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LAUNCH FACILITY REQUIREMENTS FOR A LIQUID FLUORINE UPPER STAGE

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ABSTRACT

In a parallel activity to the development of a liquid fluorine upper stage vehicle, the problems associated with the launch facility must be addressed. This paper describes the factors that must be considered in the design and operation of such a facility. Among the factors discussed are general fluorine system requirements, launch facility requirements, safety considerations, and modification costs. Specific attention is given to storage and transfer, vapor disposal, leak detection, spills, aborts, range safety, and personnel protection.

INTRODUCTION

A parallel activity to the development of a fluorine stage is the development of the supporting ground facility. General information regarding handling of fluorine is available but the specific problems associated with fluorine aerospace ground equipment require delineation. In particular, it is necessary to consider the problems associated with the handling of this extremely reactive propellant in areas where personnel and sophisticated equipment are needed to support normal launch activities of an upper stage containing up to 20,000 lb of fluorine. The general safety requirements for liquid fluorine will be more severe than those imposed on systems using earth storable propellants. Consequently, extreme care must be taken to minimize all hazards associated with fluorine. This paper describes the equipment and techniques that must be considered for such a facility modification.

GENERAL FLUORINE SYSTEM REQUIREMENTS

The highly reactive nature of fluorine requires that the fluorine system be specially constructed and prepared. The selection of materials, control of contamination, and passivation of the system are primary examples of these general requirements. Numerous documents, such as references listed, give extensive data in these areas. The use of these documents is highly recommended. Since this information is readily available and is generally applicable to all fluorine facilities, these items are treated only briefly in this paper.

Material Selection

Material selection is of prime importance in the design of a facility using liquid fluorine. Basically, all materials react with fluorine under some conditions, and frequently these reactions are violent. Clean metals react slowly with fluorine at ambient or lower temperatures, forming a metal fluoride film on the surface that stops or greatly reduces subsequent reaction. However, if the metal is contaminated, the fluorine reaction with the contaminant may increase the local temperature to the point where the metal will react rapidly with the fluorine. If the fluorine supply is not removed, this reaction may become self-sustaining. Organic materials generally react violently on contact with fluorine, resulting in ignition or explosion. The heat of reaction is always high and unless the heat can be rapidly transferred away from the reaction zone, ignition is probable.

The degree of the reaction with any material is a function of the quantity and concentration of fluorine available, material, temperature, and time of exposure. Since a wide variety of operating conditions will exist, and material compatibility is a function of these conditions, it is very important that the material selection be based on the actual intended use, e.g., materials compatible with gaseous fluorine may not be compatible with liquid fluorine.

System Cleanliness

The most important factor in the safe operation of a facility using liquid fluorine is system cleanliness. The majority of system failures due to burn out or ignition can probably be traced to contaminants in the system. Commercial liquid and gaseous fluorine contain contaminants such as OF2, O2, N2, CF4, CO2, and HF, but the quantities are generally small and present no great problem. System corrosion may be increased due to these contaminants, but it is felt that this increase in corrosion is insignificant. Of greatest concern is the contaminant left in the system due to incomplete cleaning or contaminants that enter the system during or after assembly. Any system material that comes in contact with fluorine should be immaculately clean to avoid uncontrolled reactions. Support commodities such as pressurization helium and purge nitrogen used for fluorine systems should be filtered, dry, and free of hydrocarbon contaminants. Once assembled, the system should be kept under a positive pressure to prevent the entrance of air and water vapor into the system. Extensive studies have been conducted on the reaction of organic materials under passivation conditions using gaseous fluorine.
These studies indicate that organic contaminant reactions are sometimes incomplete and the residue can be violently reactive with liquid fluorine, either spontaneously or on shock or impact. Therefore, stringent cleaning requirements to eliminate contaminants from the system are absolutely necessary.

After assembly, moisture may enter the system if a positive pressure is not maintained at all times. If moisture is present when fluorine is introduced into the system, it will react to form hydrogen fluoride, which can cause extensive corrosion damage. If sufficient moisture is present to condense and form accumulations of water or ice, a violent reaction may occur when fluorine is introduced, resulting in possible burnout of the system.

Because elimination of contaminants is critical, it is of utmost importance to establish and adhere to stringent cleanliness requirements. A number of satisfactory cleaning and verification methods have been developed by the various fluorine facilities and are described in the literature.

Passivation

All parts of the system that will be in contact with fluorine during actual operations must be passivated before liquid fluorine is introduced into the system. Passivation makes the internal surfaces of the system inert by controlled reaction with gaseous fluorine. The internal metal surfaces react and inert metal fluoride films are formed that prevent or retard further reaction. In the past it was felt that this controlled reaction would also remove any system contaminants that remained after cleaning, but recent investigations indicate that this is dangerous practice. (2) Passivation must not be considered the final cleaning step. The system should be passivated only after the necessary cleaning and drying have been completed.

Passivation can be accomplished in a number of ways, including the vacuum method, purge method, or combinations of these, depending on system size and complexity. Briefly, the vacuum method involves system evacuation, followed by pressurization with gaseous fluorine. The purge method involves displacement of an inert purge gas with a gaseous fluorine purge. Final passivation should be performed using undiluted gaseous fluorine at the maximum system operating pressure and at ambient temperature.

LAUNCH FACILITY IMPACT

The basic problem is to provide the necessary propellant storage, transfer, and disposal facility for supporting an upper stage requiring up to 20,000 lb of liquid fluorine. Various facility configurations, vehicle loading methods, and specific factors affecting the design of such a facility are discussed in detail.

LF₂ Storage Methods

One of the primary considerations in the design of a fluorine launch facility is the selection of the fluorine storage method. Practical methods of LF₂ storage include on-pad storage, on-umbilical tower storage, mobile storage, and in vehicle tank storage. The principal elements, advantages, and disadvantages of each of these concepts are presented.

On-pad storage, downwind from the launch operation is safe and practical. All preload activities can take place in the revetted, protected, and isolated area while other on-pad activities are progressing. The storage area can be located at a distance from the vehicle to provide maximum protection from any on-pad vehicle incidents. The transfer lines from the storage area to the space vehicle tanks will be long and require considerable cooldown time, either with LN₂ or LF₂ before vehicle loading.

The principal elements of this loading system include a permanent remote storage area and transfer piping to the vehicle. The storage dewar will be used to receive and store liquid fluorine from mobile dewars and also serve as a ready service vessel during transfer operations.

A second practical method of on-pad storage would be to locate the storage dewar in the umbilical tower or launch/umbilical tower (L/UT). Storage in this area would be at the vehicle fluorine tank level and would include both LF₂ and LN₂ dewars (see Figure 1). The advantages of this approach are the reduction of cooldown time, rapid response loading, localized launch pad affected area, and a reduction in venting or in LN₂ precooling requirements. The disadvantages are the storage of LF₂ in the immediate vicinity of operations personnel and the higher susceptibility of damage either to or from the space vehicle in case of problems.

The principal elements of this loading system are the ground load station at the base of the umbilical tower, transfer piping up to the proper level of the umbilical tower, a loading dewar, and transfer piping to the vehicle. The loading dewar will be used to receive and store liquid fluorine from mobile dewars. The dewar will be vacuum and LN₂ jacketed to retain the fluorine with no boil-off losses.

The fluorine dewar is loaded from a loading station at the base of the umbilical tower through a liquid nitrogen-jacketed line. This transfer can be accomplished prior to launch day. A mobile dewar is moved to the loading station when replenishment is necessary. The liquid nitrogen jacket on the fluorine line is dual purpose because it is also used to transfer liquid nitrogen to the nitrogen dewar loaded on the umbilical tower.

Since catastrophic dewar failures are almost unknown, this system does not present a severe hazard. However, to further decrease the hazard
potential of the system, the storage dewars would be located in a special enclosure. This enclosure can be constructed on the outer edge of the umbilical tower, out of the path of most operations. The structure would use blast walls to separate the dewars from the umbilical tower. Blast walls would also be placed between the nitrogen and fluorine dewars. The enclosure would be equipped with a water fog deluge system for fire control and decontamination in the event of dewar rupture or burnthrough.

A third storage method involves use of mobile dewars that can be carried up the equipment elevator to the vehicle fluorine tank level. Even if several dewars were required to fill the vehicle tanks, this system has advantages of low fixed facility costs and the extremely localized effects on the total facility. Existing mobile dewars with an LF2 capacity of 450 gallons weigh 10,000 lb (not including the LN2 or LF2 weight) and are approximately 23 ft long, 11 ft high, and 8 ft wide. These dewars can service a space vehicle with a maximum of several loads. This system would not provide rapid loading because several connections are required and the logistics of moving the dewar to the vehicle would require some time. Remote operation would be more difficult and personnel would be in a relatively restricted area (no rapid egress available). If only a few launches are planned, the mobile dewars could be located behind the barrier as discussed previously without the additional costs of fixed piping and dewar systems. Another possible configuration would use mobile equipment located at the base of the umbilical tower with a fixed transfer line to the vehicle. Rapid personnel egress would be a major advantage of this system over the other mobile system.

A fourth method of loading the space vehicle involves preloading of the LF2 tank before mating the stage to the booster. The tank would be loaded from a permanent or mobile de- war in a remote service area. This process has been used successfully for earth storables on several payload packages. It has a severe disadvantage in that the lightweight vehicle tank will contain a hazardous cryogenic commodity for several days while checkouts occur. The maintenance of the unvented tank would require an active refrigeration system on or associated with the vehicle.

The specific quantities of propellant, countdown time available for loading operations, number of launches anticipated, and launch pad safety restrictions will be important criteria in selecting the proper storage method.

Propellant Transfer System

The transfer system configuration must be selected concurrently with the storage system. Major areas to be considered include transfer lines, control valving, and the method of fluid transfer.

The type of transfer line depends on the storage method and the length of the line. For short distances the transfer line may be uninsulated. For longer distances, the transfer lines should be vacuum or LN2 jacketed. Where the venting or disposal of copious quantities of fluorine is undesirable, the lines should be LN2 jacketed. The LN2 jacket can be filled first to precool the line. The LN2 also eliminates heat transfer into the LF2 during transfer. If the LN2 jacket is maintained at atmospheric pressure, the fluorine will be subcooled with a vapor pressure of approximately 5 psia. However, a slight positive pressure (20 psig) in the LN2 jacket will maintain the LF2 at a vapor pressure slightly above atmospheric to prevent the entrance of contaminants.

The addition of an LN2 jacket has several advantages. Since fluorine will not react with LN2 in small quantities, the jacket can absorb some fluorine leakage with only minimal hazard. The leak can be detected by sampling effluent from the LN2 vent stack. Considerably less fluorine disposal or recycling will be required since no fluorine boiloff will occur. The less hazardous operation of precooling the transfer lines with LN2 permits a shorter duration LF2 transfer, which shortens launch pad restriction time. Since the propellant is maintained in a single-phase flow condition, less pressure will be required for transfer.

Heat transfer rates from the atmosphere to a nitrogen-jacketed transfer line have been evaluated for various pipe diameters and frost or insulation thicknesses. Nitrogen consumption in pounds per hour can be readily estimated using this information. The transfer line must be sized to meet the flow rate and operating pressure requirements of the specific system. If adequate transfer pressure is available the line size should be optimized for diameter. However, if pressure drop is critical, the line should be optimized within limits of practical sizes. For subcooled liquid fluorine, the line size can be selected using standard equations.

Liquid fluorine can be transferred by pumping or gas pressurization. It is desirable to transfer fluorine without pumping. Although some development work has been done on LF2 transfer pumps, a review of the literature failed to reveal any operational transfer pumps presently in service. Pressurized transfer with makeup pressure by helium is essentially trouble-free and very reliable. The necessary transfer pressure can be calculated by adding the frictional loss and the head loss from standard equations. When transferring to the vehicle, the minimum acceptable pressure at the vehicle tank will be 16 psia to preclude tank implosion and prevent contamination from entering the tank. Transfer of the fluorine from ground level to an upper stage level will require relatively high pressure. These pressures exceed the maximum operating pressure of presently available dewars, necessitating the design and fabrication of high-pressure storage vessels or the use of a pump transfer system.

Regardless of the type of transfer system selected, design of the control valve(s) should use remote operation. Transfer valving and control systems should not present major problems for the
designer since several operational fluorine facilities use adequate methods of transfer control. Proper valve wiring (normal position in power loss) and automatic system safing (closing valves to isolate any damaged area) should be determined by a thorough hazard or failure mode analysis and incorporated in the design.

Space Vehicle Tank Loading and Ground Hold

A number of alternative on-pad loading concepts are available. Fester, Page and Bingham have derived and experimentally proven a satisfactory no-vent loading concept. Rose suggests that an LN\textsubscript{2} overspray can be added to the vehicle tank and the resulting gaseous nitrogen can be used effectively to purge the high performance multilayer insulation system on the tank. NASA LeRC has used an open top integral LN\textsubscript{2} tank (beanie) in facility operation and Rocketdyne has used a closed top beanie. Another alternative is to load the tank in a vented condition, although this is not desirable since vented vapor disposal or reliquefaction is required.

Fester, et al., in the Liquid Fluorine No-Vent Loading Studies concluded a no-vent fill of a prechilled vehicle tank is very feasible. Based on this no-vent loading study, this method appears satisfactory for loading fluorine into a vehicle tank. The primary criterion, aside from not venting, is to maintain a positive pressure inside the tank to prevent implosion. The tank would include an integral tube-type heat exchanger on the tank wall.

Before loading, the ambient temperature tank would contain 100% gaseous fluorine at about 60 psia. The loading process would be initiated by cooldown of the tank by passing cold GN\textsubscript{2} or LN\textsubscript{2} through the integral heat exchanger. After the tank has been cooled, propellant loading would be initiated. The condition of the propellant being loaded would be such that its temperature would be slightly greater than its atmospheric saturation temperature when entering the tank. The temperature of the tank and loaded liquid would be maintained slightly above the atmospheric saturation temperature to maintain the ullage pressure slightly above one atmosphere. As loading commences, condensation of vapor prevents the ullage pressure from rising appreciably. After loading is complete, the tank would be pressurized with helium to 15 psi above propellant vapor pressure and the integral heat exchanger would be used to maintain the propellant temperature within the desired temperature band for ground hold. Adequately high flow rates will be attainable with this method as long as the initial commodity in the warm vehicle tank is a condensable, such as GF\textsubscript{2}.

No-vent loading is a very acceptable approach for conducting load operations with high-energy propellants at the launch complex, where release of toxic and reactive vapors must be minimized. Empirical data obtained in a 300-gallon LF\textsubscript{2} flow facility agrees well with the analytical model developed in this program.

Rose modified the airborne tank by adding an LN\textsubscript{2} spray system in lieu of the integral tube-type heat exchanger. Two manifolds, one at the top, and one at the midsection of the tank, and several perforated tubes are used to distribute a thin film of liquid nitrogen over the outside surface of the tank under the multilayer insulation. This thin film of liquid nitrogen intercepts incoming heat before it reaches the tank wall. The intercepted heat vaporizes the liquid nitrogen and the resulting gaseous nitrogen diffuses out through the multilayer insulation. In this way, the spray cooling system purges the insulation and protects the tank from incoming heat. Transfer is still by the no-vent load method.

The spray cooling system is used only for cooldown, but it can be continued if an unexpected hold is encountered after the fluorine tank has been loaded. Normally, the gaseous nitrogen purge that is maintained before loading propellants is continued until launch. Both the gaseous nitrogen purge and the liquid nitrogen used for cooling are introduced into the insulation through the same manifold.

In their facilities, NASA LeRC and Rocketdyne use an LN\textsubscript{2} container that is integral with the tank. Although it was developed for ground storage, it is possible to adapt the design for airborne use. An open-top beanie as shown in Figure 2 can be used to recondense the fluorine vapors resulting from heat input to the tank. The beanie can be drained just before launch. Rocketdyne's closed beanie (see Figure 3) can provide the same type of condenser with an additional feature of a controllable vent to keep the LN\textsubscript{2} pressurized and the fluorine tank pressure closely controlled.

Another approach would be to cooldown the vented vehicle tank with fluorine as the initial transfer step similar to the loading methods used with other cryogens. Heavy venting and the necessity to recondense the GF\textsubscript{2} or dispose of many pounds of expensive fluorine makes this system very undesirable. This method would necessitate continual topping during ground holds.

The most efficient loading concept can be chosen after vehicle on-pad-loaded hold times, tank sizes and configurations, loading flow rates, insulation materials, and pad safety requirements are known.

Vapor Disposal

Propellant handling at a launch facility will require the venting of fluorine vapors during transfer, depressurization, or purge activities. Methods of disposal of these vapors must be evaluated and incorporated into the facility to prevent endangering personnel, property, water shed, vegetation, or local wildlife. Due to the toxicity and reactivity of fluorine, venting directly
to the atmosphere must be prevented. Several methods are available to eliminate venting or to dispose of normal vent vapors in a safe manner.

(3) Since it appears unlikely that all venting can be eliminated, a combination of methods appears feasible. The storage vessel can be equipped with a recompress to liquify boiloff vapors from the system, a vaporizer for self-pressurization, and an LN2 jacket to subcool the stored propellant. These features result in a no-loss storage system that requires no normal venting. However, venting of the storage system could be required due to a control system malfunction or LN2 shortage. This venting along with normal transfer line purging or vented tank loading methods would require the system to incorporate a vapor disposal system.

Methods available and presently used to detoxify or dispose of fluorine vapors include hydrocarbon burners, charcoal reactors, or alkaline chemical treatment. (3) The methods most adaptable for use at a launch facility are the hydrocarbon burner or charcoal reactor. The hydrocarbon burner type is installed at the top of a vent stack and reacts the fluorine with propane or methane above the stack exit. The reaction product is basically CF4 and HF. Since HF is only slightly less toxic than fluorine and is more corrosive, this system should only be used in areas where venting of these products would not be harmful or the vent rate is controlled so that tolerable atmospheric HF concentrations are not exceeded. A charcoal reactor similar to the one shown in Figure 4 would be the best system for use at a launch facility of the size being considered. (3) This method involves the reaction of fluorine with wood charcoal to form CF4 which is basically inert and nontoxic. (6) Small quantities of fluorine can be detected in the reactor effluent, but are generally below 100 ppm and will rapidly disperse into the atmosphere. The disposal rate is dependent on the surface area of the charcoal available for reaction. The rate increases as the size of charcoal particles decreases. Moisture or impurities in the charcoal may result in HF in the effluent, but the quantity should be small compared to that of a hydrocarbon burner.

Both of these disposal methods can be used to dispose of 100% fluorine vapor or vapor diluted with N2 and/or He. Some dilution of the vented fluorine vapor with an inert gas is recommended to decrease the reaction temperatures and prolong the life of the disposal system.

LEAK DETECTION

Leaks can be classified as hazardous to personnel and/or hazardous to equipment. Adequate literature is available to help in the selection of appropriate sensors for detection of the various levels of leaks. Consistently, however, these articles point to the inadequacy of all instruments designed for fluorine detection. Several acceptable units are available, but each will need attention to assure proper operation and sensing at a launch complex. Basically six types of leak detection methods are available.

1) The human nose;
2) Ammonium hydroxide squirt bottles;
3) Potassium iodide paper;
4) An electrical warning system;
5) Chemical instruments;
6) Infrared sensors.

Extensive elaboration of these methods would only be repetitive to other articles.

Briefly, however, the conditions that must be detected can be separated into gaseous fluorine leaks, liquid fluorine leaks or spills, and vapor concentration in effluents.

A gaseous fluorine leak may stem from a leak in an ambient temperature gas system, a semicooled liquid system, such as during cooldown, or a small leak in a liquid system when cooled down. Any leaks require immediate attention to eliminate them. Most common among these are leaky fittings, disconnects, valve stems, and instrumentation ports. The human nose is a very good sensor for low concentrations and can be relied upon to tell a technician when concentrations are growing. Ammonium hydroxide squirt bottles, potassium iodide paper, or an electrical warning system of the burglar alarm type can be effectively used to sense the leak. When leakage is detected, the system should be vented; the exact location determined, and immediately repaired. Safety requires that all leaks be repaired in an unpressurized and purged condition.

Liquid fluorine leaks or spills are very hazardous. Usually a liquid leak will cause burning on contact with almost anything, including protective clothing, surrounding incompatible or contaminated equipment, and often the line from which it came. Leaks of this nature can be sensed with infrared sensors or burnout wires located in the area of potential leaks. These sensors can be used to operate automatic deluge systems or to automatically isolate the affected area. Conditions that must be detected, but are not necessarily hazardous, include fluorine concentration in jacket vent systems, in the disposal stack, or in effluent purge gases.

As noted, the LN2 jacket around fluorine transfer systems helps minimize the hazard associated with a leak in the fluorine line. Unfortunately, it also obscures the location and makes detection difficult. The addition of a fluorine sensing instrument in the jacket vent system will aid in determining the concentration, if any, of fluorine being vented. A quantity limit, beyond which a warning is sounded, can be established and used.

A very good method of determining when the charcoal level in the disposal unit is low is to sample the disposal stack effluent. A small
amount of fluorine will always be present so the sensor could be set to sound the alarm at a level of 100 ppm. Sensing the hot effluent, however, may be difficult with existing equipment.

Before any system that have previously contained fluorine can be opened for maintenance it must be thoroughly purged with an inert gas. Equations regarding the required length of purge time exist and can be used in conjunction with effluent samples to assure safe concentration levels. Chemical sensors are very acceptable for this application.

Leaks and spills are detectable and while they pose the most hazardous safety conditions, they can be minimized by proper design, care, and operation.

**Propellant Spillage**

The design of any fluorine handling facility must include provisions for handling accidental releases of fluorine. Although fluorine systems are designed to eliminate all leakage, the reactive and cryogenic characteristics of the fluorine make it virtually impossible to guarantee the prevention of accidental spills.

Dispersion is usually considered effective for small leaks of gaseous fluorine that create non-hazardous concentrations. The escaping fluorine is allowed to diffuse into the surrounding area and be dispersed by atmospheric conditions. The amount of fluorine that can be disposed of safely by this method is governed by the location of the fluorine system. If the system is in a relatively remote area, fairly substantial amounts of fluorine could be safely released without treatment. The reactivity and toxicity of fluorine make it necessary to treat most leakage or spills to limit damage. Treatment methods include water deluge and chemical neutralization.

Deluging of fluorine spills with a fine water spray actually results in reaction of the fluorine with the water. The product of the reaction is hydrogen fluoride. Sufficient water is used to react with the fluorine and to dilute the resulting hydrofluoric acid to a harmless concentration. The reaction is exothermic, but this heat is absorbed by the excess water used in the deluge. Use of water for neutralizing fluorine spills must be carefully evaluated because the reaction is violent. In the case of large spills it is difficult to apply sufficient quantities of water to control the reaction. Insufficient water only tends to spread the contamination. At the other extreme if a small leak is deluged the damage done by the water may be far greater than that which would have been done by the fluorine itself. It is necessary to contain and neutralize the contaminated water prior to release into the water shed.

Another method of treating spills is to neutralize the fluorine chemically. For liquid fluorine systems, it is possible to provide catch basins which contain limestone. The spilled fluorine is channeled to the limestone where it reacts and is neutralized. Other systems have been devised that blanket spill areas with soda ash which neutralizes the fluorine. The dry soda ash deluge method results in a solid residue that will present tremendous clean-up problems.

The method for handling fluorine spillage must be selected to suit the requirements of the specific system. A method which is attractive for one area can be completely unsuitable for another. Selection of spill control for a launch facility must be based on system requirements, probable spill quantities, and system location. On the bright side, many studies of fluorine spills indicate the magnitude of the problem is grossly overstated. In addition chances of these spills occurring can be greatly reduced, if not eliminated, by proper design and operation.

**Aborts**

A launch facility for a liquid fluorine upper stage must have the capability of safing the vehicle should a launch be delayed or aborted after propellants have been loaded. The design of the facility must provide for three different types of aborts or delays.

The system must be capable of maintaining the fluorine on board for extended hold periods if an unscheduled launch delay is encountered. The fluorine must be maintained in a flight condition throughout any hold period. Because it is cryogenic the fluorine will boil off during any hold unless it is continuously cooled. Other cryogens are usually topped to make up for the boil-off losses. Fluorine can also be topped, but it is necessary to neutralize or recondense the vent gases. To prevent excessive venting it is possible to refrigerate the fluorine tank to maintain it in a no-vent condition.

The fluorine ground support system must provide a means for off-loading in the event the launch is aborted before liftoff. The off-loading capability should include a rapid detanking mode for emergency situations. Normal detanking can be accomplished by back transfer to the facility storage dewar. The storage dewar will have to be vented down if it is being used for topping or if loading has just been completed. The vent gases from the storage dewar must be channeled through the disposal system. Detanking can be accomplished by pressure transfer using the vehicle pressurization system to maintain the tank pressure.

The necessity of venting the facility storage dewar, and in some cases terminating topping operations to prepare for off-loading, could greatly delay an emergency off-loading. Therefore, it may be necessary to have a separate emergency dump system. Emergency off-loading of most cryogens is accomplished by dumping the propellant into a catch pond where it is allowed to boil off. This cannot be permitted with fluorine. Therefore, it may be necessary to have a catch dewar ready at all times to receive the fluorine in the event it is necessary to dump the tank. Another
possible method of emergency dumping would be to off load the tanks directly to the vent disposal system. The remote location of the system would provide sufficient transfer lines to allow the liquid to boil off before it reached the disposal system. If necessary, a holding tank could be included in the system to retain any liquid until it boiled off and to control the disposal rate.

One other type of abort affects the fluorine system. This is a catastrophic abort which occurs prior to or immediately after liftoff. The ground support system must be designed to minimize fluorine damage in the event of this type of abort. Features of this system would include minimizing the amount of fluorine left in transfer lines and protecting storage dewars from damage.

SAFETY CONSIDERATIONS

General safety considerations will not differ appreciably from those presently in effect for other toxic or cryogenic propellants. The three specific areas of safety that will require special emphasis are range safety, atmospheric conditions, and personnel protection.

Range Safety

As with any operation conducted at the Air Force Eastern Test Range (AFETR) a launch facility for a liquid fluorine stage must meet range safety rules. It is also necessary for general fluorine safety rules to be met. This means that a complete review of the current range safety rules must be made to ensure that a comprehensive set of rules are established.

In general, the range safety rules governing toxic and cryogenic propellants are directly applicable to this system. These cover areas such as environmental safety, pad access, atmospheric conditions, time of loading, etc. However, in some areas, such as protective clothing, the current rules are not adequate for fluorine. This indicates that each rule must be reviewed to determine if changes are necessary.

Education is one of the prime problems in obtaining adequate and realistic range safety requirements for a fluorine system. To the uninformed the word "fluorine" conjures up visions of uncontrollable destruction. Thus, people who are not familiar with fluorine technology will generally set safety standards that are unnecessarily restrictive. In some extreme cases the attitude is to insist that fluorine cannot be handled safely and therefore will not be permitted.

This problem makes it mandatory that a primary effort in developing a fluorine launch facility is the education of operations and safety personnel. A coordinated effort can then be made to develop adequate, comprehensive range safety rules for fluorine systems.

Atmospheric Conditions

To prevent creation of unnecessary hazardous conditions it is necessary to define the atmospheric conditions under which operations can be conducted. Toxic and corrosive vapors must not be carried by the winds into areas where personnel or property damage can occur. Therefore, it will be necessary to evaluate any proposed launch facility to determine which wind corridors permit safe operations. Fluorine equipment must be located to take advantage of prevailing winds to disperse any fluorine vapors into safe areas.

Figure 5 shows a theoretical launch complex layout for a fluorine vehicle. The fluorine storage area and vent disposal burner have been sited so that they are downwind of all activities the majority of time. The wind corridor indicates the permissible wind direction for propellant transfer or launch operations. The hazard zones indicate the areas where exposure can be expected, should a spill occur. This type of evaluation should be made for any fluorine launch facility.

An additional consideration to be included in selection of wind corridors is the launch trajectory. The allowable launch wind corridors should be selected so that the propellant released from a vehicle destructed after launch will be dispersed in a safe area.

Other atmospheric conditions that curtail operations include temperature inversions, which prevent adequate vapor dispersion, and rain or fog. Venting or inadvertent fluorine releases during periods of precipitation result in the formation of hydrogen fluoride, which not only causes severe corrosion of the facility, but also contaminates the vegetation, soil, and water shed. Soil and atmospheric sampling programs should be established to monitor for any long-term increase in contamination due to fluorine operations.

Personnel Protection

Much has been prepared regarding the subject of personnel protection associated with fluorine systems. Practices should not differ considerably from protective equipment and safety practices for more conventional earth storable hypergolic propellants such as hydrazine, IRFNA, nitrogen tetroxide, etc. The past record of handling fluorine is significantly free of accidents and can form the basis for the personnel protection program at a launch complex. Personnel protection extends far beyond any connotation of clothing and first aid. To summarize, personnel protection must include the following areas:

1) System design considerations;
2) Safety practices, rules, and regulations;
3) Training programs;
4) Launch complex operations including -
a) Restriction of access to authorized and necessary personnel,

b) Personal and equipment cleanliness,

c) Protective clothing and breathing equipment,

d) Controls for maintenance of transfer or storage systems,

e) Provision of warning sensors.

A brief discussion of each of these areas follows.

System Design Considerations - The protection of personnel from the hazards of fluorine must be considered starting with the design of the transfer and storage system. It will be an important consideration in the choice of the location, layout, buildings and equipment design. The geography of the terrain, meteorological data, and proximity to congested or densely populated areas or to inhabited buildings should be included in the basic considerations. All the above factors include the protection of disinterested and uninformed personnel in surrounding areas. Rapid egress for operating personnel must be considered in locating piping, components, and pieces of equipment.

Safety Practices, Rules, and Regulations - The standard safety practices that prevail at installations where hazardous or flammable chemicals are stored should be in effect at the launch facility. These practices include restricting the traffic near or in the area and adopting the buddy system. During any potentially hazardous operation in restricted quarters, trained personnel must be equipped with self-contained breathing air and complete protective clothing so they may come to the immediate aid of the operating personnel in case of a spill or fire.

All operating procedures must be thoroughly checked out on a dry or LN$_2$ filled system before operations begin with fluorine. Of course, strict adherence to the procedures is mandatory. A periodic review of rules and regulations and a periodic dry run of the procedures is suggested.

Training Programs - The already successful training programs in effect at KSC and APEIR, can easily be modified to include fluorine training. The alleviation of fear with retention of respect must be a major goal of these training programs. Personnel from operational fluorine facilities can assist in the preparation of these training programs.

Restriction of Access to Authorized and Necessary Personnel - The potential hazards increase in proportion to the lack of knowledge of fluorine and its properties. For this reason, only authorized personnel should be permitted on the launch complex during any fluorine operations. Official visitors can be permitted if they are briefed on the basic fundamentals and are continuously escorted by well-informed and well-trained employees. They should also be escorted to safe areas prior to starting any hazardous operation such as vehicle tank loading. Any unnecessary personnel, even though adequately trained, should be prohibited from the proximity of any hazardous propellant during transfer operations.

Personal and Equipment Cleanliness - Most or all operational fluorine facilities have experienced failures associated with lack of proper cleanliness controls. The required cleanliness level inside the system is not argumentative but personal cleanliness seems to be questioned. Tools, gloves, hands, uniforms, etc, should be free of particles, grease, dirt, lint, and general contamination. Washing of hands both before and after fluorine system work is essential. The small amounts of hydrogen fluoride which may be present on valves, lines, connections, etc, can burn almost as quickly and severely as fluorine. External cleanliness helps to promote and maintain internal system cleanliness, and the latter is mandatory.

Protective Clothing and Breathing Equipment - The NASA-LeRC policy to use protective equipment only when it improves safety should be a cardinal rule.

(6) Three different levels of protection seem warranted. Operations personnel should be outfitted with aprons, face shields, hard hats, gloves, and boots (see Figure 6). Each of these items must be quickly removable in case of fire. Rapid movement from the area is the prime reasoning for this level of garmenting. A second, and more protective style of clothing includes, a self-contained breathing air pack and a full protective uniform. A person in this clothing can withstand higher levels of fluorine concentration for short periods of time and can aid operations personnel in case they become disabled in a fluorine atmosphere. Even this equipment should be able to be removed rapidly since it won’t be compatible with direct sprays of fluorine and may ignite and burn. Operating personnel may be outfitted with this uniform if they must enter a very restricted area and cannot evacuate the area completely in case of a problem. A third type of protection is applicable for most other personnel required on the complex during hazardous operations. This consists only of a gas mask equipped with a special fluorine cannister (see Figure 7). This device must only be used to effect an immediate evacuation from the area. Blockhouse personnel, supervisors, inspectors, safety personnel, and personnel working in other areas should be equipped in this manner.

Experience has shown that no safety clothing has been devised that will give guaranteed protection against a high pressure jet of liquid or gaseous fluorine. (3) The important thing regarding protective materials is to subject them to a test under simulated operational conditions, as opposed to reliance on data from other tests that may or may not be under similar conditions, and then restrict their use to the proven conditions.

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Controls for Maintenance of Transfer or Storage Systems - Since it is desirable to maintain a positive pressure in a fluorine system, any entries into the system can be assumed to spray liquid or gas upon opening. Extra precautions must be taken to assure no fluorine, and little or no pressure, is in the system before entry. Assurances should include valve position checks, in-line fluorine concentration sensors, pressure gages, helium or nitrogen purges, tags on valves to assure no position change, and safety positioning of all powered valves in case of a power outage.

Provision of Warning Sensors - With self-contained breathing apparatus or gas masks, where the wearer will not sense fluorine concentrations by smell, automatic warning sensors must be provided. Possibly a system of red, yellow, and green would be appropriate — with a green indicating below maximum allowable concentration (MAC), yellow indicating above MAC but below an emergency evacuation level, and red indicating an emergency evacuation level. These sensors must also be aural since the personnel will not constantly monitor them.

Cost Evaluation

A brief evaluation of the costs required to modify an existing facility to handle fluorine indicated the costs would be of the same magnitude of any similar size cryogenic system. Of course if a LN$_2$ system must also be added, the cost will be higher due to this second cryogenic system. The following table shows approximate activation costs for the facility concepts discussed in this paper. These values include costs for materials, cleaning, and nominal installation. No conceptual or final design, procedure preparation or checkouts are included in the approximate costs.

<table>
<thead>
<tr>
<th>Storage Concept</th>
<th>Approximate Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Pad</td>
<td>$250,000</td>
</tr>
<tr>
<td>Umbilical Tower</td>
<td>$200,000</td>
</tr>
<tr>
<td>Mobile:</td>
<td></td>
</tr>
<tr>
<td>At base of tower</td>
<td>$100,000</td>
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<tr>
<td>On equipment elevator</td>
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<td>Vehicle Tank</td>
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CONCLUSIONS

This discussion has indicated the basic factors that must be considered in the design, installation, and operation of a launch facility in support of a fluorine upper stage. Although liquid fluorine is more reactive than currently used propellants and requires special handling techniques, there appears to be no insurmountable problems associated with its use. Techniques and equipment for supporting an upper stage fluorine vehicle are currently available and it only remains to apply this information to the problem of a specific vehicle and associated launch facility.

REFERENCES


BIBLIOGRAPHY


Figure 1 - Fluorine Storage Equipment
Figure 2 - Open Top Beanie

Figure 3 - Closed Top Beanie
Figure 4 - Charcoal Reactor for Fluorine Disposal
Figure 5 - Wind Corridor Requirements
Figure 6 Personnel Protective Equipment

Figure 7 Gas Mask for Evacuation Use