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The Development Philosophy for SNAP Mechanisms*

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Mechanisms used in the control of SNAP (Systems for Nuclear Auxiliary Power) reactors face a life of many years in a hostile environment of high temperature (1000° F), high radiation (10^{20} nvt), and space vacuum (10^{-13} torr) without maintenance. The development approach for these mechanisms could either have been one of creating a congenial environment by a secondary support system or of producing mechanisms capable of direct operation in the hostile environment. For the SNAP reactors it was decided that this latter approach gave the highest overall system reliability.

This paper discusses this direct approach concept to hardware development and describes the steps taken for the successful development of the SNAP reactor control system mechanisms. The resulting whole new family of state-of-the-art mechanism components, such as actuators, bearings, gears, springs, limit switches, and position sensors, is briefly described.

The SNAP 10A system was successfully flown in 1965, and the SNAP 8 system is being readied for ground test later this year.

I. Introduction

During the last ten years, the Atomics International Division of North American Rockwell has been engaged in the development of the SNAP (Systems for Nuclear Auxiliary Power) reactor systems for the Atomic Energy

Commission. These are compact, liquid-metal-cooled, nuclear reactors coupled to various power conversion systems. The SNAP 10A system (Fig. 1), which was successfully flown in April 1965, was coupled to a thermal electric power conversion system and produced 500 W of electrical power. The SNAP 8 system, which is being readied for ground test later this year, will produce 700 kW thermal, and, when coupled to a mercury rankine

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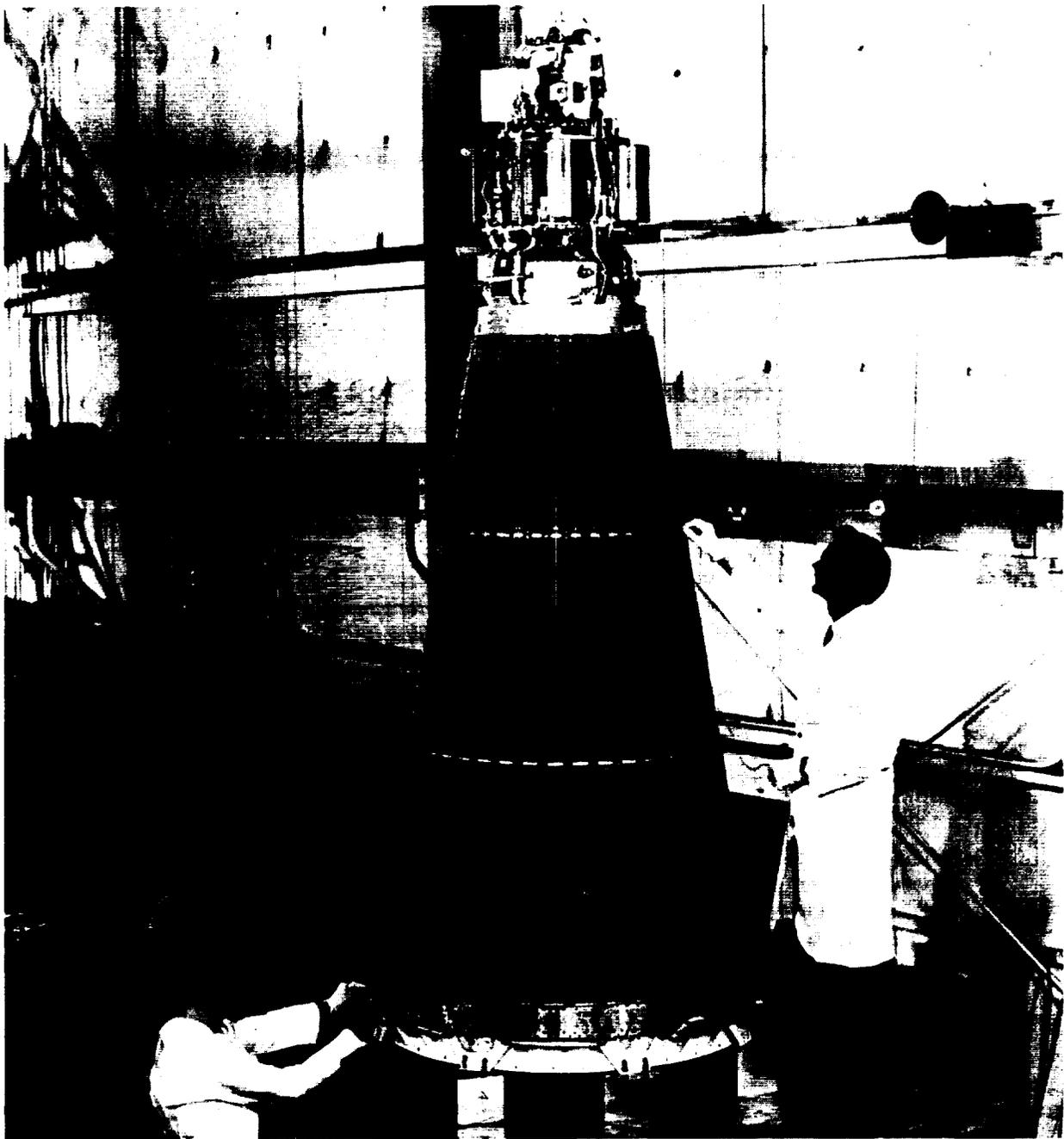


Fig. 1. SNAP 10A system being acceptance-tested prior to its successful space flight in April 1965

power conversion system, will produce 70 kW electrical power. If it is coupled to a thermal electric system similar to the 10A system, it will produce 15 kW electrical power.

II. Description of SNAP Reactors

These SNAP reactors provide a very strenuous environment in which mechanisms must operate, including space vacuum, high temperature, and high nuclear radiation after being subjected to launch, shock, and vibration. No repair or maintenance is possible during the several years that these nuclear reactors are operating. Size, weight, and reliability are naturally of prime importance. For weight consideration, it is desirable to omit or minimize both thermal insulation and nuclear shielding between the mechanism and the reactor. The components in close proximity to the reactor receive a radiation dose as high as 10^{20} nvt (fast neutrons) and 10^{11} rad (gammas) during a one-year period. The thermal heat generated by the reactor results in mechanism temperatures from 1000°F, near the bottom of the core vessel, to 1300°F at the top.

Because of space startup of the reactor, the mechanism must operate from subzero temperatures to the high steady-state temperatures above. Structural integrity, dimensional stability, and frictional characteristics of the mechanism must be kept within functional tolerances. Design requirements are further complicated by the vacuum of outer space. Exposed surfaces become "super" clean, providing opportunity for contacting surfaces to vacuum-weld together. The launch imposes shock loads up to 35 g, with accelerations to 100 g. Random noise vibrations can result in peaks up to 50 g, depending upon the launch vehicle.

The SNAP 10A and SNAP 8 reactors are cooled by liquid metal (NaK) and have homogeneous uranium hydride fuel (Fig. 2). The reactors are controlled by increasing or decreasing the leakage neutrons with external Be reflectors. The reflectors are semicylindrical drums that surround the reactor core vessel and rotate toward the core or away, as required.

III. The SNAP Reactor Control Mechanism

The reactor control mechanism is composed of an electromagnetic actuator that rotates the drums through a gear train upon command from an electronically pro-

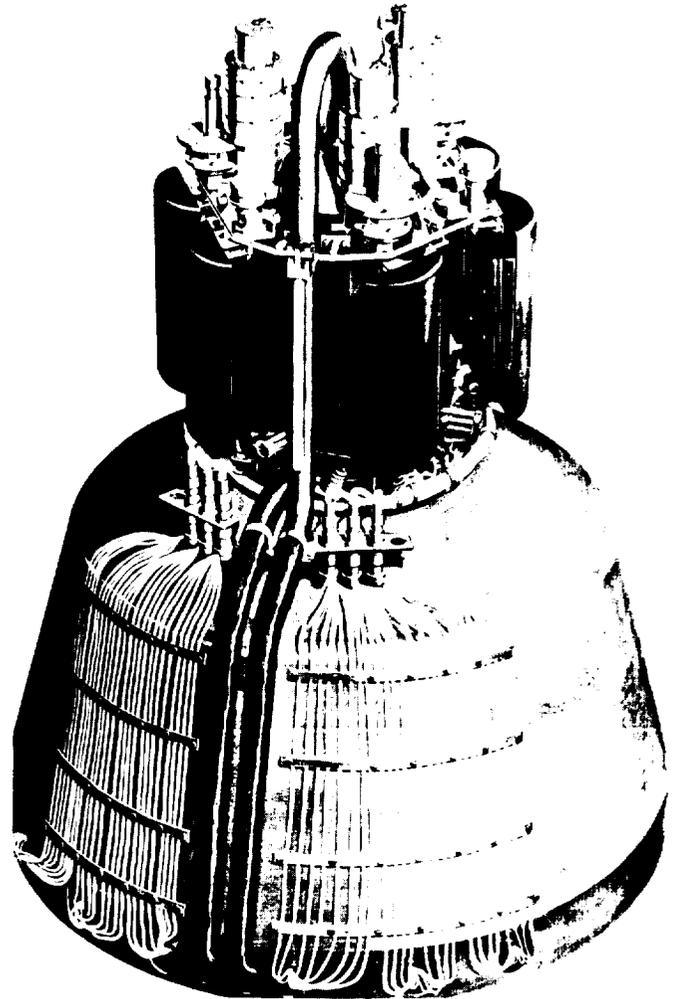


Fig. 2. Artist's sketch of the SNAP 8 reactor

grammed controller, along with the necessary auxiliaries such as position sensors and limit switches.

As soon as the space vehicle is in an established orbit, a ground command signal initiates reactor startup (Fig. 3). The electromagnetic controller is energized and controls the system by a programmed sequence of signals to the control drum actuators.

The direction, rate, and order of stepping action are preset in the programming. The coarse control drums are released and rotate to the full-in position. At this point the reactor is still subcritical, and the three fine control drums then start their rotation inward. Each drum is stepped sequentially.

During the startup, there are several preset rotational rates, with the rates decreasing as the reactor becomes

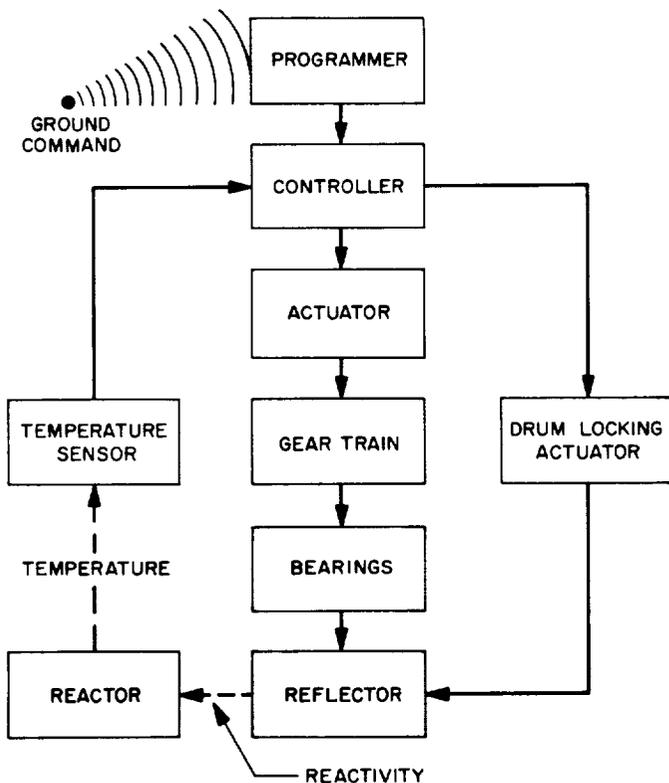


Fig. 3. SNAP 8 control system logic

critical and temperature or heat generation is established. When the reactor power level reaches the desired temperature, negative reactivity is introduced as a result of the temperature coefficients of the grid plate and fuel, thus dampening the power transient. After the initial temperature transient there is a gradual rise in power, with corresponding rises in the system temperature and coolant flow. This process continues until the reference temperature is reached. The temperature sensors then signal the controller, and the power to the control drum actuators is stopped. When the reactor outlet temperature varies from the design reference temperature, a temperature sensing switch signals the controller and the actuators step the drums to correct the reactivity.

IV. Design Philosophy

The detailed explanation of how this control system operates was given to show its simplicity. It is readily apparent that a mechanism to perform this function could have taken the form of a hundred different designs. The question is, then, why this one?

In the development of the control mechanisms for the SNAP reactor, we have established three basic philoso-

phies. The first of these is that we accept the fact that the shortest, most direct route to achieving the end objective may not be a direct line through the normal way of doing something. Second, the reliability is generally increased by the elimination of backup systems and by the reduction of the number of parts. Third, the fastest and least expensive development program is one that proceeds methodically from the understanding of the details to the evaluation of the completed assembly.

Let me illustrate each of these points. For the first, let us take the prime mover for our mechanism. We had available to us, from the prime system bus, both dc and 400-Hz ac. The rate of movement of the control drum for nuclear purposes is $\frac{1}{2}$ deg every 240 s. The generally accepted small prime mover for space applications is a high-speed ac motor, with 400 Hz being a common frequency. Were we to use a 4-pole, 400-Hz motor and a straight gear train reduction, we would end with a gear train with a ratio of two billion to one. Even if we were to use an 8- or a 12-pole motor, we would not have helped the situation significantly. Were we to pick some lower frequency, we still would end with a massive gear reduction system and still have a nonstandard prime mover.

If, however, we do not hamper our thinking by too much familiarity with how others are designing their space prime movers, but look at the basic end objectives, we quickly reach a different solution.

In the development of the hardware for the SNAP reactors, the starting point was a clear definition of the end functional requirements. The solution was then determined by the simplest and least amount of equipment to provide this function. In the point in question, the requirement is to move the control drum through small, incremental steps. The available power source is dc or 400-Hz ac. The objective is to couple these two points with the least number of incremental active components.

A dc stepper motor, with time delays between steps, represented the simplest approach. This solution circumvented many of the major problems such as lubricating the high-speed bearing and gears, the self-welding of rubbing parts, and high-speed position feedback. When this decision was reached, back in 1959, the dc stepper motors were far from the refined and widely used devices they are today.

By applying this same philosophy in the stepper motor design ("what is the basic physical law?" rather than

"what is the standard design?") it has been possible to convert the dc stepper motor from a device that produces about 2.5 in.-oz/lb at room temperature to one that produces 24 in.-oz/lb at temperatures as high as 1300°F (Fig. 4).

This has been accomplished by such unorthodox design changes as the elimination of the permanent magnet rotor and the bifilar winding normally used. A design change giving the stator and rotor each the same number of teeth and moving these torque-producing teeth to the outside periphery has resulted in the greatest incremental torque increase. The development of a technique for wet winding the coils has allowed the fabrication of units with high reliability for long life at over 1200°F.

The second point can best be illustrated by the development of components to operate directly in their normal

environment. The alternative approach would have been to supply an artificial environment, less hostile to the component, by an auxiliary system: that is, to enclose the components within a sealed envelope, so that they do not see the vacuum environment, and to supply them with auxiliary cooling. This, however, results in the system reliability being a product of the reliability of the prime component and of the auxiliary system. Our experience has shown that our system reliability decreases with each additional item of hardware.

The third point is that of an orderly development program. The development program for the system components has proceeded from the detail material or component development testing, through the subassembly testing, and then to a prototype test. One illustration of this is bearing development (Fig. 5). When the

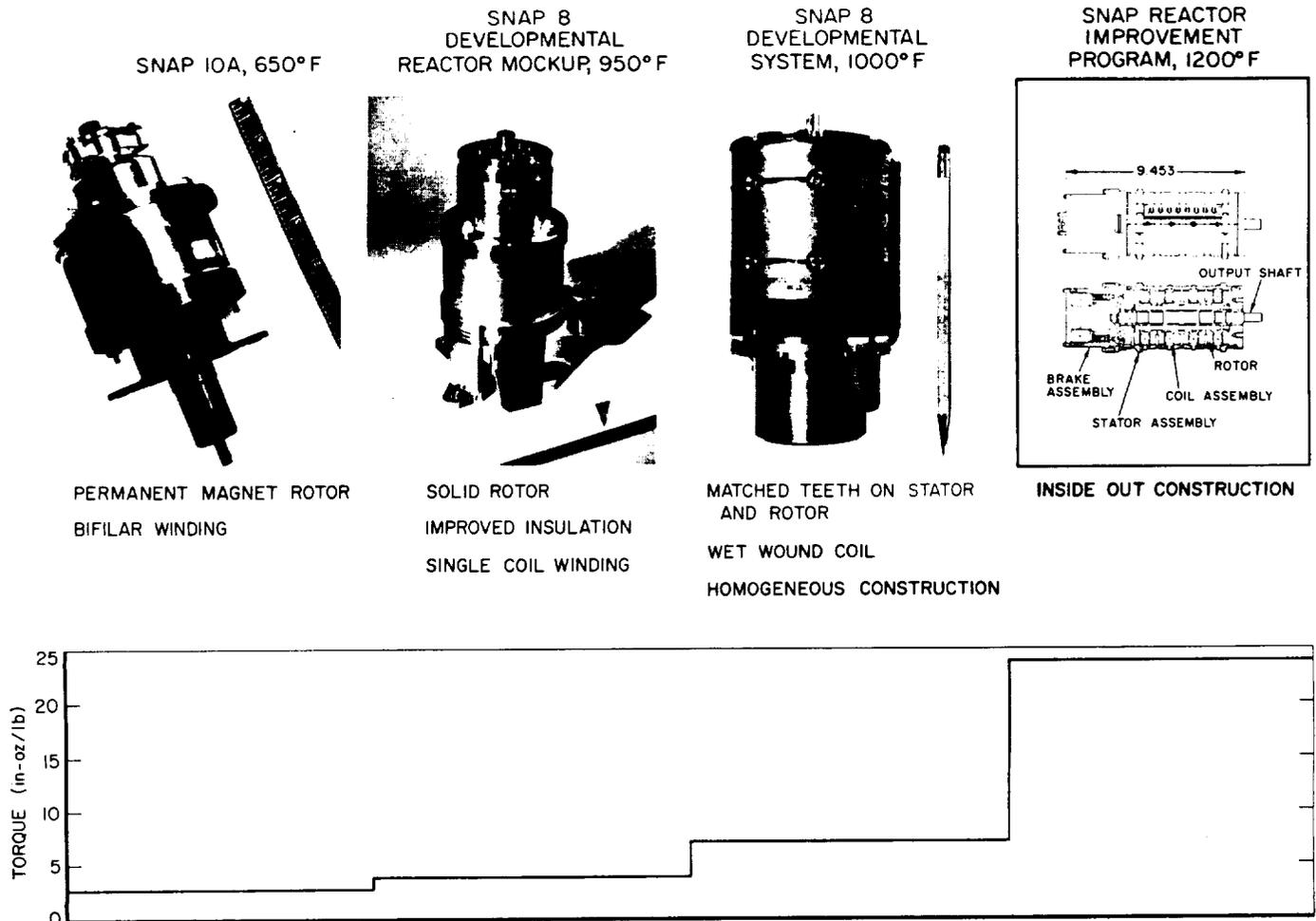


Fig. 4. Development of the dc stepper motor

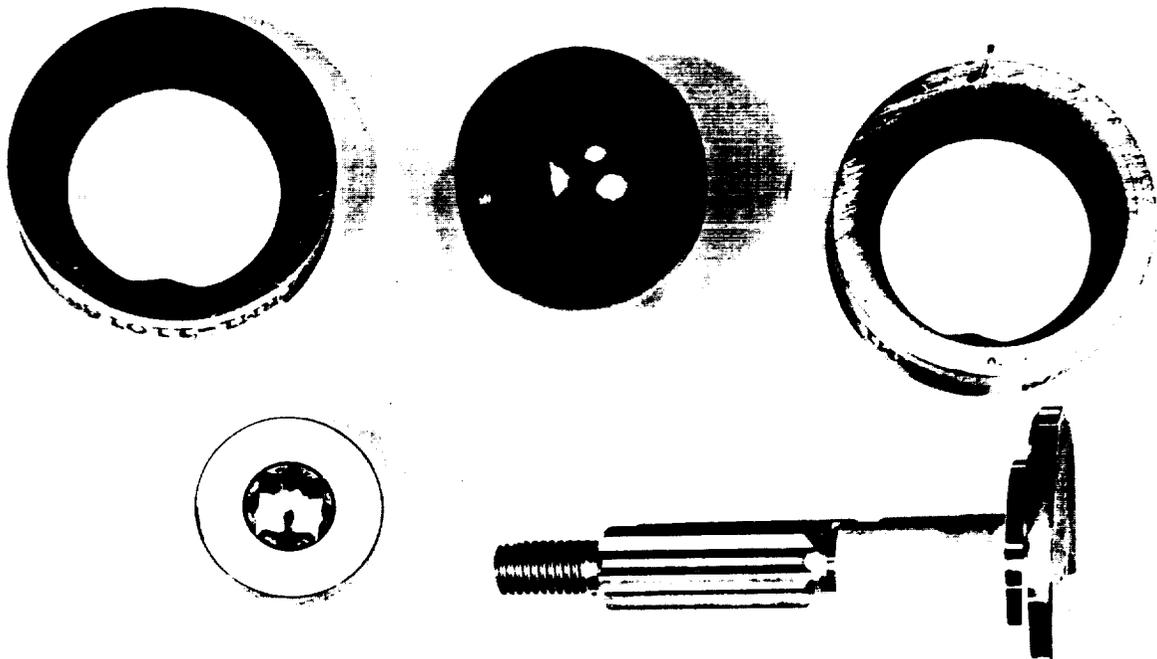
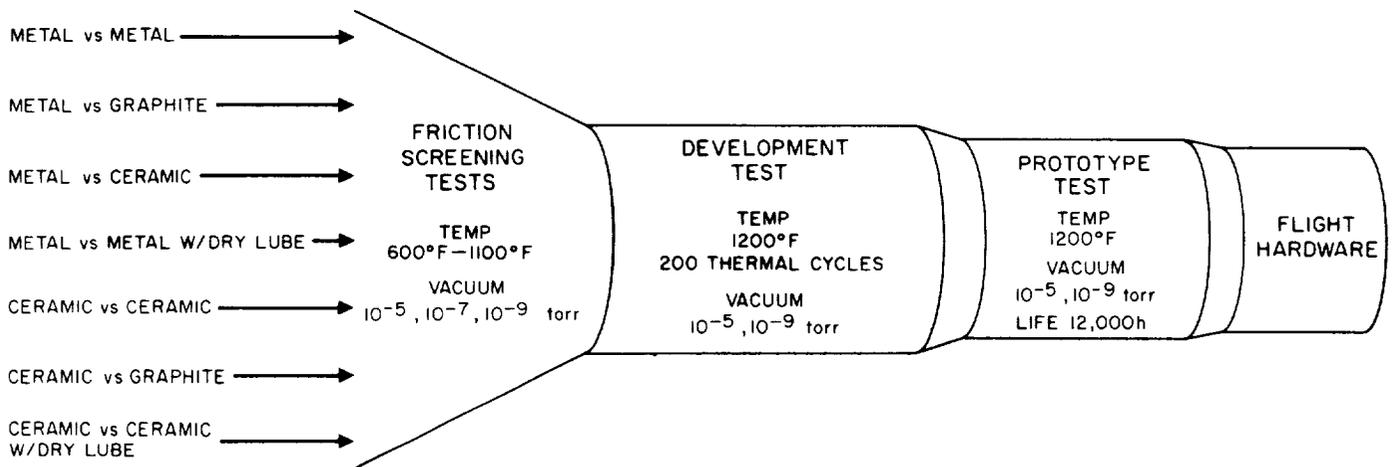


Fig. 5. Bearing material development

program started, no information was available on the friction of materials at 1000 to 1200°F in a vacuum environment. The initial tests were, therefore, material friction and self-adhesion tests. About 100 material combinations were tested to determine the ones with minimum friction and the least tendency to self-weld. Next, developmental bearings of the most promising materials were constructed and tested to verify the design calculations. Finally, prototype bearings were made and tested, under simulated conditions, for the full life requirement.

V. Thermal Environment

Because we have found that the thermal environment is the most strenuous, all prototypes are tested at 100° above the calculated operating temperature and to four times the expected thermal cycles. For the SNAP 8 reflector bearings, which are expected to operate at 1100°F and which are expected to experience 50 thermocycles during their life, prototype tests are conducted at 1200°F and through 200 thermocycles.

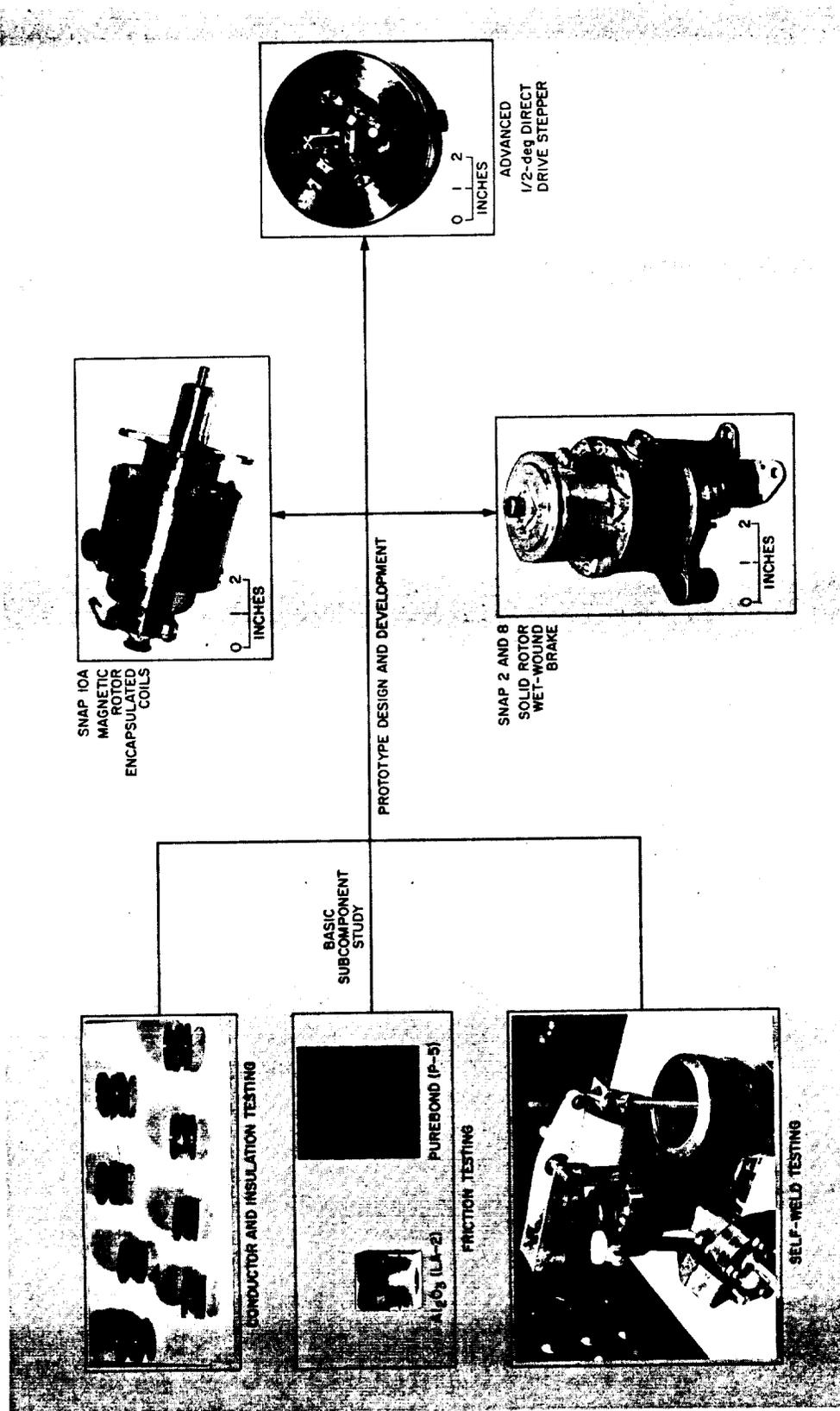


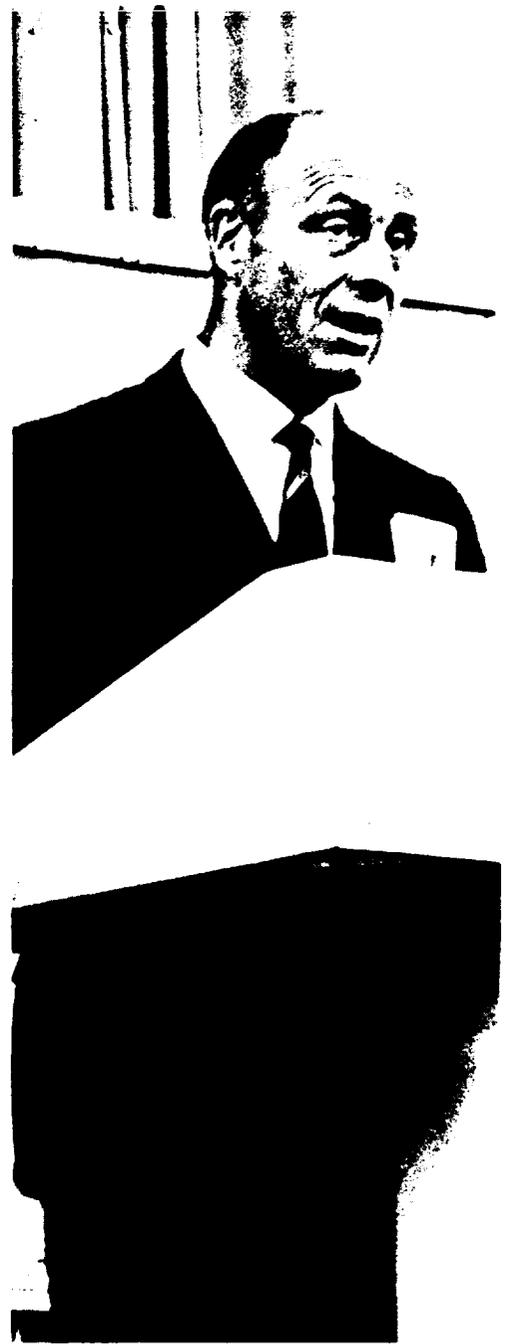
Fig. 6. Composite development plan, where component development is a common basic program to support current and proposed reactors, and the goal is maximum technology growth with minimum duplication

A more general illustration is shown in Fig. 6, where basic development tests on electrical conductors, high-temperature insulation, bearing friction, and self-welding are used as a foundation for the actuator prototype development.

VI. Flight Test Experience

The soundness and adequacy of this development approach is well illustrated by the SNAP 10A flight test.

During the preparation for launch and the count-down, not a single halt was caused by the reactor mechanism. During the 43 days of space operation, the reactor control mechanism functioned perfectly. (Paradoxically, it was the perfect functioning of the mechanism that resulted in the early shutdown of the reactor, when a spurious telemetry signal falsely triggered the "end-of-life" shutdown portion of the mechanism.) Similarly, perfect results have been achieved on ground tests where the space reactor systems have operated in similar environments for over a year.



Session II

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