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"Integral Reactor Tests in Project Rover"

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Tests of reactor systems operated at design power, or integral tests, have played a major role in the development of nuclear rocket propulsion systems for space application. The emphasis placed on such tests as a development tool arises from both technical and economic considerations. From a technical standpoint, the reactor development program has required considerable extensions of the state of the art in the fields of material properties, cryogenics, neutronics and control techniques, heat transfer, and mechanical design.

Because of the many new techniques involved and the exploratory nature of the program, it has proved difficult to separate the real from the imagined problems without conducting integral tests. Attempts to define test vehicles other than a Rover reactor which would provide the various environmental factors simultaneously, such as intense nuclear radiation fields, high thermal gradients, and a high-temperature hydrogen atmosphere, have been unsuccessful because of the high cost in dollars and development time required and the difficulty in determining other important environmental factors, such as vibration fields, which have proved to be equally important.

These considerations have lead to a program in which component testing and integral reactor tests are conducted in parallel. The information obtained from the integral tests is used to modify the component design and testing procedures.

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Rover reactors are tested at the Nuclear Rocket Development Station in Nevada (NRDS). After a criticality check at Los Alamos, the reactor components are shipped to the Maintenance, Assembly, and Disassembly facility, or MAD building, at NRDS. In the assembly bays the instrumentation is added, the reactor assembled and mounted on a test car, and wiring and pressure check-outs conducted. The reactor is then transported to a test cell by a radio-controlled electric locomotive which will also retrieve the reactor, after test firings have been completed, and return it to the disassembly bay at the MAD building. The assembly and check-out of a reactor requires from six weeks to two months.

The reactor is plugged into the test cell with a concrete plug mounted on the front of the test car, completing the heavy concrete shield wall of the test cell. This plug carries instrumentation and control connections, hydraulic lines, water cooling lines for the test cart, various high-pressure gas lines for purging and cooldown of the reactor, and a cryogenic propellant line. The test cell proper consists of a heavily shielded structure which contains the various flow systems with their associated control valves, hydraulic systems for valve and control drum actuation, and an electronic center for control and instrumentation signal conditioning and routing. Other structures comprising the test cell complex include a shielded pump room for the propellant supply turbo pump; two 55,000-gallon dewars for liquid-hydrogen propellant storage; high-pressure gas bottles to store 4-1/2 million standard cubic feet of various gases for room inerting, reactor cooldown and purging, and to provide energy for the turbine drive; and various test laboratories. The shielding is necessary to permit access to the flow system components after a test run and to protect electronic

equipment during a test. Nitrogen gas is used to inert the atmosphere within the shielded structures in order to prevent hydrogen leaks from causing damaging fires or explosions.

Modifications are in process to add two 500,000-gallon dewars for LH_2 storage, to increase the propellant flow capability, and to shield the facility from the reactor to permit operations at higher powers and for longer duration.

One of the difficult development problems from both a facility and reactor standpoint, which represented a large advance in the state of the art, was that of learning to handle liquid hydrogen at high pressure and high flow rates in a large complicated piping system and in the reactor system proper.

The test operations are controlled from a control point approximately two miles from the test cell complex. Control signals are sent from the control room over hard wire to the test cell, and data signals are received from the test cell in both a multiplexed and a direct-reading form. The direct-reading channels are displayed on meters and strip charts in real time to monitor the reactor and facility performance, while the multiplexed channels are recorded on magnetic tapes for subsequent data reduction. The control center also includes a 704 computer and data reduction center for this purpose.

An interesting feature of the control center is the use of simulators which permit a complete check-out of the facility reactor system and the operators' performance without actual operation of the reactor. The various system valves, reactivity control vanes, etc, are operated without flowing fluids or producing fissions. Electrical analogue signals corresponding

to these motions are fed into a number of interconnected analogue computers which in turn predict the signals that the various sensors measuring flow rate, reactor power level, and reactor temperature would produce. These signals are displayed to the operators exactly as they would be in a hot-reactor test. Using this technique, it has been possible to conduct eleven hot-reactor tests without compromising any test owing to a facility failure or a human error. The desirability of such procedures is evident when it is realized that a single reactor test can represent an investment of a year or more of effort and a number of millions of dollars which could be lost by a rather minor failure of a facility component or a mistake made by a technician.

Although the activity at the test cell for a hot-reactor run is mainly concerned with the reactor control and instrumentation check-out, facility check-out, neutronic and criticality calibration test, and the full-power test or tests, there are many fringe activities created by side experiments and safety considerations. The test cell area is under strict control while pre-planned check list operations are conducted for a period lasting three days including the test day. Meteorological forecasts are made and weather briefings held to assure that the test is conducted with winds blowing away from nearby inhabited areas in case a reactor is accidentally destroyed during a test, releasing its fission product inventory into the atmosphere, although this is judged to be a very remote possibility. Radiation effect experiments and dosimetry measurements are conducted next to the reactor.

Effluent monitoring for escaping radioactivity is carried out by airplanes with sensitive detectors and by portable ground stations in the test area. On some tests, animals have been stationed down wind of the reactor

on run day, and cattle feed has been exposed to the effluent and fallout and then fed to milch cows to determine the amount of radioactive iodine picked up in the milk.

These tests are performed to determine whether such reactor tests might create a health problem, rather than because of a belief that they are inherently hazardous. Information to date indicates that only in the case of a rather improbable accident with winds blowing definitely towards the heaviest inhabited area would there be any cause for concern.

After the planned reactor tests are completed at the test cell, a period of approximately one month, the reactor is retrieved by the radio-controlled locomotive and returned to the disassembly bay of the MAD building. This is a massively shielded room some 65 feet in height with 6-foot-thick concrete walls. Various remote-controlled and power-driven manipulators are controlled by personnel viewing the operation through 6-foot-thick windows of heavily leaded glass to provide radiation protection. Using these manipulators, a disassembly crew takes the reactor off the test car, removes the reactor core from the pressure shell, and transfers it to a core disassembly bay. Here the core is disassembled into its component parts which then undergo visual inspection and photography and are transferred to hot cells at either the MAD building or at Los Alamos. Many tests are conducted on the components to determine such information as structural integrity, amount of corrosion from the high-temperature hydrogen, the reactor power generation profile, and the core temperature profiles.

During the period of reactor disassembly and post-mortem, the data recorded on magnetic tapes from the instrumentation channels are processed by the data reduction center and issued as books of graphs giving the time history of the many parameters of interest. Many hundreds of temperature measurements are made on the core alone. These data are analyzed and cor-

related with the post-mortem data to give a detailed picture of the performance both of the reactor as a system and of all of its component parts. A typical test may produce 1200 channels of analogue data. While preliminary data analysis may be completed in two weeks, full post-mortem results require about two months to complete.

The information desired from a given reactor test may vary in detail, but in its broader aspects has included the following items:

1. Fission or power generation profiles. It is necessary to have as flat a power generation profile as possible in order to obtain flat temperature distributions. These distributions are different at full-power operation from those at calibration power level.
2. Structural integrity of the core and support system.
3. Degree of corrosion due to high-temperature hydrogen acting chemically on core components.
4. Startup and control behavior on liquid hydrogen.
5. Pressure distributions throughout the reactor.
6. Temperature distributions.
7. Operation and integrity of incidental hardware such as turbo pumps, nozzles, etc.

All of the early tests resulted in a failure of at least one major component and, sometimes, in the failure of many component parts. However, each test gave sufficient information to indicate how a fix might be made, or that some particular design feature represented a dead end and should be abandoned. As little as 30 seconds operation at partial design conditions has proved sufficient to obtain the required data. While these tests were dismal failures if viewed as proof tests of the design, they were highly successful as steps in the developmental program for which they were intended.

The last four tests, three on Kiwi reactors by Los Alamos and one by Westinghouse on the NERVA adaptation of the Kiwi design, were highly successful from a reactor standpoint and could be considered proof tests of the basic reactor design.

A movie will be shown of the last Kiwi run and rerun, with a total run time near design conditions of 11 minutes for the last Kiwi reactor. Post-mortem information indicates that the reactor could have been recycled a third time for the facility-limited duration.

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