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## SAFETY PROGRAM AT THE NUCLEAR ROCKET DEVELOPMENT STATION

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### Abstract

Many unique problems have been encountered and overcome in the developmental testing of nuclear powered engines for space applications, necessitating an extensive radiological and cryogenic safety program at the Nuclear Rocket Development Station. (NRDS) The radiological safety program directs itself toward the protection of personnel associated with the program and the public from direct radiation and resultant radioactive effluent. The cryogenics safety program at the NRDS directs itself to the prevention of accidents which could damage the nuclear reactor or the test facilities and in turn endanger associated personnel.

It is graphically illustrated that nuclear rocket engines do not present a radiological safety problem prior to operation, and that during and following operation, experience has proven that control measures are possible to minimize possible hazards. Of particular interest is the comparison of cryogenic and radiological safety effects.

### Introduction

The nuclear rocket (ROVER) program is a joint program of the National Aeronautics and Space Administration and the U. S. Atomic Energy Commission, under the management and direction of the joint AEC-NASA Space Nuclear Propulsion Office. The ROVER Program is concerned with developing the technology and systems for using nuclear propulsion for space missions.

Space launch vehicles of today are all propelled by chemical rockets operating on the combustion principle. The earliest source of power providing greater performance than today's most advanced chemical rocket engines is the nuclear rocket engine.

A new program such as nuclear rocket development causes need for a new look at safety considerations. Unique among those to be considered during development testing of nuclear systems are nuclear safety and cryogenic safety in addition to the more conventional and better understood considerations of industrial safety.

This presentation will address itself to each of these safety topics as they are practiced at the Nuclear Rocket Development Station (NRDS).

The Nuclear Rocket Development Station is the national site for conducting full scale tests of nuclear rocket reactors and engines and, eventually, complete stages in the United States' program to develop nuclear-propelled spacecraft for deep space flight. The station is a 90,000-acre site located approximately 90 miles northwest of Las Vegas, Nevada. (Figure 1) The plant value of test facilities at the NRDS is approximately \$85,000,000 and includes two reactor test cells, "A" and "C"; an engine test stand, ETS-1; a reactor maintenance, assembly and disassembly building, R-MAD; and an engine maintenance, assembly and disassembly building, E-MAD. A two-position engine stage test facility is presently under design.

The basic difference between a nuclear propulsion system and the more conventional chemical propulsion system is in the method of heating the propellant to provide thrust. The chemical rocket operates on a combustion principle where fuel and oxidizer are combined and burn. The resultant exhaust gases provide the thrust. A nuclear system uses a nuclear reactor to heat an extremely cold liquid propellant with a high expansion ratio and channels the resulting hot gas through a nozzle to provide thrust. So you can see we do not burn our propellant, we merely heat it. (Figure 2)

Basically what we have is liquid hydrogen being pumped from a propellant tank through a super-hot reactor, or heat exchanger, expanded and exhausted to provide thrust. The pump is turbine driven and is run by a portion of the hot exhaust gases bled off upstream of the nozzle. This is the common "bleed cycle" that permits the "boot-strap" start-up with which you are probably familiar. As the liquid hydrogen passes through the hot reactor (approximately 4000° F.) it is heated to extreme temperature. The

hot exhaust gas is then directed and expanded by the nozzle to produce useful thrust. Nuclear radiation is produced by the reactor, however, an engine shield reduces radiation levels to engine components, the vehicle and the payload. (Figure 3)

### Safety at NRDS

Unique safety considerations at the Nuclear Rocket Development Station are nuclear safety and cryogenic safety. These are in addition to conventional industrial safety practices.

### Industrial Safety

Industrial safety at the NRDS takes on several unique facets which we do not normally think of when we refer to a conventional industrial safety program. In our Industrial Program at Jackass Flats, we must, because of the relative hazards of the work, make it a preventative program rather than one which acts after the fact. We cannot afford to learn from our mistakes. We must insure that mistakes are not made to begin with. Besides dealing with the regular day to day problems of machinery, traffic, fire protection and training, our Industrial Safety Plan plays a strong role in occupational and environmental health. Industrial Safety personnel must review all plans, processes and procedures for new construction prior to the beginning of the project. In this way problems with volatile, toxic or radioactive substances are eliminated before they occur.

The Industrial Safety Program must also include provisions for assuring that all AEC and NASA contractors located at NRDS are kept aware of new Federal codes, regulations and laws and assure, through continual audit, that these provisions are correctly interpreted and carried out.

The Industrial Safety Program has initiated and used to great advantage a "Near Miss" program. This program involves assuring that all NRDS personnel are made aware of serious accidents which "almost" occurred. The "Near Miss" hopefully acts as a stimulus to employees to assure that dangerous conditions or actions will be eliminated.

Industrial safety is also instrumental in establishing procedures for, and overseeing, all emergency actions which might take place at the NRDS.

### Cryogenic and Systems Safety

A complete and comprehensive Cryogenic and Systems Safety Program is in effect at the NRDS. The Cryogenic Safety Program addresses itself to the three major problems which are associated with handling any cryogenic fluid.

1. Extremely low temperatures reduce ductility and impact resistance of most materials on contact.
2. Confinement results in pressure forming due to vaporization and expansion.
3. Severe tissue damage results when human tissue is contacted by the cryogenic fluid, its immediate container or resultant cold gases.

In addition, as you know, liquid hydrogen is volatile in air, with wide flammability limits. Very low energy is required to ignite hydrogen. Hydrogen in its liquid state probably presents us with our most serious concerns at the NRDS. Our storage capacity for LH<sub>2</sub> has grown in the past year from 586,000 gallons to 1,586,000 and our gas and cryogenic systems are rather complex as shown by the simplified flow diagram of a test cell. (Figure 4)

Although liquid hydrogen is handled daily in large quantities at the NRDS in a routine manner, constant awareness of new equipment or methods in handling this material is a must. Safety codes, based in part on the experience of organizations handling hydrogen have been stipulated and are in practical use. These codes have evolved from four basic factors:

1. Knowledge of the potential hazards of the fluid and its

system.

2. Personnel education in both the potential hazards and the technical aspects of the system.

3. Assurance that specific procedures exist and are followed during all hydrogen operations.

4. Systems engineering to preclude hazards.

Factor 1 demands that, to be effective, safety codes must be based on knowledge of the properties of the fluids to be handled, the gases produced by their vaporization and of mixtures which occur when the gases disperse into the atmosphere. The properties of the materials used to confine the fluids and the response of the human body to both the fluids and their resultant gases are essential considerations. These factors all evolve into the safety codes now in use at the NRDS.

Factor 2 requires that all supervisory and technical personnel working on a system have an intimate knowledge of equipment arrangements, facility operations and capacities, and systems operation. In addition, the interrelationships of all these features must be understood so that an effective, efficient and safe day-to-day working operation may be realized. To assure that competent and qualified personnel are available for potentially dangerous operations and tests, each affected NRDS organization carries on an extensive indoctrination and training program.

Factor 3 is primarily for use during cryogenics systems tests and activation exercises. These tests, whether being performed in the immediate test area or from a remotest control point, are under the direct control of test supervisors who have complete and up-to-date procedures and checklists. One of their primary obligations is to maintain strict test discipline throughout all phases of the operation.

During cryogenics operations, procedures dealing with every step of the operation are mandatory. The smallest task if not correctly performed could cause an expensive failure to the system or the product and jeopardize the lives of operating personnel.

Let me emphasize before going on to the next factor that personnel are not, during reactor or cryogenics operations, treated as being separate from the system. They are part of the system and function as a component. Human factors engineering is as important in the overall development of the system as reliability.

Factor 4 is probably the most important aspect of the cryogenic and system safety program. The system safety approach is somewhat different from that normally practiced in industry. Systems Safety involves applying scientific knowledge and engineering principles for timely identification and elimination or control of all potential hazards within the system. The consideration of safety of the system starts with original conceptual studies and follows through design, development, test, evaluation and operation. Ideally at the end you will have a system which is free of hazards or in some cases, such as flight hardware, you have put controls on the hazards which cannot operationally be eliminated.

A properly functioning systems safety program, not only in cryogenics systems but in any system will accomplish the following:

1. Adequate controls over known systems hazards which are inherent to the system have been established to protect personnel, equipment and property.

2. Minimum risk is involved in the acceptance and use of new methods and/or materials.

3. The requirement for retrofit actions (and their resultant costs) for safety reasons have been eliminated.

4. Maximum safety, consistent with operational requirements, has been designed into the system.

We try to categorize each hazardous condition which could occur during a reactor test. The categories are: safe, marginal, critical and catastrophic. A systems safety program emphasizes designing the system so if a malfunction occurs in one of these categories there is a backup system or procedure to control or eliminate the malfunction. A malfunction should never cause a degradation of the system from one category to the next more serious category. Each system or subsystem or component must have one or more levels of fail-safe redundancy.

A gross hazard study is performed on each system at the NRDS. This study is a quantitative non-mathematical assessment of the safety features of the end item. Areas considered in this study include:

1. Isolation of energy sources.

2. Fuels, propellants, gases and cryogenic materials, their characteristics, hazard category, handling, storage and transportation safety features.

3. Systems environmental constraints.

4. Use of potentially explosive devices.

5. Compatibility of materials.

6. Human factors.

7. Use of pressure vessels and associated systems.

8. Documentation concerning the safe operation and maintenance of the facility.

9. Training pertaining to all of the above.

When a problem area in any one of the above categories is defined, a sequence of action is then taken to make the system as safe as possible. To satisfy safety engineering criteria this sequence is in the following order of preference:

1. Design for Minimum Hazard. Every effort should be made during all phases of design to insure optimum safety through the selection of appropriate design features and qualified components.

2. Safety Devices. Known hazards which cannot be eliminated by design selection shall be reduced to a minimum by designing appropriate safety devices into the system.

3. Warning Devices. In those instances where it becomes impossible to preclude a known hazardous condition, appropriate devices shall be employed for detection of the condition and generation of an adequate warning signal.

4. Special Emergency Procedures. In those instances where design considerations or use of safety and warning devices fail to reduce the magnitude of a known or potential hazard to an acceptable level, special emergency procedures are provided. These procedures identify the hazardous period time span, actions required if such hazards occur, and special operating procedures to reduce possibility of occurrence.

An example of each of these would be:

1. If, during a reactor run there occurs a discontinuity of coolant  $LH_2$  flow, damage could result to the reactor. A backup system has been installed which will automatically continue coolant flow should the flow from any primary coolant system be reduced for any reason. This system operates completely automatically and separate from the main coolant system. The first level of fail-safe redundancy should always be an automatic reaction, not a manual one.

2. We have a rather unique device to make certain  $H_2$  systems are completely independent of one another even though they share a common line. It is known as a double block and bleed. In this set up two block valves are installed, one downstream in the common line and one upstream in the main discharge line of the system being isolated. In the liquid hydrogen system gaseous helium at a slightly higher pressure than the hydrogen is then injected into the line between the two valves. The pressure is then monitored and occasional samples of the gas are taken to assure no hydrogen seepage. In the gaseous hydrogen systems a bleed line between the two block valves bleeds off any leaking gas to the facility burn stack.

3. Warning devices are installed at certain strategic places throughout our test complexes. These devices are of two types. One for combustible gas to indicate a hydrogen leak and one to indicate excessive radiation. The hydrogen alarm is a siren, while the radiation alarm is a klaxon. The reason for two different audible alarms is to identify the type of emergency and the appropriate emergency action to be taken. These alarms not only sound locally but activate alarms in locations such as the central fire station. Also during certain tests, large enclosed areas must be inerted to preclude an explosion should a hydrogen leak occur. Panels equipped with alarms tell us when the oxygen content in these areas becomes excessive or when a hydrogen leak has occurred.

4. Emergency procedures exist for all emergencies which could occur at the NRDS. These range from a fire to an accidental criticality accident at a reactor. The procedures are written simply and to the point. In the case of accidental criticality or hydrogen leaks the action to be taken is evacuation to a safe area.

As can be readily seen, safety in cryogenics and systems takes on a wide variety of tasks to make sure that all systems are ready and safe during tests. The techniques and procedures for

working with large quantities of cryogenic materials at NRDS reflect the respect for safety that must accompany association with such materials.

### Nuclear Safety

Nuclear reactor and engine testing at the NRDS involves, in addition to many of the same safety problems that chemical rockets have, the additional requirement that consideration be given to nuclear criticality, direct radiation and reactor effluent.

Nuclear criticality safety involves the prevention of a nuclear excursion or accidental reactor startup during the handling of fuel elements, assembly of reactor, pre-test checkout, test operations, disassembly or post mortem operations.

Direct radiation from a nuclear rocket reactor during full power operation is significant (approximately 100 R/hr. at 2700 ft. for a 1000 MW reactor). This has, in the past been controlled entirely by use of isolation. The control point is 2½ miles from the reactor. (Figure 1) In the future, with higher power reactors (up to 5000 megawatts thermal), direct radiation from the reactor during power operation will be considerably reduced by a radiation shield around the core. Future tests of engine systems will be accomplished from a close-in, underground control room, providing personnel the protection that distance has provided in the past.

Disassembly of a reactor after a test is accomplished to evaluate the effects of test on structural integrity, and fuel element erosion. Because of residual radioactivity in the reactor core due to fission product inventory, the disassembly operations and post mortem examinations are accomplished in a shielded building with remotely operated manipulators.

Effluent in the form of radioactive particulate and gases is produced by the reactor during power operations by diffusion and corrosion processes. On-site and off-site radiation effects must be considered.

Nuclear criticality safety is accomplished through the use of administrative limits and written procedures for all operations involving nuclear fuel material (U-235) plus physical control by volume limiting and nuclear poisoned containers, quantity limited storage and transfer racks and multiple interlocking safety devices on the reactor. As an example, criticality control of the assembled reactor is accomplished through the use of electrical and mechanical locks on the control rods, through isolation of the reactor from hydrogenous moderating material by double block and bleed (previously discussed) on all hydrogen lines and through positive isolation of the reactor from all water systems.

Radiation safety is handled through review, inspections and audits to assure compliance of contractor procedures and activities with AEC established dose levels. Radiation monitoring and control is accomplished by the support services contractor, who supplies the monitoring services required for all NRDS activities. All personnel on the NRDS wear film badges from which we are able to evaluate individual exposures.

We have an extensive effluent monitoring and evaluation program on the NRDS. The major objective of this program is to assure our capability for adequate prediction, measurement and evaluation of potential or actual radiological hazards generated as a result of reactor test operations at the NRDS. This capability is necessary to assure that radiation, both on and off-site is minimized, and that adequate documentation of radiation levels is accomplished.

Pre-run predictions of radioactive effluent transport and diffusion are used as a criteria for final test approval. These predictions are presently being made on the basis of weather forecasts tailored for this application plus the use of diffusion equations describing downwind dilution of reactor effluent. The required weather forecast consists of the spatial and temporal variations of the winds from the surface to approximately 15,000 ft. MSL, the temperature structure of the atmosphere through this same layer and the probability of rain along the predicted trajectory. This forecast provides the input required to predict the behavior of the radioactive effluent. Dose predictions are determined for whole body external gamma, iodine inhalation and iodine dose to the thyroid through the cow-milk chain.

Gamma monitoring is accomplished with remote readout instrumentation at close-in locations and with thermoluminescent dosimeters at distances out to 25 miles.

Air monitoring is accomplished by collecting air samples on charcoal impregnated filters. For this we use portable battery powered air sampling equipment. Filters are evaluated for isotopes of iodine by use of radio chemical separation and analysis on a gamma spectrometer.

Fresh milk samples are collected from farms and dairies in downwind sector following each test. These are also evaluated for radioactive iodines by use of a gamma spectrometer. Computation of isotope quantities is performed by use of a digital computer.

Many experiments related to the NRDS effluent program are conducted by development contractors. Typical are experiments such as fission product or exhaust stream monitoring.

Fission product release experiments conducted in the laboratory involve heating of fuel elements to determine their fission product release characteristics as a function of temperature. The data obtained is used in conjunction with a digital computer code to obtain total release predictions for a particular reactor test. These release predictions are used in conjunction with the diffusion equations and existing meteorological conditions, as previously mentioned, to obtain the predictions for downwind radiation effects.

A further consideration in determining possible radiation effects is the fission product inventory of the reactor. This increases proportionately to the integrated power and is of major importance in this evaluation. In this respect the safety of a cold clean reactor is best illustrated by results derived from a test that was conducted at the NRDS in January 1965. This test involved a standard 1000 MW reactor with special control devices to produce a high speed insertion of reactivity and a corresponding reactor excursion of maximum proportion. This was purposely designed to produce a much greater effect than that which could be expected from an accident involving a ground test reactor or engine under any conceivable circumstance. The total fissions in this planned excursion were a factor of two higher than any conceivable accident with a 5000 MW reactor system. Even with an excursion of this magnitude there would be no exposure to personnel exceeding AEC guide levels at distances beyond one mile from the test location. (Figure 5) The possibility of a reactor excursion accidentally occurring is infinitesimally small due to the use of multiple criticality control systems and strict administrative control.

### Conclusions

Reactor testing at the NRDS to date has not resulted in radiation exposure to on-site or off-site personnel exceeding AEC guide levels. However, we at SNPO-N, as well as our Users and Contractors, have not been without our problems both radiologically and cryogenically. Fortunately however, none of our incidents have been of a serious nature. We in Safety at the NRDS have attempted to keep up with the giant strides which nuclear technology has taken in recent months.

Safety, in a very technical sense, has by necessity played a significant part in the growth and progress of the Nuclear Rocket Development Station.

The new hybrid technology in practice at the NRDS presents the key to future progress in space exploration without compromising the safety of those who work intimately with that technology.

# NUCLEAR ROCKET DEVELOPMENT STATION LAYOUT

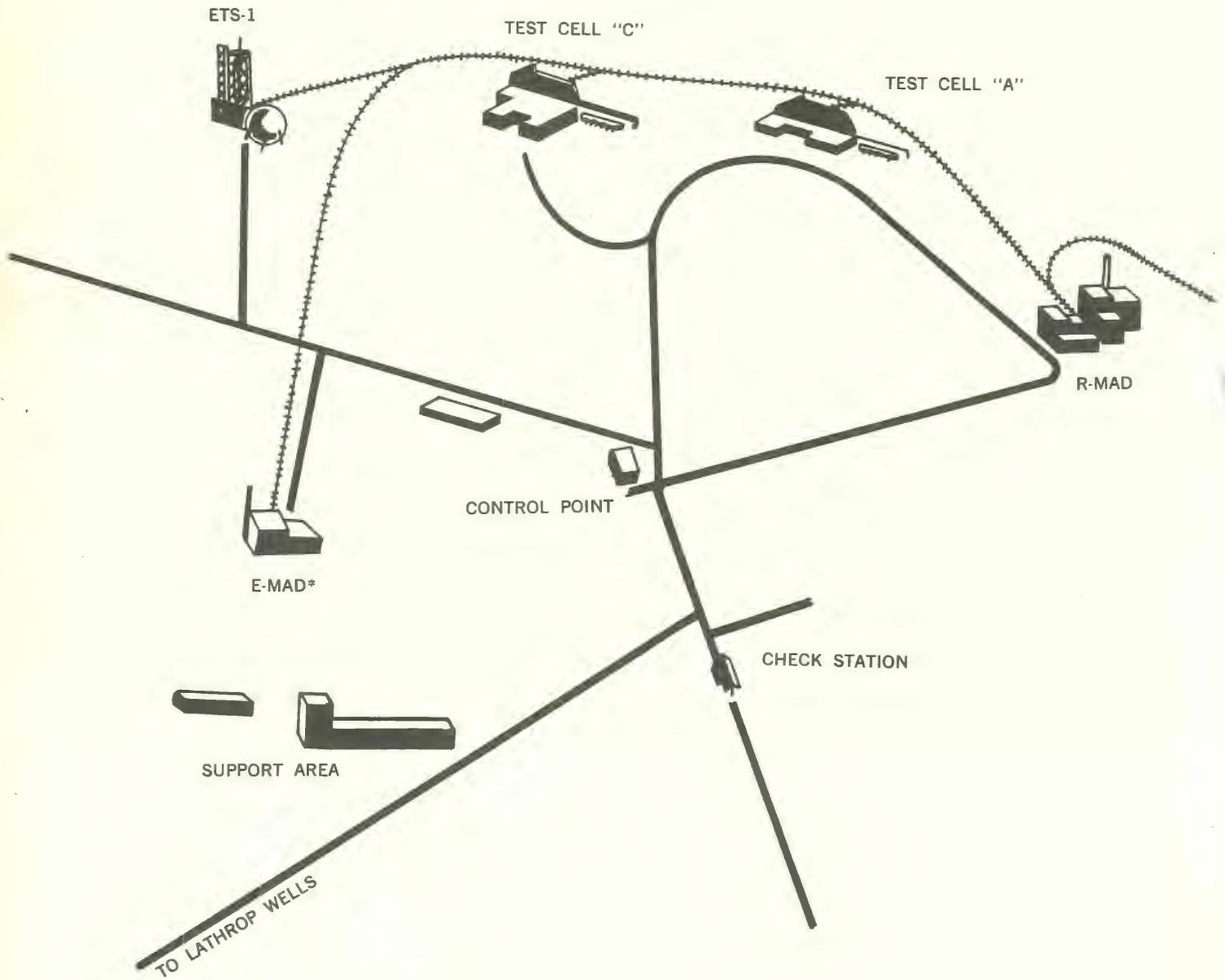
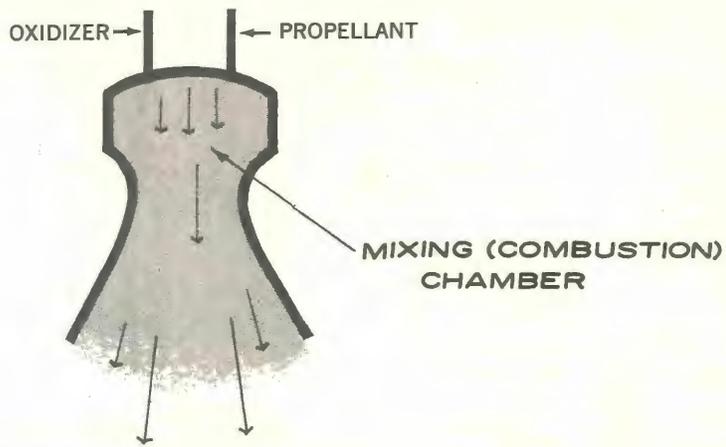
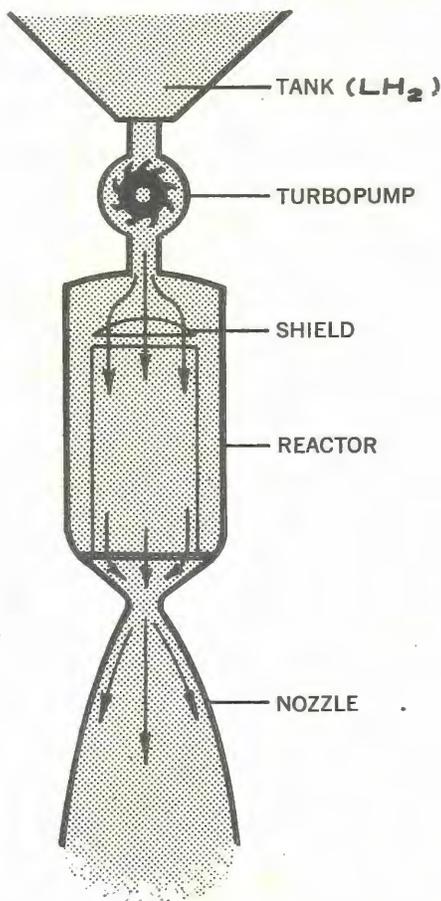


FIGURE 1

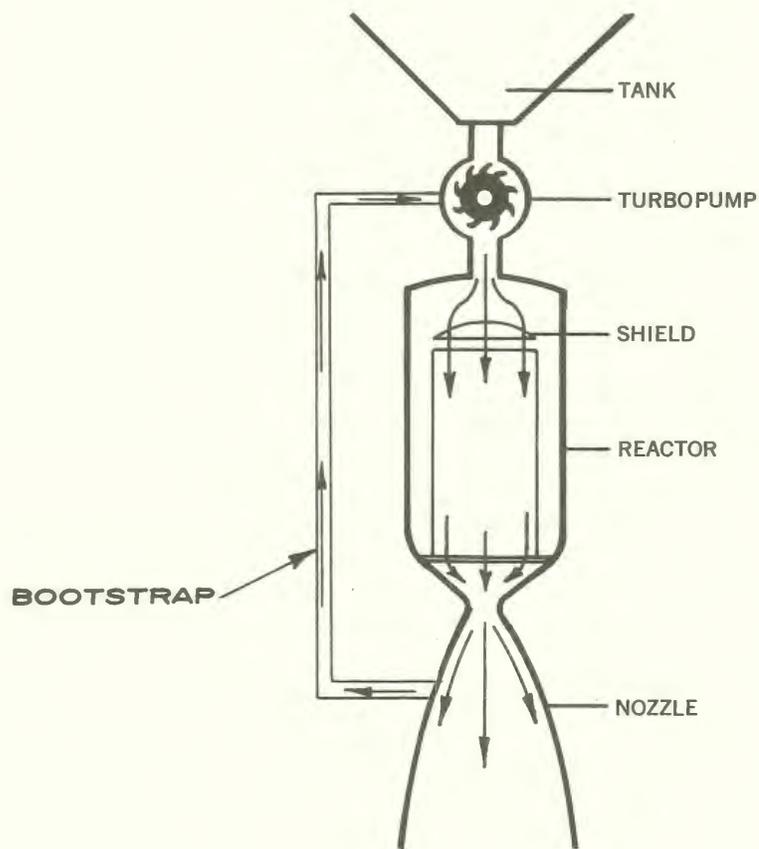


# CHEMICAL



# NUCLEAR

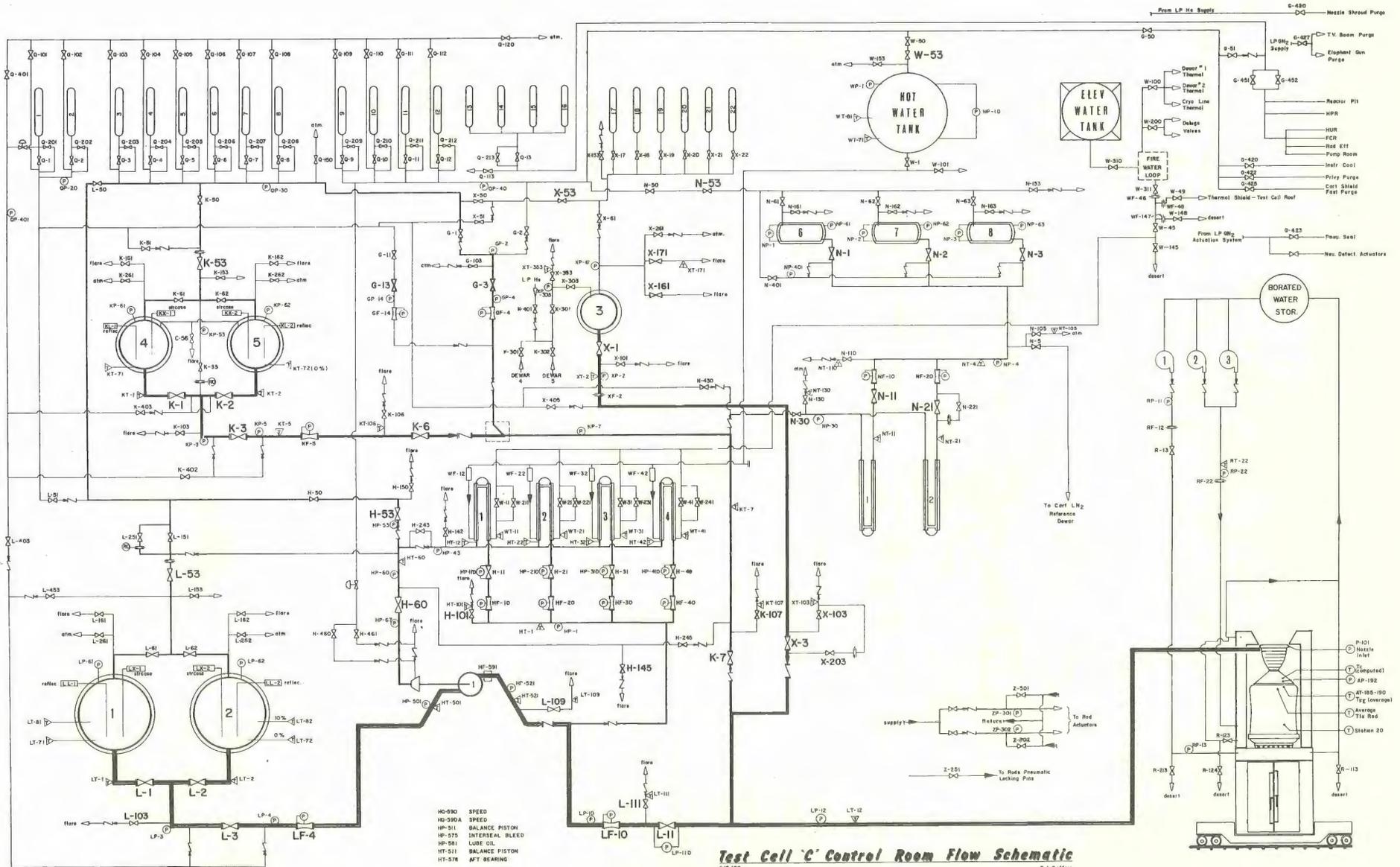
FIGURE 2



# NUCLEAR

FIGURE 3

18-31



6/2/76 REVISION 1  
 6/23/66 REVISION 1  
 8/27/66 REVISION 2  
 1/16/66 REVISION 2  
 1/16/67 REVISION 4  
 1/20/67 REVISION 5  
 T.J. Cutler

**FIGURE 4**

TRANSIENT NUCLEAR TEST EXCURSION - RADIATION EXPOSURES

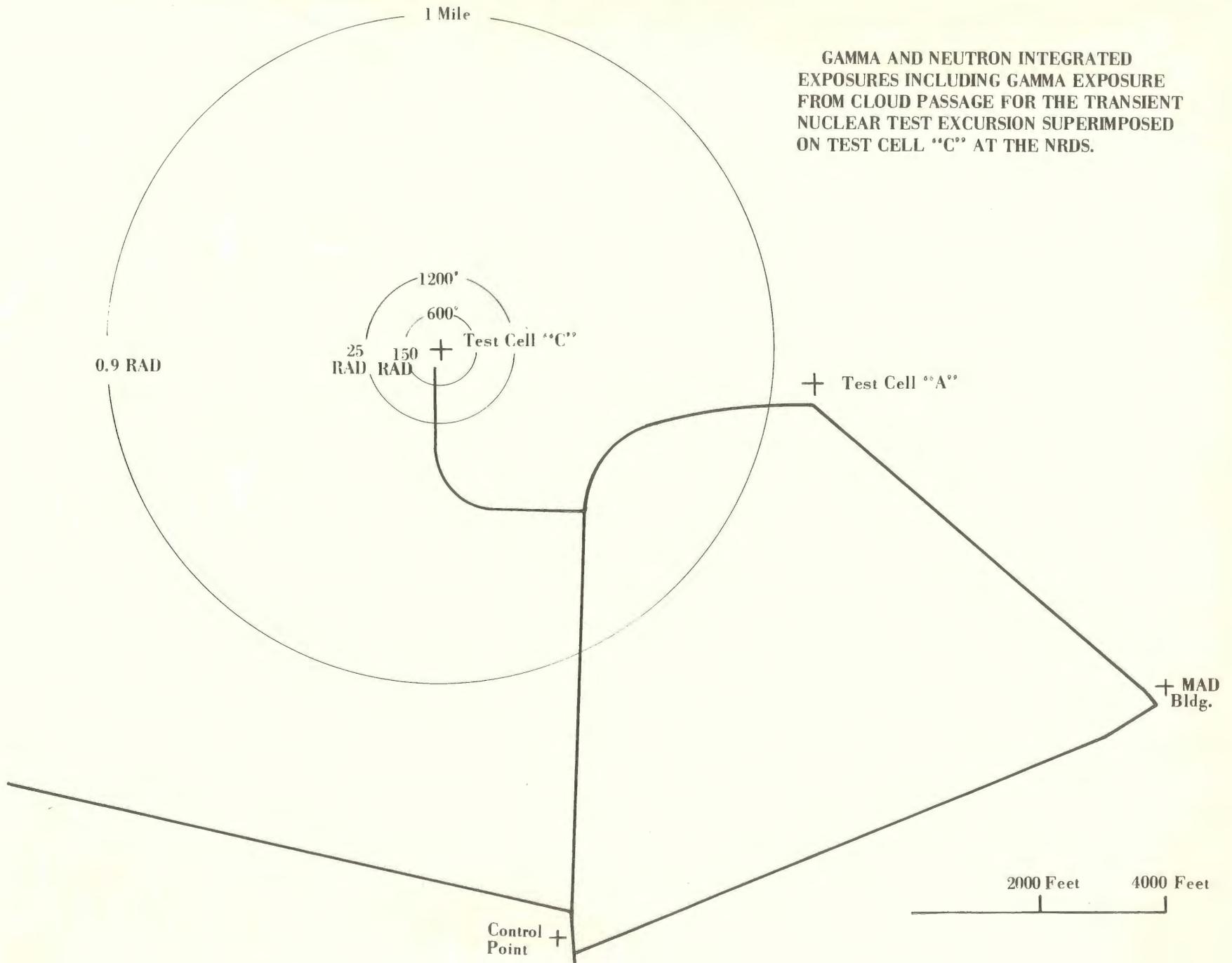


FIGURE 5