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ML-1 NUCLEAR POWER PLANT
INITIAL POWER TESTS

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AEROJET-GENERAL NUCLEONICS

ML-1 NUCLEAR POWER PLANT

INITIAL POWER TESTS

This paper describes the early testing, including the Initial Full Power Test, of the ML-1 Nuclear Power Plant. This effort was performed at the National Reactor Testing Station in connection with development of the ML-1 for the Department of Defense under contract with the U. S. Army Corps of Engineers and the U. S. Atomic Energy Commission.

The ML-1 is the prototype of a mobile nuclear power plant which is capable of trailer, flatcar, or air lift transport and is designed to supply electric power at remote military installations. The power plant, consisting of three basic packages, is the merger of a high temperature, gas-cooled, water moderated reactor with a compact power conversion system. The system operates on a closed, direct cycle using nitrogen with .5% oxygen as a working medium.

FIGURE 1
(Mockups)

The first slide shows the full scale mockup of the two primary packages, coupled and mounted aboard an Army M-172 trailer, and the control cab on a 2-1/2 ton truck. Total power plant weight is something less than 40 tons.

In addition to supporting the reactor, which is the plant's only heat source, the reactor skid contains the moderator pumps and the shield circulation system. The reactor is a heterogeneous water-moderated type, fueled with enriched UO_2-BeO. The core has 61 pin-type elements, each located in a pressure tube. The pressure tube connects the upper and lower plenum chambers to form the pressure vessel. Moderator water surrounds the pressure tube and is circulated through each tube sheet and around the pressure tubes for cooling.

The reactor core shielding and pressure vessel assembly are enclosed in a tank containing borated water. This tank is approximately nine feet in diameter and about eight feet high. The power conversion skid houses the turbine-compressor, reduction gear, alternator, start motor and all switch gear associated with the power plant. In addition, it houses the two major heat exchangers, the recuperator and precooler. The third major package, the control cab, contains all the controls and instrumentation necessary to remotely control the power plant. The control cab is normally positioned approximately 500 feet from the reactor-power conversion package.

FIGURE 2
(Inside Control Cab)

The power plant is designed to be operated with a seven-man crew on station utilizing a two-man shift plus an officer-in-charge.

FIGURE 3
(Cycle Schematic)

This is a schematic of the power cycle. Gas leaves the reactor at 1200°F and approximately 300 psia to drive the two-stage, axial flow turbine. Heat in the turbine exhaust gas, not transferred in the recuperator, is rejected in the aluminum precooler. The cool gas at low pressure is compressed nominally to a pressure ratio of 2.7, recovers heat in the recuperator, and enters the reactor at about 800°F. Speed control is effected by a bypass arrangement which allows up to 20% of the total gas flow (26 lbs/sec) to dump into the precooler inlet from the compressor discharge without passing through the turbine.

Temperature control (reactor control) is effected by six pairs of semaphore type control blades which move in vertical planes in the moderator water between reactor pressure (fuel element) tubes.

Following several months of low power (<10 kw) reactor tests,[1] the reactor skid was mated with its power conversion skid to provide for integrated power plant test operation.

FIGURE 4
(Startup Profile)

The power plant was initially brought to power in step-wise fashion as illustrated in this startup profile. Self-sustained operation was attained as predicted, at 1/2 speed and at about 1150°F turbine inlet temperature. During the initial ascension to power, reactor outlet temperature was limited to 1150°F in order to limit reactor upper tube sheet temperature to below 550°F. Post test investigation indicated that the high reactor tube sheet temperature was due to bypass coolant gas flow around the fuel element assemblies which exposed the upper tube sheet directly to gas at inlet temperature. The tube sheet temperature limit is dictated by high stresses imposed by high thermal gradients through the tube sheet between the uncooled surfaces and the internal surfaces which are cooled by forced circulation of relatively cool (<190°F) moderator water.

Bypass flow around the fuel elements was corrected by installing stainless steel (321) "O" ring-type gaskets under the fuel element seats, and incorporating provisions to apply a positive seating force on top of the vertically suspended fuel elements. This "fix" was incorporated with the reactor flooded to provide radiation shielding.

The ML-1 Full Power Test, the second ascension to power, was initiated on 27 February 1963, and successfully completed after over 100 hours of continuous high power operation. Test data indicate that the fuel element bypass flow "fix" was completely successful.

TABLE I

(Selected Test and Design Data)

Table I compares actual performance data with predicted and design data. The major performance perturbation which reduced gross electrical power output to below design value (400 kw(e)) was low compressor efficiency which is attributed to known correctable aerodynamic deficiencies in the turbine-compressor.

One surprise encounter involved the effect of relatively large thermal inertia of the system.[2] Analog studies had alerted us that these effects would be present but we did not visualize their magnitude. On the initial attempt to reach rated speed, the operational plan called for gradually increasing turbine speed using reactor outlet temperature as the controlling parameter. With the system near equilibrium at 50% speed and 1100°F reactor outlet temperature, the induction start motor was secured.

FIGURE 5
(Recorder Chart)

The speed trace on this slide shows what happened. The gas turbine proceeded to accelerate slowly to near rated speed (22,000 rpm) without increasing reactor power. Needless to say, the speed control bypass valve was used to provide speed control during the next attempt to reach rated speed. The other two curves represent data from a linear power recorder strip chart together with data from the fuel element temperature recorder during the speed transient. The indications are clearly consistent with a slight negative fuel element temperature reactivity coefficient. Although the fuel temperature coefficient had been determined to be small, the exact magnitude or sign had not previously been clearly defined.

The compact solid state control system performed satisfactorily without causing any scrams during the entire operation. Shield performance was completely satisfactory.[3]

Subsequent to the 100-hour limited endurance operation, the reactor pressure vessel developed a leak which allowed high pressure gas to enter the moderator water system. The leak is believed to be below the tube bundle and disassembly of the reactor pursuant to repair is now in progress.

REFERENCES

1. R. H. Chesworth/C. M. Rice, "Initial Test Results from the Army's Mobile Low Power Nuclear Power Plant (ML-1)," ASME Paper 61-WA-306

2. R. D. Peak, "Reactor Thermal Inertia - Turbine-Compressor Acceleration," AGN Internal Memorandum OID-472, 14 February 1963

3. N. K. Sowards, "The Development and Design of a Biological Shield for ML-1, A Mobile Gas-Cooled Nuclear Power Plant," Transactions of ANS, December 1960, San Francisco

MOCKUPS

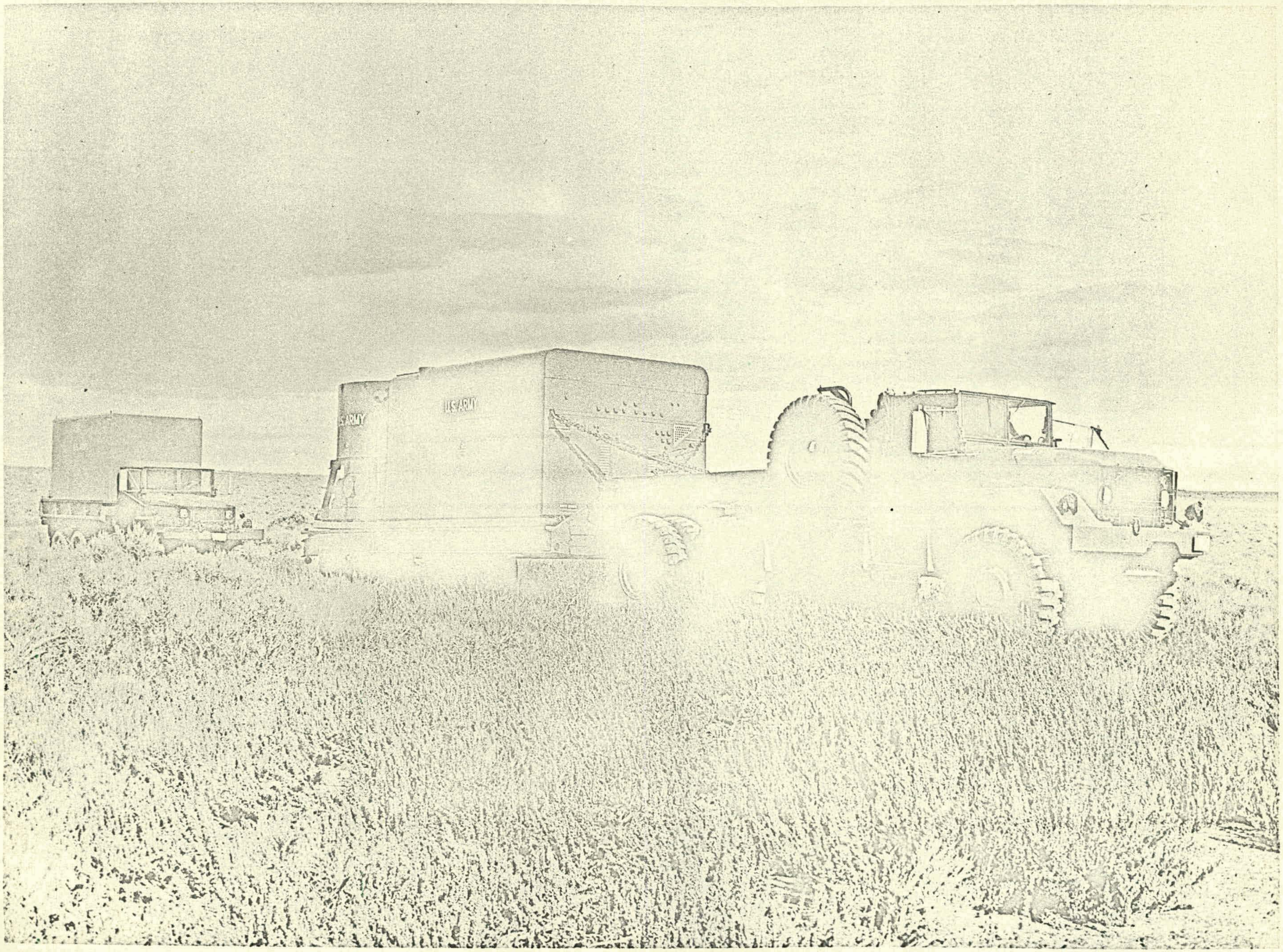
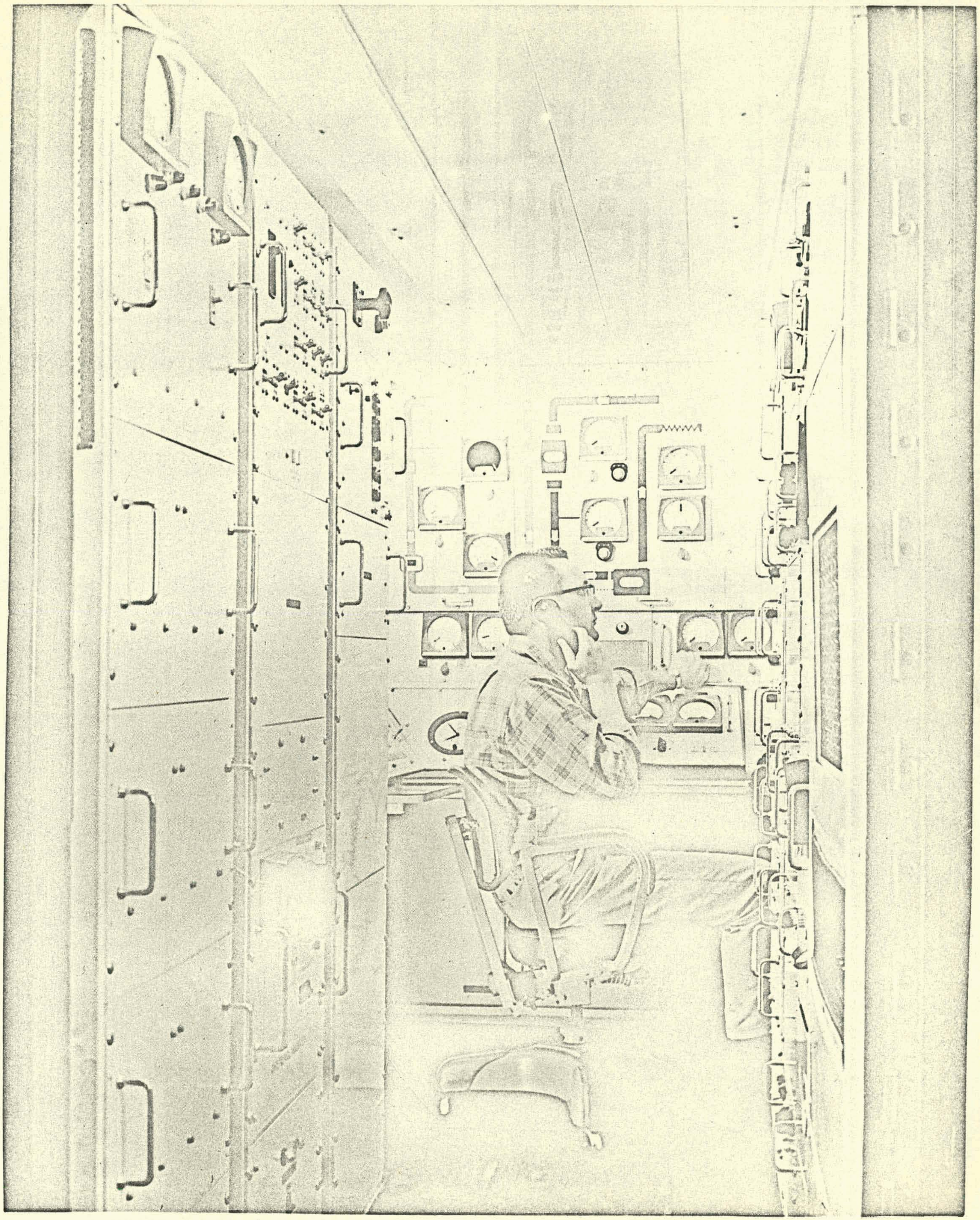


FIGURE 1

INSIDE CONTROL CAB

FIGURE 2



ML-1 NUCLEAR POWER PLANT CYCLE DIAGRAM

FIGURE 3

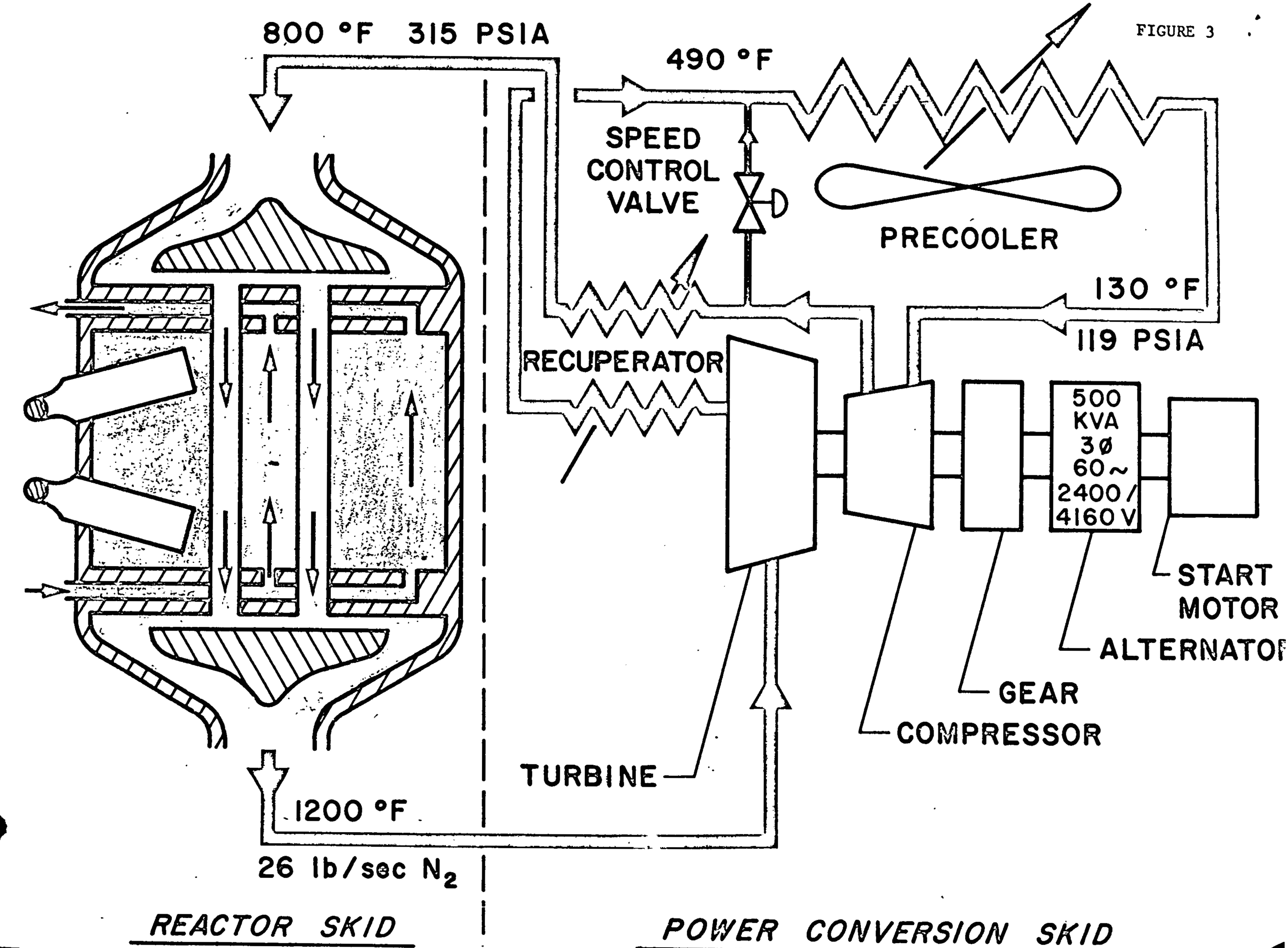
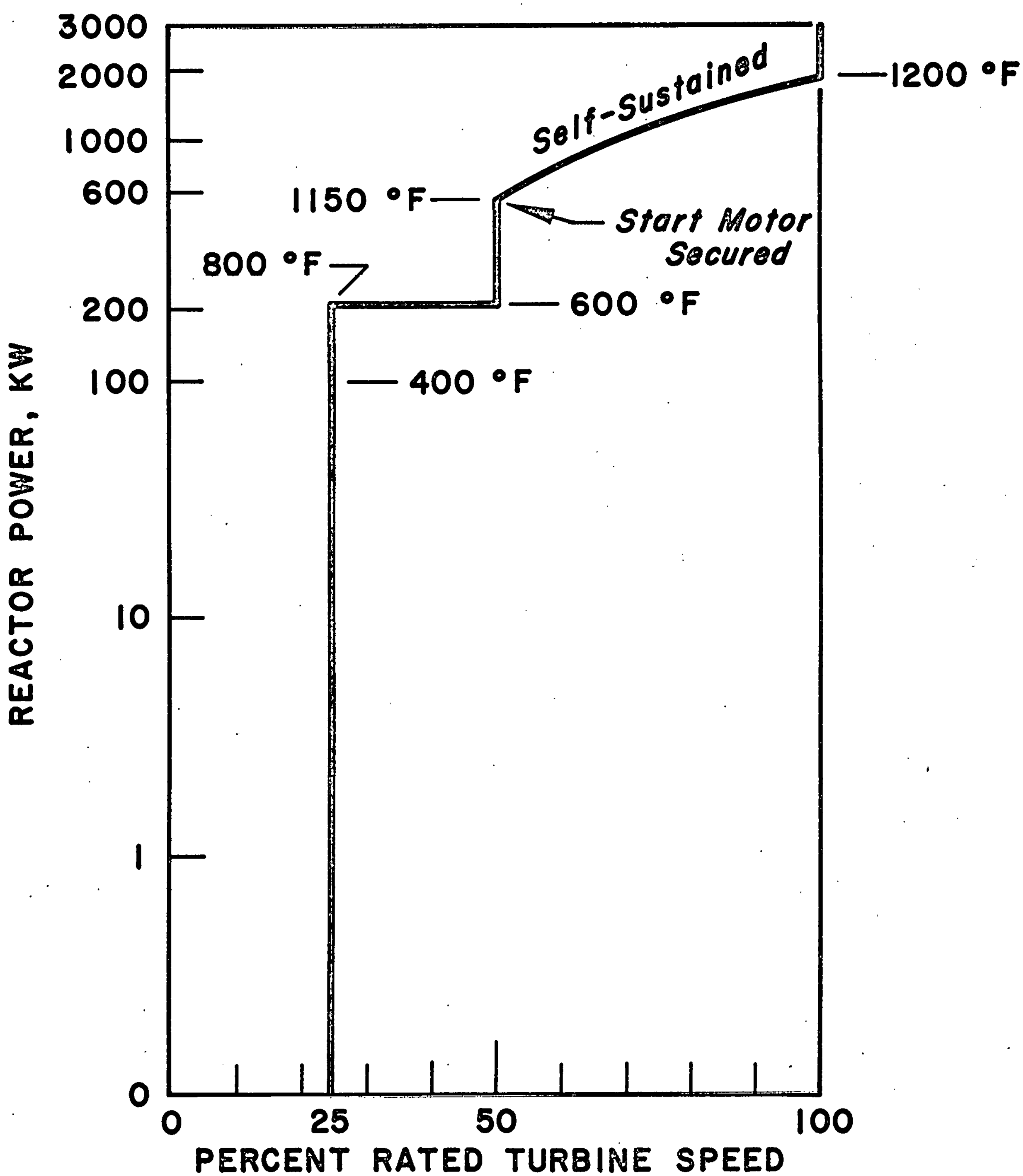


FIGURE 4

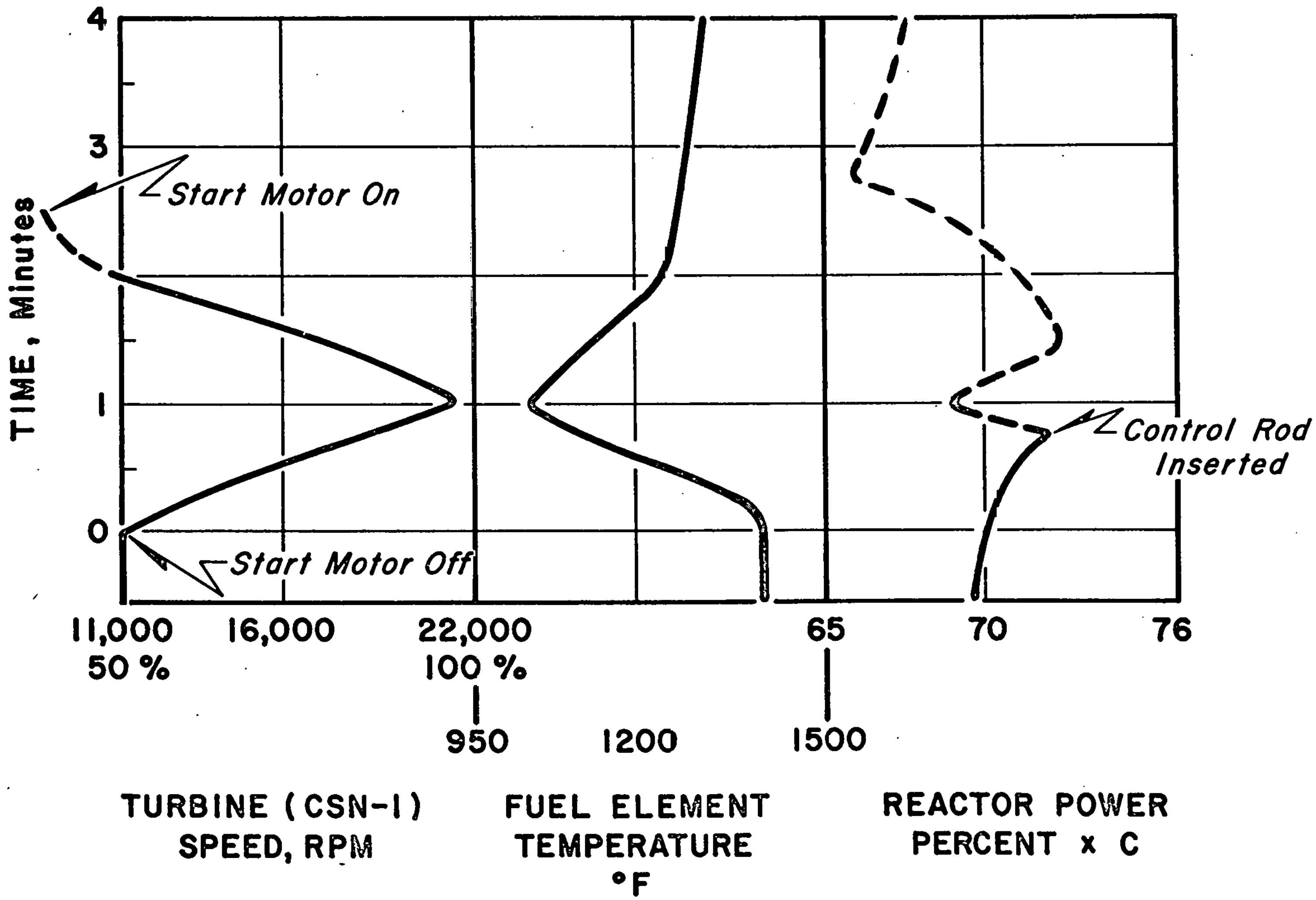
ML I NUCLEAR POWER PLANT START UP PROFILE



ML I NUCLEAR POWER PLANT

FIGURE 5

INITIAL SELF SUSTAINED OPERATION
SYSTEM TRANSIENT REFUELING
THERMAL INERTIA



R.D. Peak, OID-472 14 FEB, 1963
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TABLE I. Selected Test and Design Data

Parameter	Design	Actual March, 1963
Max. Reactor Power	3.3 Mw (th)	3.2 Mw (th)
Max. Shaft Power	400 Kw	250 Kw [a]
Reactor Outlet Temperature	1200 °F	1199 °F
Compressor Inlet Pressure	120 psia	120 psia
Reactor Inlet Pressure	315 psia	274 psia
Reactor Pressure Drop	7.2 %	4.6 %
Reactor Upper Tube Sheet Temperature	466 °F	445 °F [b]
Control Cab Radiation Level	5 mrem/hr	1.4 mrem/hr

a. Due to low CSN-1 compressor efficiency (77%).

b. After incorporation of fuel by-pass flow "fix."