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TITLE CRITICAL EXPERIMENTS IN SUPPORT OF THE CNPS PROGRAM

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ABSTRACT

Zero-power static and kinetic measurements have been made on a mock-up of the Compact Nuclear Power Source (CNPS), a graphite moderated, graphite reflected, U(19.9% ^{235}U) fueled reactor design. Critical configurations were tracked from a first clean configuration (184 most central fuel channels filled and all control rod and heat pipe channels empty) to a fully loaded configuration (all 492 fuel channels filled, core-length stainless steel pipe in the twelve heat-pipe channels, and approximately half-core-length boron carbide in the outer 4 control rod channels. Reactor physics data such as material worths and neutron lifetime are presented only for the clean and fully loaded configurations.

INTRODUCTION

The Compact Nuclear Power Source is a reactor designed to power a short-range-radar in the North Warning System. The cylindrical core dimensions were specified as 600 mm in radius and 1100 mm in height thus permitting fabrication of graphite core and upper reflector components for a Demonstration Unit to be operated at AECL Whiteshell, Canada. Specification of the simpler radial and bottom reflectors, nominally 200 mm-thick, was to await the outcome of the critical experiments. Upon suspension of plans for the Demonstration Unit, the critical experiments program was simplified so as to obtain reactor physics data less specific to the CNPS design.

THE CNPS MOCK-UP

The graphite radial reflector, specified as 200 mm-thick with an inside radius of 604 mm, was fabricated in twelve 30 degree segments. Importantly, the height of a segment was specified as 1171.1 ± 0.5 mm at the inner radius with a shoulder at the top that dropped the height 30 mm between the radii 743.7 and 754.7 mm there being a 10 mm vertical drop at 754.7: the mate to this shoulder in the upper "demo-unit" reflector has its vertical drop of 10 mm at 754.76 mm. The radial reflector segments were mounted on the stationary platform of a vertical assembly machine and, after binding, the radii of the vertical drops in the shoulders were less than 754.76 mm for all azimuths, the inner radius was indeed 604 mm, and the top surfaces were flush well within the ± 0.5 mm specification.

The cylindrical graphite bottom reflector, specified as 200 mm-thick and 600 mm in radius, was mounted on a 60 mm-thick aluminum support plate resting on top of a movable cart. The nine graphite core segments were

mounted on top of the bottom reflector and, after binding, had a 600 mm radius. Alignment was such that, when the cart was drawn under the stationary platform and locked in place, the radial reflector, core, and bottom reflector shared a common vertical axis and the four outer control rod channels were north, east, south, and west of this axis. A hydraulic ram, passing through a hole in the cart, lifted the support plate. The thickness of the ram's platen was selected such that, at the upper limit of a 2 m stroke, the core and radial reflector segments were flush within the ± 0.5 mm specification.

The upper reflector components, two massive graphite pieces each with a radius of 804 mm, were now mounted on top of the radial reflector, all keys fitting properly, and rotated to align the heat pipe and control rod channels with those of the core. The important point is that the 5559 kg graphite skeleton, so assembled, corresponds to that of the design drawings (114Y-255505, sheets 1-13). These drawings also specify the coordinates and diameters of the 492 fuel channels, the 20 material replacement channels, the 12 heat pipe channels, and the 5 control rod channels, and are vital for the analyst. Very briefly: the centers of the 61.85 mm-dia. inner heat pipe channels are 191.00 mm distant from the core axis and their azimuths are $\pm\pi/4$ and $\pm 3\pi/4$ relative to the south control rod channel; the centers of the 61.60 mm-dia. outer heat pipe channels are 438.94 mm distant from the core axis and their azimuths $\pm\pi/8$, $\pm 3\pi/8$, $\pm 5\pi/8$, and $\pm 7\pi/8$; the centers of the 34.93 mm-dia. outer control rod channels are 251.46 mm distant from the core axis; the 12.85 mm-dia. fuel and material replacement channels were drilled to a depth of 1100 mm in the 1130 mm-length core segments whereas the other channels were drilled full length.

Figure 1 shows a photograph of the CNPS Mock-up assembly area taken just prior to the loading of fuel compacts. The cart has been drawn out from beneath the reflector housing so as to expose the pattern of channels in the core. The superstructure contains the drive mechanisms for a "demo unit" boron carbide central control rod (but used by us as a safety rod) and our vernier control rod, or shim, which preempts the south control rod channel.

The 50 mm long fuel compacts have the atomic composition $U(19.9 \text{ w/o } ^{235}U)O_{1.70}Si_{1.88}C_{17.34}$ with 5.2 ppm boron equivalent impurities. A filled fuel channel contains $29.25 \pm 0.04 \text{ g } ^{235}U$.

EXPERIMENTAL RESULTS

An Am-Be neutron source, present during the loading of fuel to the first critical configuration, was removed because the much weaker natural source in the fuel permitted measurement of stable positive periods over a lower power range. The first critical configuration was: 184 central-most fuel channels filled, the 20 material replacement channels filled with graphite, the shim and safety rods at their out limits (bottoms at top surface of the core), and all other channels empty. The center of the outermost filled fuel channel was 370.0 mm from the core axis. For material worth measurements and shim calibration, the perturbed configurations had filled fuel channels in the range 180 to 207.

To compensate for the addition of stainless steel pipe (SS-316, O.D. = 48.3 mm, I.D. = 44.6 mm, length = 1237 mm, and mass = 5000g) to the 12 heat pipe channels, addition of normal boron carbide rods (23.90 mm-dia. and total length of 1100 mm) to the north control rod channel, and

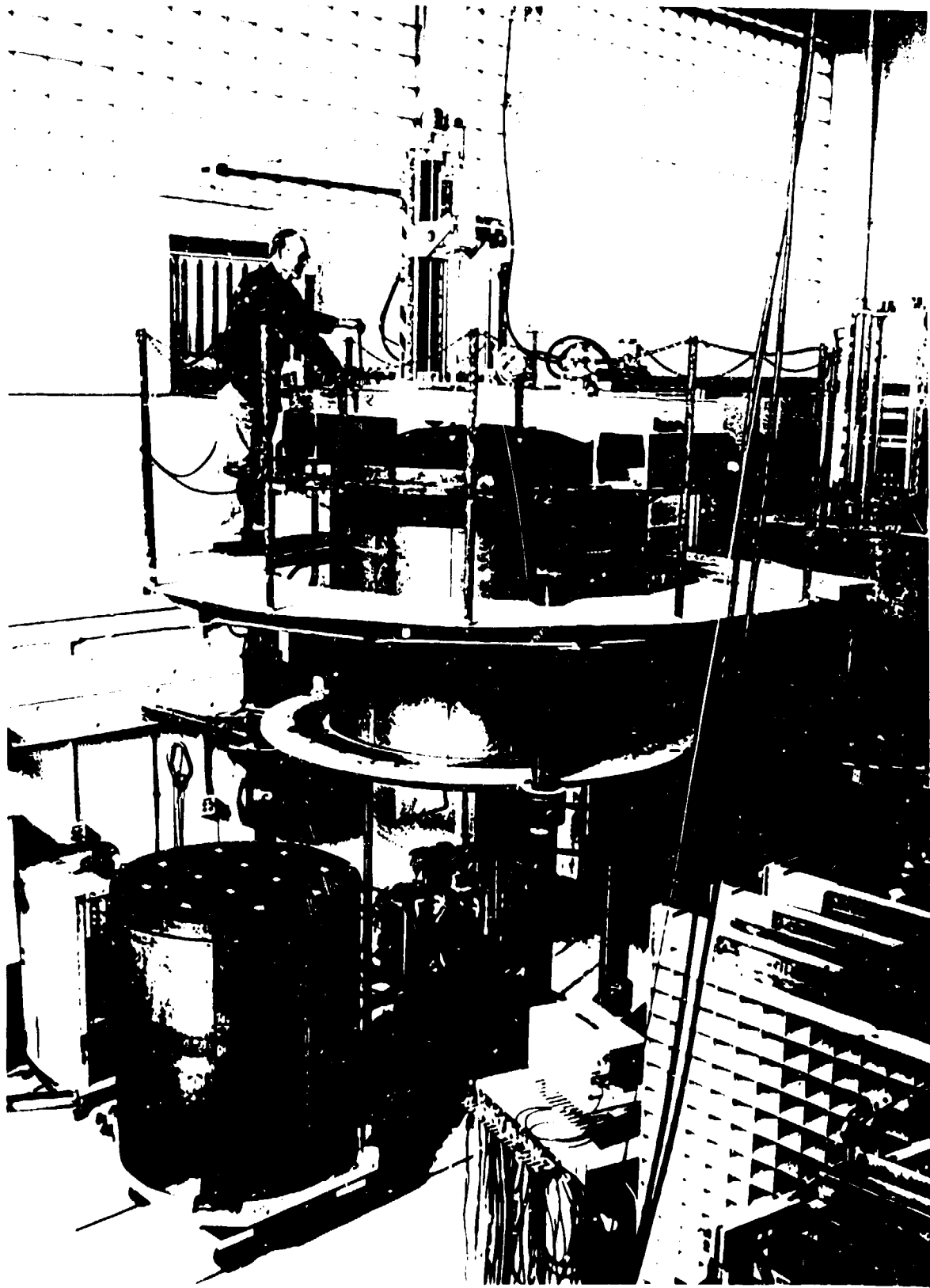


Fig. 1. Photograph of the assembly area for the U^{235} Mock up taken just prior to the loading of fuel.

insertion of the shim 628 mm into the core, required filling the central-most 396 fuel channels.

A fully loaded critical configuration was: all 492 fuel channels filled, the stainless steel pipes in the 12 heat pipe channels, a 650 mm-length of normal boron rods (starting at the bottom of the core blocks 30 mm below the fueled core bottom) in the north, east, and west control rod channels, and the shim inserted 356 mm into the core.

Table I gives neutron lifetimes, safety rod worths, and shim worths for the clean and fully loaded core configurations. Neutron lifetime, L , was inferred from Rossi α measurements in the vicinity of delayed critical, which gave β_{eff}/L , and the calculated¹ value, $\beta_{eff} = 0.00737$. The directly measured values of β_{eff}/L were used in the Inhour Equation to obtain reactivity versus stable positive period and thence the shim calibrations presented in Figure 2. The worths of the safety rod (the "demo-unit" central control rod) were determined by the rod-drop method where neutron detectors monitor count rate before the drop (in this case a pneumatically driven drop) and either during the drop or after the drop: results obtained from internal detectors monitoring count rates before and during the drop and results from external detectors monitoring count rates before and after the drop were in good agreement. The worths of the shim were determined by integration of the differential worths.

Table II gives material worths in the clean and fully loaded cores. The polyethylene was inserted into the replacement channels in steps of 4 rods and the worth per rod decreased monotonically with the total mass inserted. The values given in the table are for polyethylene rods in all 20 material replacement channels.

Figure 3 gives the observed dependence of reactivity on temperature in the fully loaded core. For this measurement, 18 thermocouples sampled the temperature distribution in the core. With the ram down, calorods near the radial surface of the core (all covered by an aluminum foil tent) heated the core to about 80C at which time the calorods and aluminum foil were removed. After assembly, critical shim position and thermocouple readouts were tracked during a 4 hour cooling period. Strictly, core temperature means average core temperature as determined from the 18 thermocouple readings. Calculations¹ had indicated that the dependence of reactivity on the reflector temperature was very weak and we had no thermocouples on the reflector surfaces.

The CNPS was designed to give equal heat loads to the 12 heat pipes under operating conditions. Although not a good check, enriched uranium foils placed along the outer walls of the stainless steel pipes were irradiated and their activation measured. Results are given in Table III.

ACKNOWLEDGMENTS

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REFERENCES

1. RONALD G. PALMER, "Postanalysis of the CNPS Critical Experiment", These Proceedings.

Table I. Neutron lifetime and Control Rod worths

	<u>Clean Core</u>	<u>Fully Loaded Core</u>
Neutron lifetime	0.57±0.01 ms	0.31±0.02 ms
Central Control Rod worth	7.6 \$	4.3 \$
Shim worth	3.0 \$	2.5 \$
Central Control Rod worth with enriched (54.9% ¹⁰ B) B ₄ C		4.8 \$

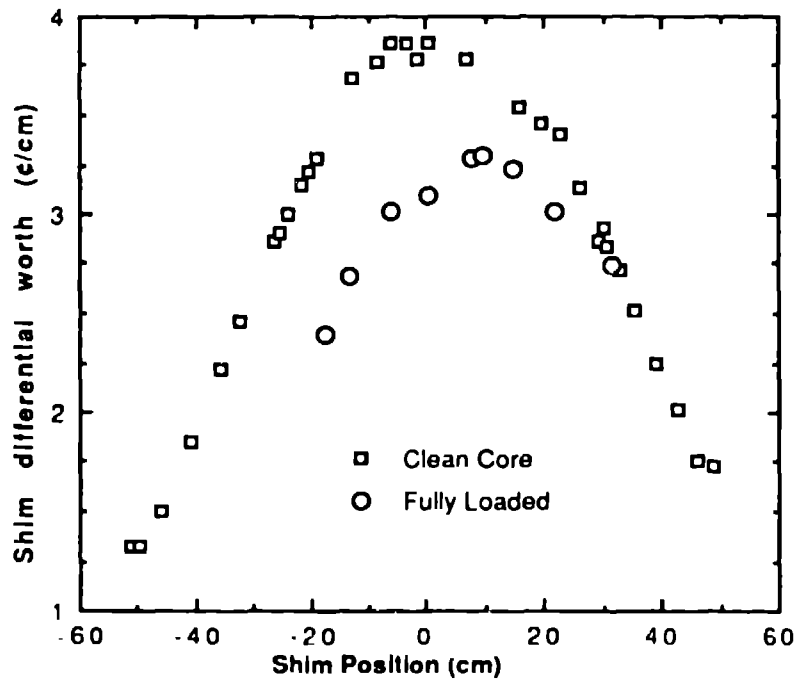


Fig. 2 Shim differential worth

Table II. Material worths

<u>MATERIAL and LOCATION</u>		<u>WORTH (cents/kg)</u>
CLEAN CORE		
Graphite	in central replacement holes	10.7
BeO	in " " "	13.3
1/4" POLY	in " " "	294
3/8" POLY	in " " "	266
Zirconium	in inner heat pipes	-3.9
Zirconium	in outer heat pipes	-1.4
316 SS	in inner heat pipes	-36.7
316 SS	in outer heat pipes	-22.0
Fuel Compacts	at core radial surface	50.0
FULLY LOADED CORE		
Fuel Compacts	in central replacement holes	11.4
Depleted Fuel	in " " "	-15.6
3 mil ²³⁵ U foil	" " "	226
Fuel Compacts	at core radial surface	10.5
Graphite	at core radial surface	2.3
Graphite	at reflector radial surface	0.5

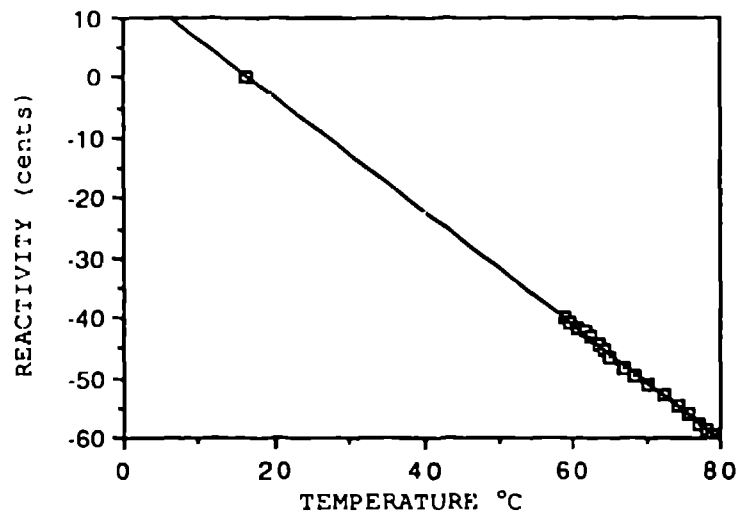


Fig. 3. Reactivity dependence on temperature in the fully loaded core.

Table III. ^{235}U activation in heat pipe holes

Z (cm) / θ	outer core heat pipes				inner core heat pipes	
	$\pm\pi/8$	$\pm 3\pi/8$	$\pm 5\pi/8$	$7\pi/8$	$\pm\pi/4$	$\pm\pi/4$
45	1154 \pm 05	1184 \pm 13	1201 \pm 07	1194 \pm 05	1570 \pm 20	1644 \pm 04
15	1390 \pm 11	1363 \pm 10	1349 \pm 08	1333 \pm 05	1778 \pm 04	1789 \pm 09
-15	1312 \pm 08	1212 \pm 10	1170 \pm 20	1148 \pm 08	1586 \pm 04	1411 \pm 11
-45	886 \pm 06	796 \pm 24	768 \pm 11	748 \pm 04	1102 \pm 04	994 \pm 11
Est. Average over core length	1207	1158	1140	1123	1532	1479

Note: Z denotes the vertical position of an activation foil relative to the core center and θ denotes its azimuth relative to the shim.
 The arbitrary normalization of activation was to gamma counts per minute per gm of foil, 22 hours after irradiation.
 The distribution of boron carbide in the core tilts the fissioning flux upwards and slightly towards the shim.