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SAFETY OF RIFT VEHICLE LAUNCH AND FLIGHT OPERATIONS

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Introduction

The Reactor-In-Flight-Test (RIFT) Project was initiated in June 1962 to develop a nuclear stage and vehicle capable of performing advanced missions in space. The RIFT flight test program consists of a series of ballistic flight tests at the Merritt Island Launch Area - Atlantic Missile Range (MILA-AMR) to demonstrate this capability.

The Marshall Space Flight Center is charged with the design, development, fabrication, system integration, and static tests of the RIFT vehicle. The Launch Operations Center will conduct launch operations at MILA. The Lockheed Missiles and Space Company was selected as the prime contractor for RIFT stage design, development, etc. NERVA engine development is the responsibility of the Space Nuclear Propulsion Office (SNPO), and Aeroject-General Corporation has the contract for the engine development with a subcontract to Westinghouse for reactor development.

The RIFT development and test program involves not only about all the complications of a large chemical stage development but also the problems arising from the potential hazards of a nuclear reactor capable of producing very high power levels. Safety, therefore, must be an important and integral part of the program from conception through design, development, and test.

RIFT Stage and Vehicle Description

The RIFT vehicle configuration, Figure 26, consists of the S-1C stage, S-11 stage, S-N stage, instrument unit, and nose cone. The RIFT stage is 33 feet in diameter, and 80 feet long; the total SATURN V/RIFT vehicle length is over 350 feet.

The S-1C booster now being developed for the SATURN V launch vehicle is approximately 140 feet long, uses five Rocketdyne F-1 engines producing a total of 7.5 million pounds thrust, and has a propellant capacity of approximately 4.5 million pounds of LOX and RP-1.

The S-11 stage will be included as a dummy in the RIFT flight test to provide structural and dynamic simulation. The S-11 is approximately 80 feet long and will be ballasted for propellant-weight simulation on the RIFT flights. For operational missions, the S-11 stage would be powered by five Rocketdyne J-2 engines producing a total thrust of approximately 1 million pounds and would have a total propellant capacity of approximately 900,000 pounds of LOX and LH_2.

The RIFT S-N stage is approximately 80 feet long and consists of a propellant tank, nuclear engine, and interstage. Liquid hydrogen contained in the welded aluminum tank will be forced through the reactor by a combination of tank pressure and engine turbopump action, absorbing heat from the reactor before passing into the thrust chamber as hot hydrogen gas. The RIFT stage propellant capacity is approximately 100,000 pounds, but for operational missions the tank size may vary between 100,000 and 200,000 pounds depending upon the specific mission.

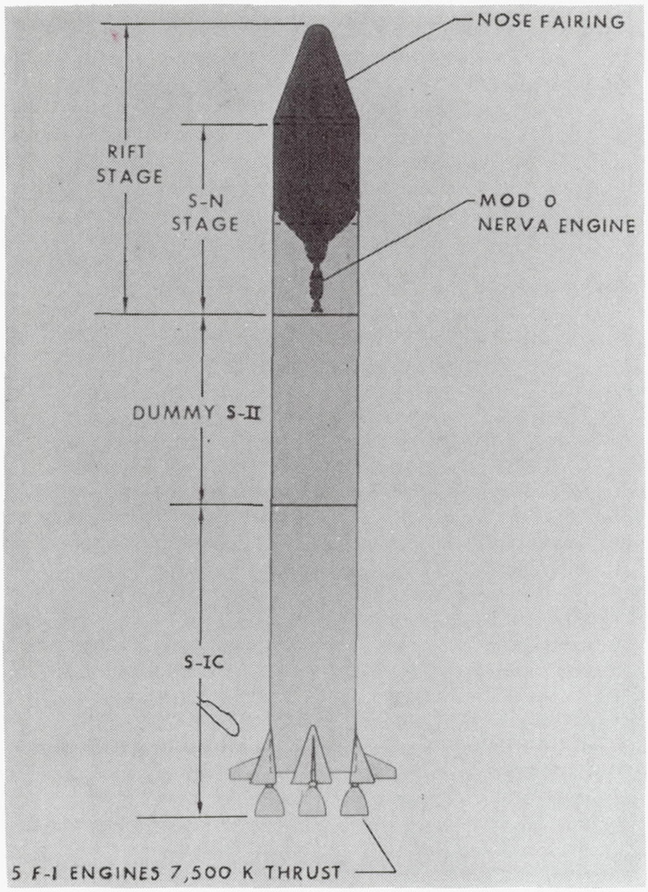

Figure 26. SATURN V/RIFT vehicle

The Instrument Unit (IU) containing the guidance and controls for the vehicle is 3 feet long and is mounted between the S-N stage and the nose cone which projects above the IU to a length of 50 to 60 feet along a half angle of 15 degrees.

S-N Stage Safety Systems

The S-N stage safety systems, in addition to the SATURN V vehicle safety systems, are designed to reduce to a minimum the potential hazard associated with the flight of a nuclear-powered rocket. To provide maximum safety and reliability for the reactor-in-flight tests, the flight system must be capable of responding to all foreseeable malfunctions and of achieving an acceptable termination of the flight program at any point within the defined flight span.

Major S-N stage safety systems are as follows:

- Criticality monitoring system
- Propellant prevalve
- Stage-Engine operational sequence safety system
- Stage GN_2 purge system
- Engine purge system
- Engine safety system
- Stage destruct system

A radiation monitoring system with detectors at strategic locations throughout the stage will provide information on neutron count and gamma radiation on a continuous basis. Alarm circuits will be triggered if preset levels are exceeded.

An isolation valve, referred to as the propellant "prevalve," will be located at the propellant tank outlet to prevent leakage of liquid hydrogen into the reactor system before scheduled thrust buildup. This valve consists of a stainless-steel disc surrounded by an annular ring of shearable metal alloy which provides a hermetic seal to the tank outlet line.

In-flight initiation of the S-N stage operations requires that specific functions be accomplished in sequence with appropriate safety interlocks to ensure the safe startup, operation, and shutdown of the reactor/engine system. This function is performed by the stage-engine operational sequence safety system.

An inert-gas purge system will be used to reduce or eliminate undesirable gases such as oxygen from the propellant tank, interstage and forward equipment areas, and engine system. Reducing oxygen to less than 1 percent by volume in the inert gas will eliminate the oxygen/hydrogen explosive hazard.

Several engine safety systems are being considered. An anticriticality poison system would incorporate poison wires in the reactor to prevent reactivity buildup in case of inadvertent control-drum operation or immersion of the reactor in water. An anticriticality destruct system in combination with the stage destruct system would destroy the reactor in case of in-flight malfunction after booster separation and before engine power increase from 1-percent power hold to 100-percent power. A postoperational destruct system would fragment a radioactive engine and reduce the core to particles fine enough to reduce radiation to an acceptable level.

The stage destruct system will initiate engine shutdown and propellant tank destruction upon receipt of a properly coded RF signal. High reliability is achieved through use of two independent redundant circuits powered from separate electrical power buses. A common antenna system and common ordnance components are used because of their inherent reliability.

Prelaunch Testing

Nuclear rocket flight test stages, unlike chemical stages, will not have been test fired before flight because of the fission-product buildup and the induced radioactivity that such testing would produce. It is therefore mandatory that the development test program for RIFT include extensive prelaunch testing, effective quality assurance procedures, and as much simulation of flight conditions as practicable.

The RIFT program includes tests at the Propellant Tank Facility and the Cold Flow Facility and captive testing at the Nuclear Rocket Development Station (NRDS). Twenty to thirty test firings, simulating in-flight conditions, and functional sequences are to be conducted at NRDS before the first RIFT flight.

Preflight Operations

The safety record of chemical rocket operations involving large quantities of explosive and toxic materials at the Atlantic Missile Range has been outstanding. This record has been achieved through careful planning, thorough training, and adequate facilities and equipment.

The introduction of a nuclear-powered stage requires a new and complete examination of the elements which have contributed to the safety of chemical rocket operations plus additional study of the problems peculiar to the nuclear system.

The Merritt Island Launch Area and the Atlantic Missile Range are well suited for nuclear launch operations with ample space for facilities and required exclusion areas. MILA and Launch Complex No. 39 (LC-39) from which the SATURN V, and therefore RIFT, will be launched, are shown in Figures 27 and 28. Three launch pads are located along the ocean 8730 feet apart. This distance is sufficient to prevent damage to a vehicle in the event of an explosion of another vehicle on an adjacent pad during simultaneous checkout operations. The Vertical Assembly Building (VAB) in which the chemical stages will be checked out and erected is located approximately 3-1/2 miles west of the southernmost launch pad. A Nuclear Assembly Building (NAB) will be located approximately 1/2 mile north of the VAB.

The closest public habitation to the LC-39 pads is along Highway US 1, and at Titusville, 10 to 11 miles away. Access to the VAB will be by barge, railroad, or highway.

The AMR extends from Cape Canaveral, Florida, into the Indian Ocean beyond South Africa and includes island tracking stations, instrumented ships and aircraft, and all necessary equipment for data acquisition and reduction incident to long-range missile and space vehicle operations.

A brief examination of the prelaunch operation which the SATURN V/RIFT vehicle will probably go through at MILA will furnish the basis for more detailed consideration of potential hazards. The SATURN V stages and RIFT will be shipped to MILA by ocean-going vessels. Arriving at the canal terminus near the VAB, the S-1C and S-11 will be rolled off on their transporters and towed to the VAB, Figure 29. There, the S-1C will be erected on the Launcher Umbilical Tower (LUT) and the S-11 will be taken to the low-bay area of the VAB for checkout. The RIFT stage will be towed on its transporter to the NAB for checkout and mating with the engine.

The reactor, engine, and RIFT stage will each be subjected to detailed inspections for shipping and handling damage, followed by functional checkout as required. The reactor will be mated to the engine and the subsequent checkout will probably include a criticality test to verify control-drum calibration and core reactivity. Following this test, the integrated NERVA engine/RIFT stage will be checked out and prepared for transportation to the VAB.

At the VAB high bay, the S-11 will have been erected on the booster and final mating of the RIFT stage and the Instrument Unit (IU) will take place. After the mechanical mating and alignment of the stages and IU, the stages are mated to the LUT Ground Support Equipment (GSE) and limited-stage/GSE checks performed before electrically mating the stages with each other. Following the completion of the stage-GSE compatibility tests, the stages will be electrically mated and the launch-vehicle systems test performed.

When the complete vehicle is in a ready condition, the crawler-transporter, Figure 30, is moved into position under the LUT. Hydraulic jacks will lift the LUT and vehicle and move out the crawlerway to the launch pad where the LUT will be positioned onto prepared pedestals. The crawler will then move the arming tower, Figure 31, into position at the launch pad for ordnance installation and final servicing, Figure 32.

At the pad, the LUT and space vehicle services such as digital data link communications circuitry, pneumatic and propellant lines, environmental controls, and power supply lines will be connected, the vehicle aligned, and ordnance installed.

The launch-pad program will consist of the following:

Limited subsystem verification check from the Launch Control Center (LCC)

Checkout of hardwire backup circuits to LCC

Tank pressurization test

Propellant loading test

RF systems test

Simulated flight test

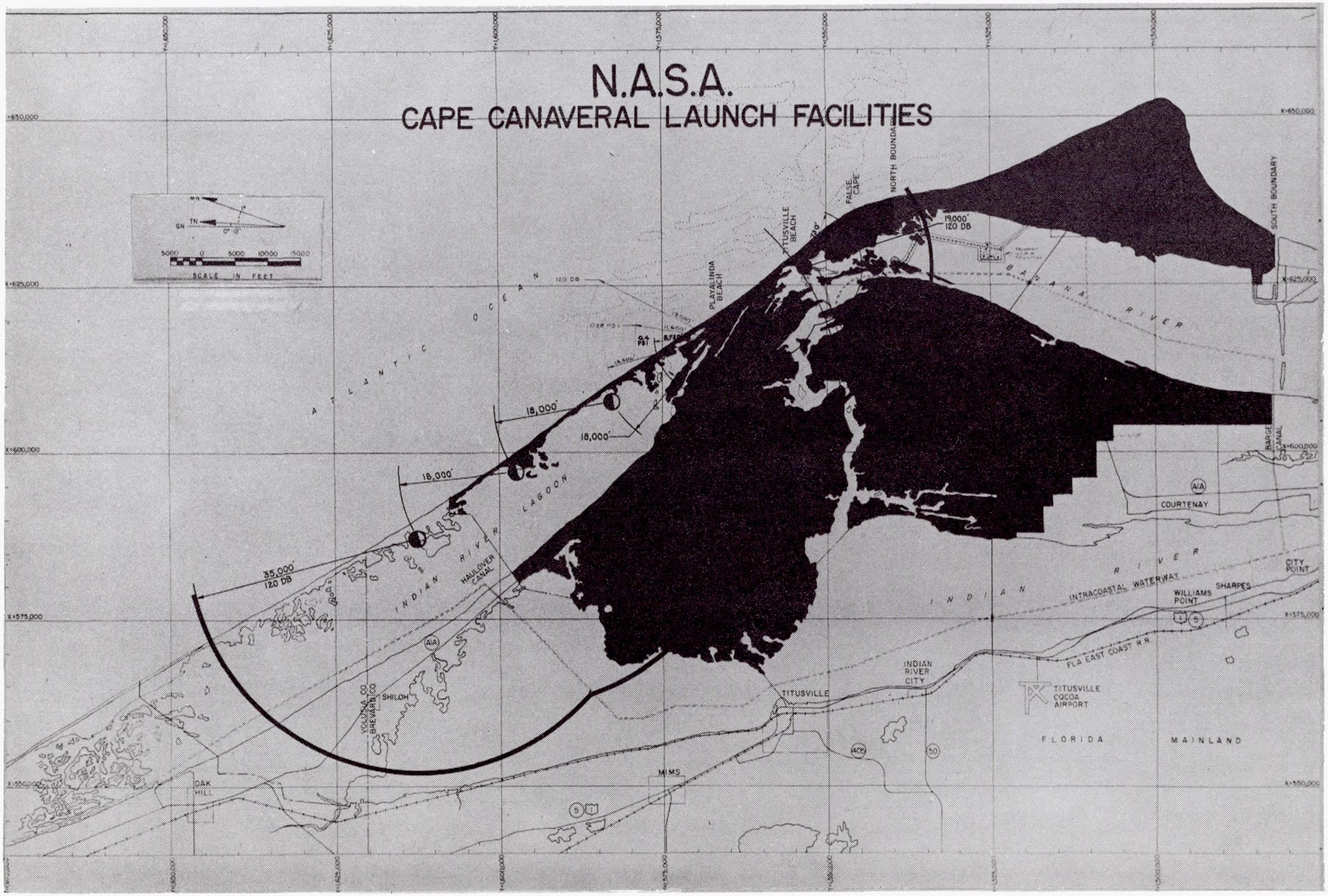

Figure 27. Merritt Island launch area

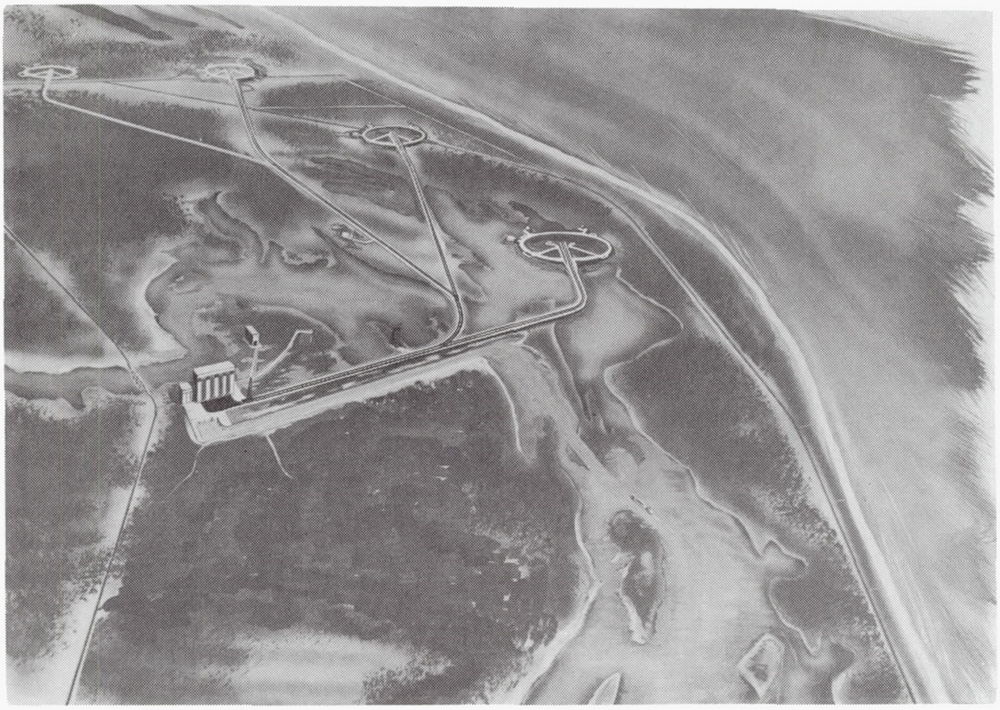

Figure 28. Launch Complex 39

Figure 29. Vertical assembly building

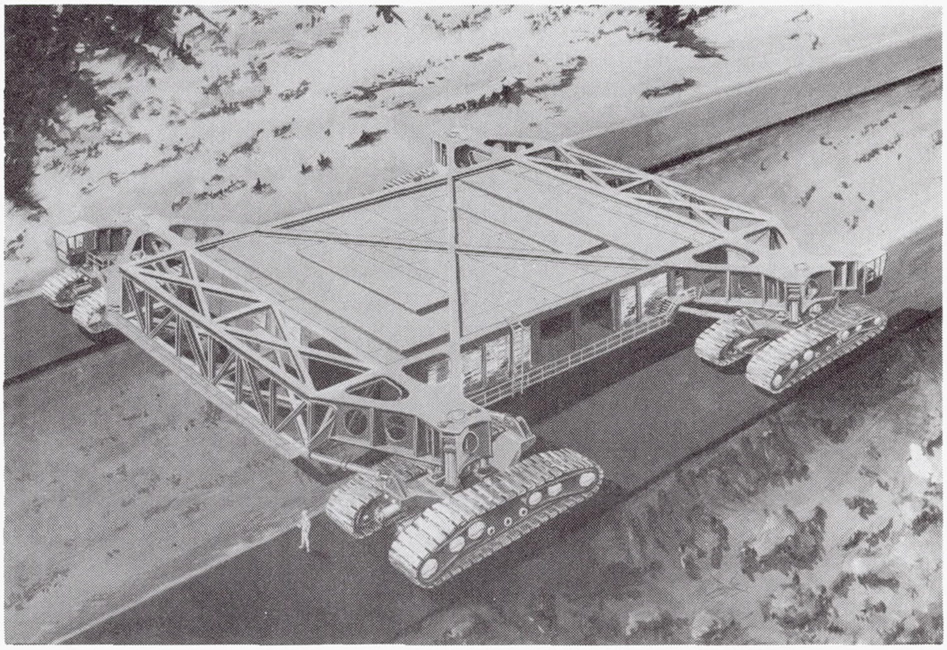

Figure 30. Crawler-transporter

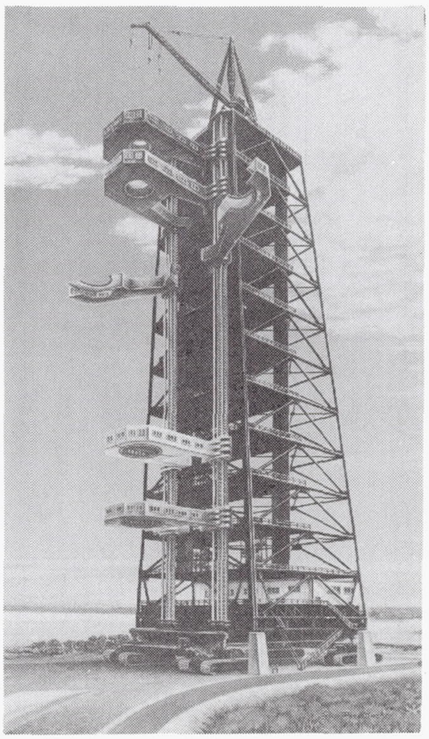

Figure 31. Arming tower

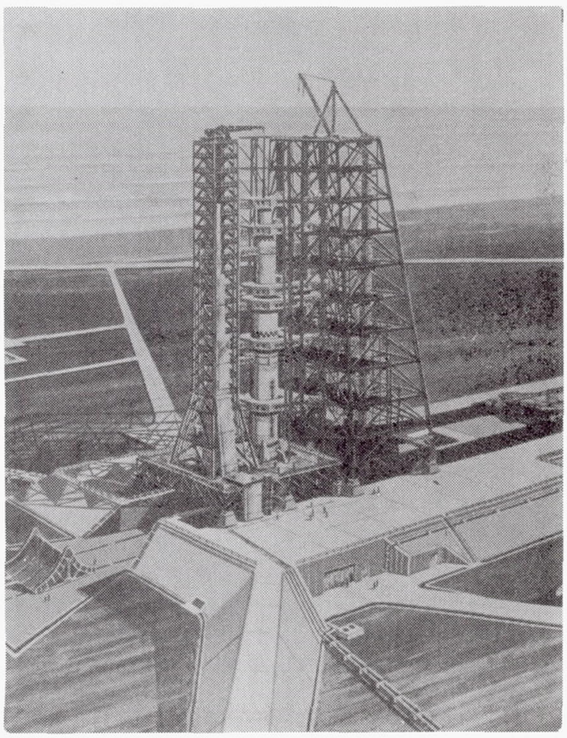

Figure 32. Launch site - LC39

Following a successful simulated flight test, the vehicle is ready to enter the 10-hour countdown preparatory to launch.

Flight Operations

A typical trajectory for the RIFT mission is shown in Figures 33 and 34. The NERVA engine will operate through programmed cycles and cool down before final impact in the deep ocean area beyond the Blake escarpment.

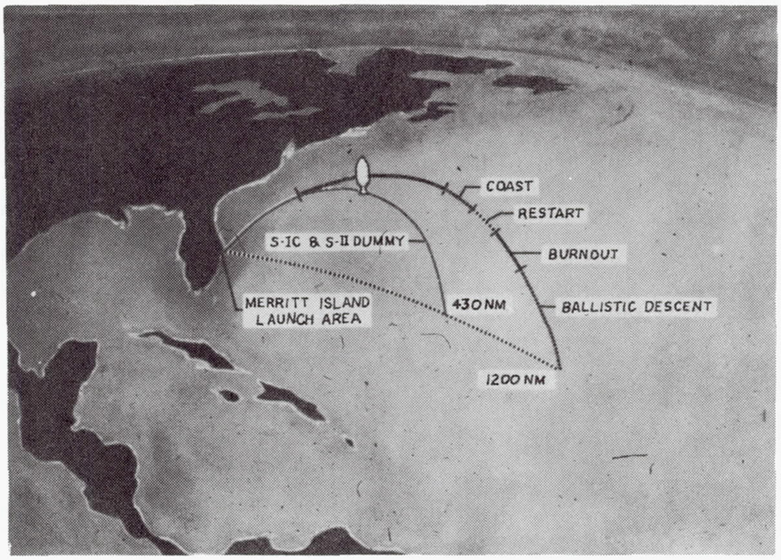

Figure 33. RIFT trajectory - Lob

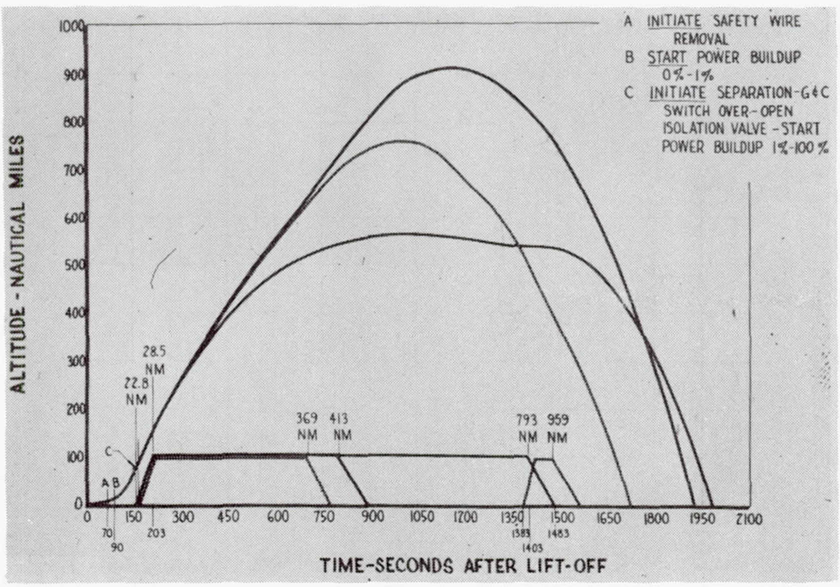

Figure 34. RIFT trajectory - Ballistic

Safety Considerations

Before attempting to identify steps in the SATURN V/RIFT operation which could lead to a nuclear hazard, it is necessary to consider the conditions under which a nuclear excursion is credible. Several such conditions are readily identifiable:

- Control-drum runout
- Hydrogen filling of reactor
- Core compaction from impact or explosion
- Water immersion
- Immersion in RP-1

With the above conditions in mind, a step-by-step examination of the proposed SATURN V/RIFT operation at LC-39 will readily identify potentially hazardous conditions. Such a qualitative procedure, although necessary, can be misleading since the probability of occurrence of some of these so-called "credible accidents" may be so low as to make their consideration unrealistic. It will therefore be necessary to subject this sequence of operations to a quantitative analysis before judging the safety of the operation.

The reactor for the NERVA engine will arrive at MILA with full shipping poisons in place and can probably remain in this condition until it is mated with the engine. The type of poison system to be employed throughout the operation at MILA is a problem that is under active consideration at this time and will not be discussed in this paper although the final poison system selection will have a major effect on safety problems. During all ground checkout operations except reactor criticality and related tests, the reactor will contain at least enough poison to prevent inadvertent control-drum operation from causing a nuclear incident. The ultimate goal is to include sufficient poison to prevent the reactor from becoming critical under any conceivable circumstances.

NAB Operations

A review of the safety of operations as proposed within the NAB shows that only two of the accidents described previously merit any further consideration since no explosive propellants or liquid hydrogen will be present in the NAB. Consideration is therefore limited to control-drum runout and reactor deformation because of ground impact. Control drums will be locked and the core at least partially poisoned during the reactor/engine mating operation and during transit within the NAB. Thus, from a handling standpoint, the worst conceivable accident would be a drop of the partially poisoned core from a height of, at most, 20 feet during the initial operation of picking up the core for mating with the nonnuclear engine assembly. Preliminary analysis indicates that the dropping of a partially poisoned core from 20 feet will not result in a nuclear incident. Drop-test experiments will be conducted on scale reactor models to provide data from which core deformation calculations can be made.

Control-drum override poisons and drum locks must, of course, be removed during the performance of criticality checks and control-drum calibration in the reactor/engine checkout area. Thus, the safety of the system is degraded to its lowest level at this point in the operation. Criticality tests will be remotely performed in a controlled area from a shielded control room which would protect test personnel from direct radiation and fission-product dispersal in the event of a nuclear incident. The probability of a nuclear incident is quite remote since a large number of similar operations will have been performed, the particular core under test will have undergone a similar test before shipment, and a complete transit history will be available to give any indication of abnormal conditions or potential difficulties. Even so, the possibility of a control-drum runout at this point cannot be ruled out completely.

The NAB will have a detailed personnel rad-safe protection program, an enclosed-area monitoring system, emergency protection equipment, and possibly a continuous engine/reactor monitoring system. All areas associated with reactor, reactor/engine, and engine/stage mating operations will be controlled, with limited access only to authorized personnel. These areas will be equipped with extensive detection equipment monitoring each area at several locations for air contamination, gamma rays, and neutrons. These systems will be coupled with an audible alarm system preset to actuate at a given radiation level. These fixed monitoring systems will be augmented by portable detection systems in critical areas such as the reactor and reactor/engine assembly areas.

Transport NAB to VAB

The VAB is approximately 3000 feet from the NAB. Since transfer time may be scheduled to avoid unfavorable weather conditions, an accident does not appear credible that could result in a nuclear incident during this operation. Core poison is installed, drums are mechanically locked, and since there is no water along the route, water immersion is not credible.

Operation in the VAB

Before arrival of the RIFT stage, the S-11 stage will have been checked out and erected on the S-1C. The RIFT stage on its transporter will be positioned under the 250-ton crane in the high bay, removed from the transporter for mating to the interstage, and then hoisted into position on the S-11 stage.

Inasmuch as the drum locks and core poisons are not removed in the VAB, a drum-runout accident is not likely. Handling during the mating of the RIFT stage to the S-11 stage appears to be the only area in which an accident could occur. Although the possibility of such an incident seems extremely remote, the core compaction resulting from dropping the stage from an engine gimbal height of approximately 275 feet must be analyzed to determine the credibility of a nuclear incident.

Transport from VAB to Launch Pad

The distance from the VAB to the launch pad of 3-1/2 to 4-1/2 miles (depending on which pad is used) is traversed by the crawler at a maximum speed of 1 mile per hour. It can move at this speed against a steady wind of 40 knots. Winds greater than 99-percent probability during the strongest wind month (54-knot peak winds at 400 feet) necessitate immediate stoppage of the operation. A forecast of hurricane conditions would necessitate transfer back to the VAB, which is designed for hurricane protection. The crawler maintains the entire launcher platform level with ±10 minutes of arc over the entire distance, including the 300-foot transition curve to the pad.

During the operation, the only hazard apparent is the abundance of water on either side of the 150-foot crawlerway. It would be possible for the nuclear stage to be immersed in shallow water if the entire vehicle were tipped or blown over during the transit phase of the pad. If the poison system devised for the reactor core is found to be sufficient to prevent an excursion even in the event of water immersion, then this ceases to be a problem for consideration. The nuclear consequence of tipping the entire vehicle over into shallow water with the reactor partially poisoned and the control drums locked requires detailed analysis. If it is found that an excursion could result, the magnitude of such an accident would then have to be weighed against the probability of such an accident ever occurring and the costs of land filling 300 feet on both sides of the crawlerway. When the equipment to be used in this operation and the experience that will have been amassed in several years of SATURN V operations are considered, the possibility of such an accident seems extremely remote.

Launch-Pad Operations

Overall operations at the pad before launch are expected to take approximately 2 weeks. Upon arrival at the pad, all LUT and vehicle service interconnects between the launch facility and LCC will be made. They include all digital data links, communications, pneumatic and propellant supply lines, environmental controls, and power distribution cables. All electrical interfaces are made at the launch facility distributor located at the pad terminal connection room. After all connections are made, overall vertical alignment of the vehicle is accomplished. The crawler then moves over to the arming tower (parked 7000 feet away from the pad) and moves it into position around the vehicle, thus providing 360 degrees of access to the vehicle for ordnance installation and special servicing requirements.

Installation of all ordnance that could not be installed in the VAB because of safety considerations is performed concurrently with other pad operations. (Note that although ordnance is installed, it is not armed until the day of launch.)

The overall launch-pad program, including the simulated flight test, is conducted preparatory to the launch countdown.

The simulated flight test will include a complete launch-day simulation. Compatibility with the range is verified at this time. This test is conducted through the high-speed data link between the LCC and LUT, the same link used in the VAB simulated flight tests. The hardwire system uses battery-powered independent circuitry as a backup link between the LCC and pad for safing and monitoring of the launch vehicle at the pad in the event of data-link failure. Critical reactor and engine control circuits for the RIFT stage will be monitored through this system. Up to this time, all of the pad operations discussed have been performed with the reactor control drums still mechanically locked and the reactor core poison in position.

Upon completion of a successful overall simulated flight, the vehicle is ready to enter the 10-hour countdown phase of the launch operation.

Up to launch day, the overall launch-pad checkout should not provide any greater degree of hazard from the nuclear state than that present during the VAB high-bay checkout because the drum locks and core poisons are still in place. The safety of the overall system is somewhat degraded as the countdown progresses by the connection of ordnance initiators and arming of the reactor destruct system. Removal of core poisons (if required) and removal of manual control-drum locks degrades the engine/reactor system safety to the level existing during the performance of criticality checks in the NAB. Propellant loading further degrades the system safety from an explosive hazard standpoint. All of the accidents previously postulated could occur at the launch pad including possible impact of the reactor in shallow water as a result of an early flight failure. Thus, the nuclear hazards associated with the following conditions must ultimately be analyzed in detail:

Gross control-drum runout during the latter phases of countdown (after removal of poison and manual locks).

Immersion of the reactor in liquid hydrogen or RP-1 as a result of an explosion rupturing propellant tanks. (Injection of liquid hydrogen into the core through an engine valve failure or leak is precluded because of the prevalve used.)

Implosion of the reactor core as the result of an explosion on the pad.

Impact of the nuclear stage in shallow water as the result of an early flight failure.

As indicated, the time period during which these accidents could occur in the launch-pad area is quite small (approximately from T-5 hours up to launch time and immediately thereafter). To provide for these possible accidents, the following personnel, equipment, and procedures will be available for support in the launch-pad area:

An extensive launch-complex radiation detection and warning system.

Salvage vehicles and equipment.

Trained salvage crews for cleanup operations (protective clothing, portable radiation-detection devices, etc.) will be available.

Methods, equipment, and facilities for disposal of radioactive waste material.

Emergency plan for predicting affected areas.

Plans, based on detailed environmental surveys, for control of on- and off-site areas.

The equipment and planning will be based on the philosophy that even though the postulated accidents are not likely to occur, all credible eventualities must be provided for.

Flight

The most hazardous phase of any rocket operation, and particularly one containing any kind of a nuclear device, is the period immediately following ignition and continuing into the early flight phase. In conjunction with the vehicle destruct system, the reactor destruct system previously described can be actuated by the range safety officer as soon as a vehicle deviates from its planned trajectory. The incorporation of a reactor poison system capable of in-flight actuation would provide further backup to the reactor destruct system.

Impact of the reactor off-shore does not constitute any more of an immediate hazard to personnel than an accident in the vicinity of the launch pad. Such an impact may, however, require continuing surveillance to protect the populace from contaminated marine life or from radioactive material carried by ocean tides and currents.

Downrange activity during a typical RIFT flight will be supported by stations in the Bahama Island chain (Grand Bahama, San Salvador, and Grand Turk Islands), instrumented ships, and aircraft. The ships will be on station 5 hours and the aircraft 1 hour before launch to cover re-entry and impact. Additional ships and instrumented aircraft will be required for the RIFT flights to monitor the fate of airborne and seaborne fission products released by the postoperational destruct of the NERVA engine. The same airborne and surface craft requirements exist to monitor and record radioactivity in case of the impact of an expended NERVA engine into deep water.

Conclusions

The RIFT vehicle, typical RIFT trajectories, prelaunch, launch and flight operations and their related safety considerations, based on current planning, have been described. It should be emphasized that the launch of the RIFT vehicle is several years away and the potential hazards of the operation have been subjected to only preliminary study.

The evaluation of the safety of RIFT operations is and will continue to be of prime importance as NERVA and RIFT designs mature and as test data evolve. Much work has been done in support of the RIFT flight-safety program, and these efforts are being intensified to ensure satisfactory solution of the related safety problems before flight testing begins.

Current data and analyses lead to the conclusion that the probability of a nuclear incident of any kind as a result of planned RIFT operations at Cape Canaveral is remote and that the dangers involved should such an incident occur are acceptably low.