient rod worth indicated worth still exceeded the 1.4% limit (1.49% measured). Transient rod drive shims were adjusted to set the in limit at 9.15 inches and subsequent measurements showed the worth of the full stroke of the transient rod to be 1.35% ρ .

The attached Figures 2, 3, 4 and 5 are calibration curves for control and regulating blades constructed from data taken on 14 and 15 March. Figures 6 and 7 are plots of transient rod worth for full travel and from present in position to full out. Data for these curves was taken from subsequent runs as well as during the period when other calibration data were taken. Total worths of control elements are indicated on Figure 1.

Core reactivity was determined to be 4.05% ρ . Shutdown margin measurements by rod drop indicated 3.7% ρ , while use of the calibration curves for individual control elements indicated a shut down margin of 3.5% ρ , both with regulating blade full out.

On 18 March, a verification of adequate shutdown margin with the regulating blade and the control element with maximum worth full out indicated 0.77% ρ subcritical under these conditions. The reactor is not subcritical with these two control elements and the transient rod full out, so F25-R10 cannot be operated with the transient rod and drive removed and a partial unloading must be done before the transient rod is removed for maintenance.

Measurements of sample reactivity effects and void coefficient were completed on 18 March. Results are indicated in Table 2. The sample reactivity effects are well within the capability of the automatic control system or operator response at low power, and even more so at full power where the facilities are typically used.

Table 2 Reactivity Effects of Samples and Voids

Condition	Reactivity Change (% ρ)
Rabbit	
Maximum size Cadmium sample	-0.005
Maximum size Water sample	+0.001
Whale	
Load Whale in D8	-0.007
Maximum size Cadmium sample	-0.079
Maximum size Void (Air) sample	-0.020
Void Coefficient of reactivity (does not include void in control blade shrouds)	-0.116%/Void

An attempt at estimating the temperature coefficient of reactivity was made on 3 June 1974. With the pool at 100°F and no Xenon inventory the reactor was operated at low power while the cooling system was operated to reduce pool temperature. Since both bulk pool temperature and fuel temperature were changed, the coefficient measured was actually the difference in water and fuel temperature coefficients. The measured value was $+2 \times 10^{-7} \Delta K/^{\circ}C$ at 90°F, with a large uncertainty due to the extremely small reactivity change measured. This is in agreement with the expected performance based on past experience at this facility, and may indicate that the composite fuel temperature coefficient is smaller for the mixed core at low temperatures.

E. POWER ESCALATION AND CALIBRATIONS

Power escalation and calibration of power level channels was begun on 18 March. The initial step--to 100 kW indicated--and power calibration indicated actual power of 84 kW. Detector adjustment was not made based on this calibration since the probable error in the calibration (only 2°F ΔT) was greater than the difference in indicated and actual powers. On 18 March, power calibration runs were made at indicated 300 and 500 kW levels. Actual power at 500 kW was measured to be 520 kW and detector positions were

adjusted to agree with the heat balance. Calibration runs were made at 700 and 900 kW indicated power levels. Upon reaching 900 kW, noisy signals on linear power and period recorders were observed (1-3% deviations on power level channel). Further information on this phenomenon was developed later and will be discussed later in this report.

The power calibration at 900 kW showed actual power to be 882 kW. The detectors were again adjusted to agree with actual power (20 March) and a calibration run was performed at an indicated 1000 kW. Results of this calibration indicated actual power to be 1017 kW. Another detector position change was made (since the meter can be read accurately only to $\pm 0.5\%$, the detectors were adjusted to read 102% at the 1017 kW level). A repeat of the calibration showed actual power to be 997 kW at an indicated 1,000 kW.

On 22 March, the gamma (pulse power) ionization chamber was adjusted to read 0.219×10^{-6} amps/MW (equivalent to 600 MW/inch on the fast recorder trace.)

F. PULSING TESTS

On 22 March, pulsing testing began with reactivity insertions up to 1.2% ρ . On the afternoon of 22 March, after a 1.3% ρ pulse the transient rod failed to drop after the normal delay time. The operator scrambled the remaining major control elements. A subsequent investigation indicated binding of the transient rod due to clad damage. Appropriate notifications were made and a report (March 26, 1974 letter from R. J. Cashwell to Director of Licensing, USAEC, Subject "Report of Abnormal Occurrence and Corrective Action") on the problem and corrective action gives details of the problem.

During the shutdown for repair of the transient rod clad, a request for a technical specification change to allow use of an aluminum or air follower on the transient rod was submitted to USAEC. It was hoped that use of the follower might reduce the "noisy" operation at full power by slightly reducing the power density at the center of the core.

The repaired transient rod was installed and tested on 2 April. On 3 April, tests were made to assure the repair had not changed the reactivity worth of the transient rod. The initial pulse testing was then completed. (The test program was then interrupted for required laboratory courses including isotope production runs at 900 kW, control element calibrations, and pulse testing. The pulse testing for the laboratory class is included in the data on pulsing characteristics in Figures 8 through 13.) After the technical specification change was approved, an aluminum follower was added to the transient rod (25 April) and additional tests, reactivity measurements, and

pulsing tests were performed. The transient rod, with follower attached, has a reactivity worth of 1.38% β with an "in" position of 8.90 inches. Pulsing characteristics are depicted in Figures 8 through 13. Data for the mixed core are plotted with data from the standard TRIGA core in our facility and with prototype TRIGA data. Mixed core curves of peak power vs. period, peak power vs. width at half maximum power, and full width at half peak power vs. period are in agreement with previous data, as expected. Again as predicted, the curves showing inverse period and inverse width at half-maximum power vs. reactivity insertion show the effect of decreased prompt neutron lifetime. The slope of the inverse period vs. reactivity insertion data for the mixed core correlates with a prompt neutron lifetime of 29.7 μ sec, compared with the estimated value of 28 μ sec (54% of total core power in 9 bundle FLIP region).

The maximum fuel temperature from pulsing (1.4% β insertion) was measured to be 375°C.

Figures 8 and 9 show pulse peak power and energy release vs. reactivity insertion and transient rod fired position.

G. FULL POWER TESTS--FUEL TEMPERATURES, FLUX DISTRIBUTIONS, COOLANT TEMPERATURES

Two FLIP instrumented elements are included in loading F25-R10 (in bundles F41 and F42) along with a single standard fuel instrumented element (22). A difference of 70°C in indicated temperature (for all 3 thermocouples) was measured during high power operation with the two FLIP instrumented elements interchanged. Since the large difference in readings does not occur during pulse operation, it was assumed that the difference in reading was due to a difference in heat transfer efficiency. This hypothesis was further checked by measuring the time required for the element to cool from 200°C to 100°C after a pulse. The element in bundle F42 (higher of the two readings) had a cooling time of 27-31 seconds compared to 21-23 seconds for the element in F41. The standard TRIGA element, which has been exposed to more than 1000 pulses and 3,500 MW hours of operation has a cooling time of 22-26 sec. It is concluded that the difference in readings for the two FLIP instrumented elements is due to a difference in heat transfer from meat to clad. Table 3 lists, for all distinct fuel element locations in the core, power generation per element, predicted fuel temperature, and measured fuel temperature. In most cases the values were measured with only one of the FLIP elements and the other value is calculated based on the observed difference in instrumented

Table 3 Core Loading F25-R10

Calculated Power Density and Fuel Temperature and
Measured Fuel Temperatures--Full Power

<u>Core Position</u>		<u>KW in Element</u>	<u>Predicted Temp. °C</u>	<u>Measured Temperatures (°C)</u>		<u>Bdle 22 STD</u>
				<u>Bdle 41 FLIP</u>	<u>Bdle 42 FLIP</u>	
D 5	NE	18.1	372	Can't Measure		
	NW	16.1	360	Can't Measure		
	SW	18.1	372	Can't Measure		
E 5	NE	17.4	363	402	365	
	NW	16.1	350	395	356	
	SW	16.9	360	402	365	
	SE	17.0	361	397	361	
E 4	NE	15.4	342	382	343	
	NW	15.4	342	383	346	
	SW	16.1	350	384	348	
	SE	17.0	361	380	343	
D 4	NE	16.1	350	397	359	
	NW	16.1	350	399	353	
	SW	17.4	363	400	363	
	SE	16.2	350	398	342	
F 5	NE	9.3	272			290
	SE	6.7	239			238
F 4	NE	8.0	257			260
	NW	8.8	266			280
	SW	6.3	238			233
	SE	5.7	223			216
F 3	NE	5.8	230			200
	NW	6.8	242			222
	SW	4.9	210			185
	SE	4.6	204			175
E 3	NE	7.4	250			240
	NW	6.6	237			269
	SW	6.9	242			275
	SE	7.4	250			246
D 3	SW	6.9	242			280
	SE	8.3	261			260

element response. Measurements of effect of axial rotation of instrumented elements on indication while in the same core position showed variations of 10°C in locations of relatively flat flux distribution and 20°C in areas where a sharp flux gradient was expected. An uncertainty of 15°C should therefore be assigned to the measured fuel temperatures since the axial rotation orientation could not be adjusted in many grid locations.

The measured FLIP temperatures show good agreement with predicted temperatures (within uncertainty in readings) except in a few cases. The measured values from bundle 42 are all high by about 40°C , however. The fuel temperature measurement in E4-SE was considerably lower than predicted, but that element position is one of extremely large flux gradient and rotation of the element would probably bring the measured value more into agreement.

Standard fuel measured temperatures show poorer agreement with predicted temperatures primarily because the mesh intervals for standard fuel regions were larger in the computer calculations.

Figure 14 shows reactivity loss versus power level. The total reactivity loss from zero power to full power is 1.92% compared to almost 3% for the original standard TRIGA fuel core. This effect was expected due to the variable temperature coefficient in the FLIP fuel.

Figure 15 shows measured fuel temperatures versus power in the instrumented elements while located in their normal positions in core loading F25-R10.

Measurements of neutron flux were made by self-powered detector traverses in available coolant channels in one quarter of the core. A Cr-Al thermocouple mounted on the tip of the flux probe allowed measurements of coolant temperature. Previous measurements of temperatures at the fuel element top end-box had shown temperature rises much smaller than expected.

Data from these runs are not presented graphically due to uncertainties in detector vertical position. Vertical flux distributions are similar to those in previous cores. Although the measurement method used does not allow measurement of the horizontal distribution of flux with any detail (measurements can be made only at 3 inch increments), the peak vertical fluxes approximate the gross horizontal flux distributions predicted by calculations. This includes peaking at the FLIP-standard fuel interface and at the core periphery.

Temperature measurements indicated a maximum temperature rise of 89°F in the positions between fuel bundles in E6 and E5 grid positions. This compares to a bulk water temperature in that channel of 183°F . Considerable horizontal mixing was noted near the top of the core, and thermocouple outputs showed fluctuations thought to be due to the mixing and the large numbers of bubbles in the coolant stream near the top of the core.

H. POWER FLUCTUATIONS

The power fluctuations referenced earlier in this report were investigated extensively. Chart line width increased to the equivalent of 2% power variations as power exceeded 900 kW initially. (Compare with 0.6% variation at low power from diffuser operation). The jitter in instrument traces was found to be correlated on both linear power instruments indicating a reactivity disturbance. Examination of channel output on a fast strip chart recorder with amplification of deviations shows negative flux deviations which return to the stable condition at a frequency of 3-5 per second at normal core inlet temperature ($80-100^{\circ}\text{F}$) and a maximum deviation of 1.8%. With core inlet temperature at 115°F , the frequency increases to 4-7 per second with maximum deviations of 6% negative and average deviations of less than 3%. With no operator action, there is no divergent behavior and gross power level remains quite constant. With the servo control channel dead-band increased, automatic operation is uneventful.

The severity of the oscillations have decreased with operation to the present indicated 0.125 inch chart line width (on a 10 inch recorder) with occasional negative deviations of 0.25 inches at a core inlet temperature of 112°F during extremely warm weather.

In view of the measured coolant temperatures during full power operation, it does not appear that the reactivity disturbance is caused by local boiling. The coolant exiting the core contains large numbers of bubbles which do not collapse, indicating the bubbles to be dissolved air which has come out of solution due to the temperature increase through the core. The bubbles are more profuse than with the previous standard TRIGA fuel core, and a greater number of large bubbles is observed. The gaseous air activity monitor does not indicate higher than normal A^{41} activity in the exhaust air, however. The conclusion reached is that the reactivity disturbance is due to dissolved

air bubbles in the core. Discussions with personnel at a similar facility indicated the same phenomenon was observed and that similar conclusions were reached as to its cause.

Operation at full power on either manual or automatic control is considered reasonable unless the oscillations show a tendency to diverge. The magnitude of the disturbance is expected to continue to decrease with further operations, both due to maintenance of lower dissolved air inventory due to routine operation and due to flux distribution changes with further operation of the mixed core.

I. REACTIVITY CHANGE WITH FUEL BURNUP

Total operation with the mixed core at the time of this report is only 4 MW days and no conclusions can yet be made on rate of reactivity change. Information on reactivity change with core life will be developed and reported in Annual Reports.

J. FLUXES IN EXPERIMENTAL FACILITIES

Thermal neutron fluxes and gold cadmium ratios were measured by activation techniques. Since the experimental facilities use standard sample containers, the data on flux was developed to indicate fluxes at standard container locations. Figures 16 and 17 indicate the fluxes available for irradiations. It should be noted that the values given for flux in the Whale Tube is not the centerline flux but that flux to which samples in 2/5 dram vials around the periphery of the Whale carrier are exposed during an irradiation (These containers rotate on their vertical axes during irradiations.). The flux in the Porpoise Tube is effectively the same as that in Whale D. Pneumatic tube flux is given as that on the centerline of the Rabbit.

K. CONCLUSIONS

Measured operating core parameters are in close agreement with those predicted by machine calculations. No safety analyses are changed by observed core characteristics.

The only behavior not predicted is the reactivity disturbance at full power described in Section H of this report. The power fluctuations have decreased with operation of the core and are expected to decrease further

after redistribution of samarium. Even the largest fluctuations observed do not preclude safe operation.

The restored core excess reactivity (4.05%) coupled with the smaller reactivity loss at full power (about 1% less) makes this core approximately equivalent to the original 25 bundle standard TRIGA core (excess 4.9%). Thermal neutron fluxes in experimental facilities are about 30% lower in the mixed core than in the original TRIGA core, primarily due to the large proportion of power in the central FLIP region. The mixed core experimental facility fluxes, in turn, are about 30% higher than those in the 30 bundle core replaced by the mixed core.

In summary, the 9 bundle FLIP mixed core has achieved the desired objective of restoring core excess reactivity and an increase in experimental facility fluxes. Further refuelling with FLIP fuel will increase the available neutron fluxes. The only decrease in capability resulting from the mixed core is the smaller pulses and the elimination of vacant grid lattice positions due to present technical specifications. Should the experimental program be hampered by these limits, changes in Technical Specifications will be requested, based on measured behavior.

FIG. 1

DATE 3-15-74

CORE
LOADING F25-R10

EXCESS 4.05 % Δ K/K

S.D. MARGIN 3.7 % Δ K/K

#1 BLADE 1.86 % Δ K/K

#2 BLADE 1.94 % Δ K/K

#3 BLADE 2.10 % Δ K/K

REG. BLADE 0.357 % Δ K/K

TRANSIENT 1.37 % Δ K/K

KEY:

⊙ INSTRUMENTED ELEMENT

G GRAPHITE REFLECTOR

S SOURCE

WC,WD,WE WHALE TUBES

PT PORPOISE TUBE

34 THRU 42 FLIP FUEL

FIG. 2

#1 CONTROL BLADE WORTH

F25-R10 CORE

MAR 15 1974

FIG. 3

#2 CONTROL BLADE WORTH
F25-R10 CORE
MAR 15 1974

FIG. 4

#3 CONTROL BLADE WORTH
F25-R10 CORE
MAR 15 1974

FIG. 5

FIG. 6

TRANS. ROD WORTH - WITH ALUM. FOLLOWER

F25-R10 CORE

APR 18 1974

FIG. 7

PULSE WORTH CURVE WITH ALUM. FOLLOWER

F25-R10 CORE
APR 18 1974

FIG. 8

PULSE PEAK POWER & ENERGY VS.
REACTIVITY INSERTION, F25-R10 CORE

FIG. 9

PULSE PEAK POWER & ENERGY VS.
TRANSIENT ROD FIRED POSITION
F25-R10 CORE

FIG.10

Inverse Period and Inverse Width at Half Maximum Power vs. Prompt Reactivity Insertion - Prototype Reactor
UWNR Data Indicated $1/\tau$ $\sim 1/\tau$

FIG. II

Peak Power vs.

Reactor Period -
 Prototype Reactor
 UWNR Data Indicated

FIG. 12

Full Width at Half

Peak Power vs. Period

Prototype Reactor

OWNR Data Indicated

FIG. 13
 Peak Power vs.
 Full Width at Half Peak Power -
 Prototype Reactor
 UWNR Data Indicated

FIG. 14

REACTIVITY LOSS VS. POWER LEVEL
F25-R10 CORE

FIG. 15

FUEL TEMP. VS. POWER LEVEL
F25-R10 CORE

FUEL TEMP., °C

400

300

200

100

0

100

200

300

400

500

600

700

800

900

1000

POWER, Kw

BUNDLE NO.:

42 C & B

42 T

41 C & B

41 T

22

C: ON $\varnothing$

T: 1" ABOVE $\varnothing$

B: 1" BELOW $\varnothing$

FIGURE 16

FIG. 17

THERMAL FLUX & CADMIUM RATIO IN PNEUMATIC TUBE

F25-R10 CORE, 1 MW