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A LOGISTICS AND POTENTIAL HAZARD STUDY OF PROPELLANT SYSTEMS FOR A SATURN V DERIVED HEAVY LIFT (THREE-STAGE CORE) LAUNCH VEHICLE

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ABSTRACT

The Bush Administration has directed NASA to prepare for a return to the moon and on to Mars – the Space Exploration Initiative. To meet this directive, powerful rocket boosters will be required in order to lift payloads that may reach the half-million pound range into low earth orbit. In this report an analysis is presented on logistics and potential hazards of the propellant systems envisioned for future Saturn V derived heavy lift launch vehicles. In discussing propellant logistics, particular attention has been given to possible problems associated with procurement, transportation, and storage of RP-1, LH_2, and LOX, the heavy lift launch vehicle propellants. Current LOX producing facilities will need to be expanded and propellant storage and some support facilities will require relocation if current Launch Pads 39A and/or 39B are to be used for future heavy lift launches. No major technical problems are envisioned except for improved noise-abatement measures. Included in the report is a discussion of suggested additional studies, primarily economic and environmental, which should be undertaken in support of the goals of the Space Exploration Initiative.

SUMMARY

As part of the Space Exploration Initiative for the year 2000 and beyond, NASA is planning flights to both the moon and Mars. Initially, eight flights per year are planned; four to the moon and four to Mars. The proposed launch vehicle is a Saturn V derived HLLV (three-stage core) with a four-booster configuration. The payload will be large, 620 Klbs. (281 mt). Lift-off will be accomplished (Core Stage I and four boosters) with seventeen F-1A engines. The propellant system will consist of high grade kerosene fuel (RP-1) and liquid oxygen (LOX) for the first stage and LOX and liquid hydrogen (LH_2) for the second stage.

Although the proposed propellant system represents a technology which is at least thirty years old, the magnitude of the quantity of propellants which will be employed in HLLV launch vehicles presents unique logistics, handling and safety problems. The HLLV will consume 20.6 million pounds of propellant, a 340% increase over propellant consumption of the Saturn V. There are unique problems which must be addressed when handling this quantity of fuel.

Problems addressed during the course of this work period were:

- o Petroleum and petrochemical refining/production capabilities of the United States in terms of future HLLV operations and performance goals.
- o Present and future LH_2 and LOX production capabilities of the United States in terms of future HLLV operations and performance goals.
- o Logistics of transporting large quantities of RP-1, LH_2, and LOX from production sites to HLLV launch sites.
- o Storage of large quantities of propellants in the vicinity of HLLV launch sites.
- o Safety aspects and possible accident scenarios such as RP-1 emergency dumping, acoustic problems, and fireball and blast effects.

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LIST OF ABBREVIATIONS AND ACRONYMS

AFB - Air Force Base

ASEE - American Society fOR Engineering Education

Btu - British thermal unit

CCAFS - Cape Canaveral Air Force Station

DAF - Directorate of Aerospace Fuels (U.S. Air Force)

dB - decibels

EPO - Exploration Program Office

g - Earth's gravitational constant; 32 ft./sec./sec.

HLLV - heavy lift launch vehicle

KSC - Kennedy Space Center

LH_2 - liquid hydrogen

LOX - liquid oxygen

mt - metric ton; 1,000 kilograms (2204.6 lbs.)

NASA - National Aeronautics and Space Administration

NLS - National Launch System

psi - pounds per square inch

RP-1 - Rocket Propellant - 1 (refined kerosene)

SEI - Space Exploration Initiative

SSC - Stennis Space Center

VAB - vehicle assembly building

VS - short ton (2,000 lbs.)

I INTRODUCTION

On July 16, 1969, the Apollo 11 Spacecraft, freed from Earth's gravity by means of the powerful Saturn V launch vehicle, took man to the surface of the moon for the first time. Over the next three years, this phenomenal feat was to be repeated five more times. In each mission, a Saturn V launch vehicle was used to boost the various Apollo spacecrafts to the moon. The force used to accomplish the first stage of this unparalleled feat was provided by a cluster of five Rocketdyne F-1 rocket engines, each developing over 1.5 million pounds of thrust (1). Since 1972, major activity at Kennedy Space Center (KSC) has centered around the Space Shuttle and Saturn V activity was essentially terminated.

1.1 NATIONAL LAUNCH SYSTEM AND THE SPACE EXPLORATION INITIATIVE

Meeting the demands of the National Launch System (NLS) Program, as well as a directive from the Bush Administration for a return to the moon and exploration of Mars, i.e., the Space Exploration Initiative (SEI), will require the ability to lift huge payloads into low earth orbit. Such payloads may reach the half-million pound range, requiring especially powerful boosters used as strap-ons to a core vehicle (2). In order to accomplish these goals, it has been proposed that future heavy lift launch vehicle (HLLV) designs be based on tried-and-true Saturn V technology employing a new updated version of the F-1, i.e., the F-1A rocket engine (3).

1.2 THE F-1A ROCKET ENGINE

One can make strong arguments for the proposal that future HLLV designs be based upon Saturn V technology. Not only was the F-1 engine the largest, most powerful liquid rocket engine ever built but the performance of this engine was exceptional. Sixty-five F-1's were launched with a 100% flight success rate (4). In addition, the F-1 burned liquid oxygen (LOX) and kerosene (RP-1), a proven technology. To meet the challenge, which will be imposed by future HLLV designs, Rocketdyne not only proposed but has already tested an improved, modernized version of the F-1, the F-1A engine. This engine has the capability of providing 1.8 million pounds of thrust.

1.3 THE HEAVY LIFT LAUNCH VEHICLE

As part of the SEI program, the Exploration Programs Office (EPO) at KSC is considering a number of different designs of future lunar and Mars exploration vehicles. In addition to vehicles, design work is underway on the extension of Launch Pad 39A for SEI Mars capability as well as flame deflectors, new and heavier launcher decks, and enlarged vehicle assembly buildings (personal communication with Donald W. Page, National Launch System - HLLV Office, KSC, Florida, July 9, 1992).

Of the different families of future lunar/Mars vehicles being studied at EPO/KSC, the particular HLLV design considered for this study appeared to be the most ambitious. Thus the rationale for choosing this particular HLLV was that scaling down is easier than scaling up.

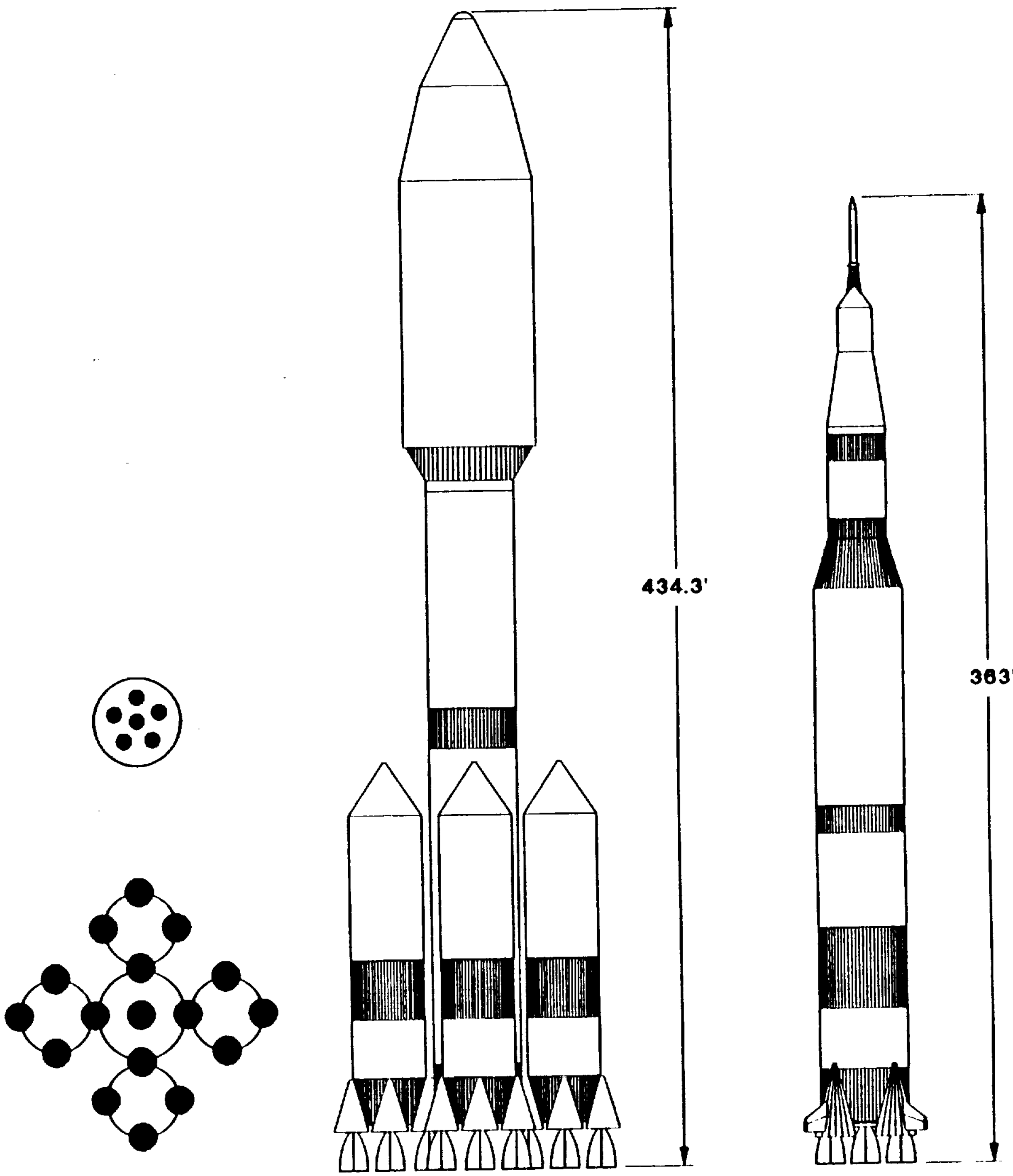

Figure 1-1. Saturn V Derived HLLV (Three-Stage Core), Four-Booster Configuration Rocket. Saturn V Rocket Included for Comparison.

1.3.1 GENERAL FEATURES. In Figure 1-1 is shown a schematic of the Saturn V derived HLLV (three-stage core), four-booster configuration rocket which was used as the basis for this study. Also included in Figure 1-1 for size comparison is a schematic of the Saturn V rocket. To the left of the figure is shown how the seventeen F-1A engines will be positioned in Core Stage I of the rocket (five engines) and in the four strap-on boosters (three engines each), as well as the positioning of the six LOX/LH_2 J-2S engines in Core Stage II.

Although the dimension(s) given in Figure 1-1 for the HLLV are impressive, a better appreciation for its size can be gleaned from Figure 1-2 in which is shown the relative sizes of the HLLV, Saturn V, and Space Shuttle.

In Table 1-1 are given some statistics for the HLLV with particular emphasis on propellant inventory.

TABLE 1-1
SATURN V DERIVED HLLV (THREE-STAGE CORE), FOUR-BOOSTER CONFIGURATION
DESIGN AND PROPELLANT DATA SUMMARY

Shroud
Diameter/Length - 50 ft./175 ft.
Weight - 114,600 lbs.
Cargo Diameter/Length - 46 ft./100 ft.

Instrument Unit Weight - 6,488 lbs.

Core Stage II - (Common Bulkhead Tanks)
Six J-2S Rocketdyne Engines (Thrust - 265,000 lbs. ea.)
Inert Weight - 136,395 lbs.
Propellants - LOX/LH_2
Reserve Propellant - 17,310 lbs.
Burned Propellant - 1,346,279 lbs.

Core Stage I - (Separate Tanks)
Five F-1A Rocketdyne Engines (Thrust - 1,800,000 lbs. ea.)
Inert Weight - 468,467 lbs.
Propellants - LOX/RP-1
Usable Propellant - 5,919,370 lbs.

Boosters (each) - (Separate Tanks)
Three F-1A Engines (Thrust - 1,800,000 lbs. ea.)
Inert Weight - 173,671 lbs.
Propellants - LOX/RP-1
Usable Propellant - 3,442,164 lbs.

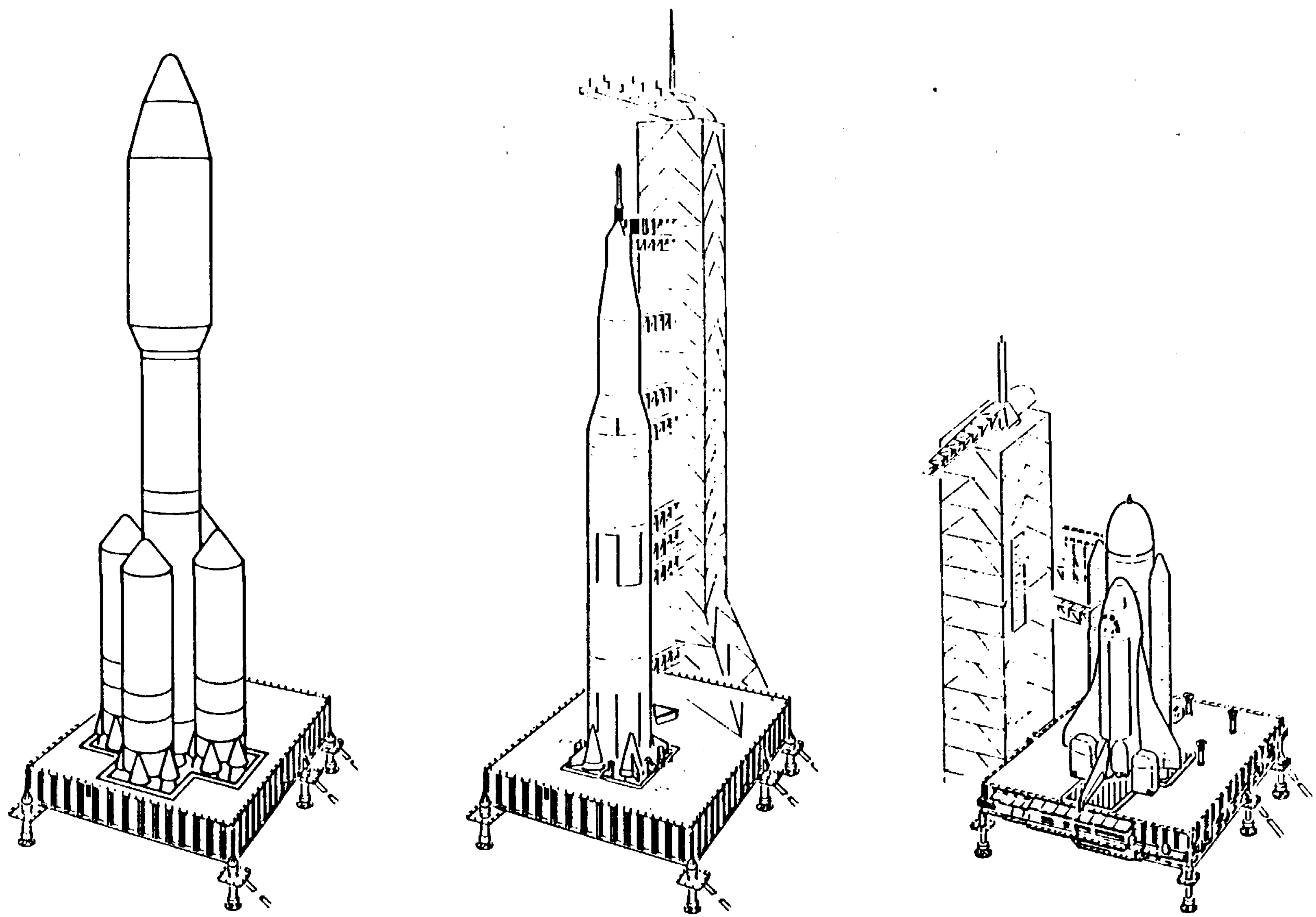

Figure 1-2. Relative Sizes of the HLLV, Saturn V, and Space Shuttle.

1.3.2 PROPELLANT SYSTEMS. Like Saturn V, the HLLV will burn LOX and RP-1 in Core Stage I, as well as in the four strap-on boosters. In Table 1-2 are given calculated values for LOX and RP-1 consumption in the HLLV with its seventeen F-1A engines, along with LOX and RP-1 consumption for the Saturn V launch vehicle (5,6). Total propellant consumption per F-1A engine calculated from the data in Table 1-1 is 1,130,000 lbs./engine, an amount 23% greater than the propellant consumption for the F-1 engine (918,060 lbs.). This value agrees well with the 20% increase in thrust reported by Rocketdyne in upgrading from the F-1 engine (1,500,000 lbs. thrust) to the F-1A engine (1,800,000 lbs. thrust).

TABLE 1-2
COMPARISON OF LOX AND RP-1 CONSUMPTION IN HLLV
(CORE STAGE I AND FOUR BOOSTERS) AND SATURN V

	PROPELLANT					
	LOX		RP-1		TOTAL PROPELLANTS	
VEHICLE	GALLONS	POUNDS	GALLONS	POUNDS	GALLONS	POUNDS
HLLV	1,399,306	13,335,382	870,314	5,874,618	2,269,620	19,210,000
SATURN V	346,960	3,306,526	213,068	1,438,210	560,028	4,744,736

Comparison of the data in Table 1-2 shows that Core Stage I of the HLLV will consume four times the quantity of LOX consumed by the Saturn V first stage and 4.1 times the quantity of RP-1.

Propellants for Core Stage II of the HLLV are LOX and liquid hydrogen (LH_2), the same as in the second and third stages of Saturn V. In Table 1-3 are given calculated values for LOX and LH_2 consumption in the HLLV with its six Rocketdyne J-2S engines, along with LOX and LH_2 consumption for the Saturn V launch vehicle (5,6).

TABLE 1-3
COMPARISON OF LOX AND LH_2 CONSUMPTION IN HLLV (CORE STAGE II)
AND SATURN V (SECOND AND THIRD STAGES)

	PROPELLANT					
	LOX		LH_2		TOTAL PROPELLANTS	
VEHICLE	GALLONS	POUNDS	GALLONS	POUNDS	GALLONS	POUNDS
HLLV	121,071	1,153,806	361,695	209,783	482,766	1,363,589
SATURN V	108,129	1,027,229	350,507	203,294	458,636	1,230,523

Inspection of Table 1-3 reveals that there will be very little difference in the quantity of propellants consumed in HLLV Core Stage II as compared to the combined second and third stages of Saturn V. In hindsight, this is not surprising since HLLV Core Stage II will have six J-2S engines whereas the second and third Saturn V stages also had a total of six J-2 engines.

In terms of propellant consumption, the major difference between HLLV and Saturn V lies in the increased quantities of RP-1 and LOX which will be consumed in the first stage of the former. The logistics of fuel supply for the HLLV is of primary concern with regard to the first stage.

Data presented in Tables 1-2 and 1-3 are summarized in Table 1-4 in which is summarized total propellants (exclusive of hypergolics) consumed in all stages of the HLLV and Saturn V.

TABLE 1-4
SUMMARY OF TOTAL PROPELLANTS CONSUMED IN ALL STAGES OF THE HLLV AND SATURN V

	PROPELLANT							
	LOX		RP-1		LH_2		TOTAL PROPELLANTS	
VEHICLE	GALLONS	POUNDS	GALLONS	POUNDS	GALLONS	POUNDS	GALLONS	POUNDS
HLLV	1,520,377	14,489,188	870,314	5,874,618	361,695	209,783	2,752,386	20,573,589
SATURN V	455,089	4,333,755	213,068	1,438,210	350,507	203,294	1,018,664	5,975,259

1.3.3 PERFORMANCE CHARACTERISTICS. Core Stage I (along with its boosters) of the HLLV with consume 19,210,000 pounds (2,269,620 gallons) of propellants in its seventeen F-1A engines, resulting in a total thrust of 30,600,000 lbs. The oxidizer to fuel ratio is 2.27:1 and exhaust gas composition for the F-1A is known (7). Thus it can be shown that during HLLV first stage burn, the major products of combustion of LOX and RP-1 will be 1,900 metric tons (mt) of CO_2, 2,200 mt of H_2O vapor, and 4,190 mt of CO. Whereas the latter is a poisonous gas, it would not (as with Saturn V launches) pose a hazard since the hot gas is quickly oxidized to CO_2. This oxidation process accounts for the pale blue flame sometimes seen below the yellow/white flame discharge from the F-1 engines during Saturn launches. Total thermal energy output from Core Stage I and boosters will be on the order of 2×10^{10} kilocalories (8×10^{10} Btu). This tremendous energy will lift a payload of approximately 620,000 lbs. (281 mt) into space at a maximum acceleration of 4.9 g's.

Since the incredible energy of the Saturn V booster with its five F-1 engines has been equated to the power output of 85 Hoover Dams (4), the power output of the particular HLLV design which is the subject of this study is on the order of 350 Hoover Dams!

II PROPELLANT LOGISTICS

2.1 RP-1

2.1.1 SOURCE. All RP-1 now utilized in launches at Cape Canaveral Air Force Station (CCAFS), as well as in earlier Saturn V launches at KSC, is procured through the Directorate of Aerospace Fuels (DAF), Propellants Branch, Kelly Air Force Base (AFB), Texas (personal communication with Curtis A. Williams, Fluids Management Group, Technical Operations Division, EG&G Florida, Inc., KSC, Florida, July 28, 1992). DAF is responsible for supplying RP-1 and LOX to U.S. Government Agencies on the East Coast but not responsible for the supply of LH_2. At the present time, the U.S. Air Force is the only customer for RP-1 which is supplied to CCAFS by Howell Hydrocarbons, Inc., of San Antonio, Texas. Howell Hydrocarbons, Inc. serves as a storage and supply source, the RP-1 being produced by local petroleum refineries, although since the termination of Saturn V several suppliers of RP-1 are no longer in business.

Currently, RP-1 is utilized as fuel in the KSC/CCAFS complex only for the first stages of the Delta II launch vehicle at Complex 17 and the Atlas I and II launch vehicles at Complex 36. The Delta booster requires approximately 10,000 gallons of RP-1, the Atlas booster 18,000 gallons, whereas the Saturn V required 213,000 gallons. In calculating RP-1 supply requirements, it has been suggested that a 16% loss of fuel should be assumed (memorandum from Jared P. Sass to James Fesmire, Mechanical Engineering Division, Gases and Propellants Branch, KSC, Florida, dated February 6, 1992). However, this factor has not been included in these calculations on the basis that, particularly with the quantities of RP-1 which will be required for the HLLV, such losses will not be tolerated considering today's tight environmental restrictions.

At 870,000 gallons per launch and eight launches per year (four to the moon and four to Mars) as planned in the SEI program, some 6,960,000 gallons of RP-1 will be consumed. However, in addition to the RP-1 consumed at launch, two to three times this amount will be utilized in required testing and certification of the F-1A engines at NASA Stennis Space Center (SSC) in Bay St. Louis, Mississippi (conference with John Nagle and Michael M. Paul, Directorate of Aerospace Fuels, Propellants Branch, Kelly AFB, Texas, July 30, 1992). SSC, which currently has the responsibility of certifying shuttle engines, is actively planning for the testing and certification of F-1A engines for future SEI vehicles.

Kerosene production in the United States in 1991 amounted to 13,952,000 barrels (585,984,000 gallons) (telephone conversation with Julie Scott, American Petroleum Institute, Washington, DC, July 10, 1992). At first this figure was thought to be of concern to figure HLLV missions since it represents an almost 52% decrease in annual U.S. kerosene production from 1988 to 1991. This decrease is only apparent since during the period 1988 to 1991 some petroleum companies began reporting jet fuel production as a separate entity. Since kerosene and jet fuels fall into the same middle distillate group during the fractional distillation of petroleum, this has the effect of lowering the overall production figures for kerosene (telephone conversation with Alice Lippert, Fuel Oil and Kerosene Sales Data (Annual), Department of Energy, Washington, DC, July 7, 1992). It is obvious from the above figures that, given the demand, refining capability exists for meeting any future HLLV RP-1 requirements. It is not expected that RP-1 supply will limit future SEI missions involving HLLV's.

2.1.2 TRANSPORTATION. Currently, the RP-1, which is employed in Atlas and Delta boosters, is transported from Howell Hydrocarbons, Inc., in San Antonio, Texas, to Fuel Storage Area 1, CCAFS in 7,000 gallon mobile commercial tankers. The RP-1 is then delivered to launch sites by 5,000 gallon refuelers although future planning provides for a 7,000 gallon KSC mobile tanker and a pumper cart to be refurbished and activated for RP-1 support (personal communication with Irving H. Stenner, Systems Engineering, Technical Operations Division, EG&G Florida, Inc., KSC, Florida, June 23, 1992, and July 22, 1992). During Saturn V activity, RP-1 was delivered to KSC/CCAFS via 10,000 gallon capacity rail tank cars. Today, only one NASA owned RP-1 rail car remains at KSC and is apparently in poor condition.

Since the capacity of a standard size rail car for RP-1 is only 10,000 gallons, this mode of fuel transportation, which deemed practical for Saturn V, will not be practical for meeting RP-1 fuel requirements for the HLLV. A more attractive means of transportation would be by petroleum product barges.

The capacity of commercial ocean-going barges for the transportation of hydrocarbons ranges between 2,500 to 7,500 U.S. short tons (telephone conversation with Roy Walsh, Waterborne Commerce Statistics Center, New Orleans, Louisiana, July 15, 1992) which for RP-1 equates to a liquid capacity of between 740,740 and 2,222,000 gallons. In addition, data from the Maritime Administration confirms that there are a number (more than 300) of tank barges with capacities exceeding 3,000 short tons available for coastline transport of fuel to the KSC/CCAFS complex (telecopier memorandum from Walter Oates, Office of External Affairs, Maritime Administration, Washington, DC, dated July 30, 1992). A petroleum barge of 3,000 short ton capacity equates to a volume capacity of 888,900 gallons of RP-1, just slightly above the HLLV RP-1 fuel requirement. In fact, according to data obtained from the Office of External Affairs of the Maritime Administration, Barge No. 35, designated for petroleum products and operated by Coastal-Belcher Towing Co., identifies Cape Canaveral, Florida, as its operating base. The capacity of this barge is given as 3,125 mt, which translates to a 1,020,648 gallon capacity for RP-1. Since the HLLV requires some 870,314 gallons of RP-1 per launch, Barge No. 35 would appear to be an ideal transportation vehicle for RP-1 fueling of HLLV.

Barge transport of RP-1 to Launch Complex 39A will not involve any new or major construction effort. The KSC Master Plan for Complex 39A shows a barge channel extending as a spur in a northeast direction from the barge channel used to transport the shuttle external LOX/LH_2 tank to the vehicle assembly building (VAB) for mating with the shuttle. This spur cuts through Jack Davis Island and terminates immediately adjacent to Launch Pad A. This channel was used to transport LH_2 by means of barge from Air Products and Chemicals, Inc., LH_2 plant in New Orleans, Louisiana, to KSC during the early days of the Saturn V missions. The LH_2 was off-loaded from barges to storage facilities at the launch complex. Later in the Saturn program, LH_2 was transported by rail tank cars and mobile tankers and barging was discontinued. This channel has probably not been used in the last two decades. However, recent aerial photographs of the Launch

Complex 39A area (taken for vegetation studies) reveal that this channel still exists and appears very distinct in the photographs. Although silting, in all probability, has occurred over the years, the channel has definitely not filled in and would still be serviceable with minor dredging.

In addition, review of the Master Plan for Complex 39B shows that, with the removal of two minor barricades, RP-1 barges could be moved via a waterway which extends from the northern tip of the channel at Pad 39A, proceeds north to the east of the pad, then turns to the west, north of Pad 39A, finally leading, by means of manmade channel, into Gator Hole, which lies to the south of Launch Complex 39B. Thus a route exists for transporting large quantities of RP-1 to Complex 39A and, with a relatively small construction effort, similar quantities to Complex 39B as well.

Some concern has been expressed that, since the channel to Pad 39A has been unused for such a long time, there may be a higher than average number of manatee (*Trichechus manatus*) existing in this waterway today. However, considering how slow a barge tug travels and with the use of suitable propeller guards, it is not expected that the manatee population will be affected in any way.

2.1.3 STORAGE. The only active RP-1 storage facilities existing at KSC/CCAFS today are two above-ground 20,000 gallon bulk storage tanks located at Fuel Storage Area 1, CCAFS. During the Saturn missions, RP-1 was stored in three aboveground 86,000 gallon bulk storage tanks located at both Launch Pads 39A and 39B. Although adequate for Saturn V missions, the total RP-1 storage at each pad (258,000 gallons) would be entirely inadequate for HLLV operations. However, the argument is moot since subject tanks are not double walled, do not meet current environmental standards (8), and therefore cannot be used.

It is proposed that the most practical method of delivering RP-1 to future HLLV boosters is direct off-loading from RP-1 barges. As discussed later in this report (Section 3.3), a preliminary hazards analysis shows that if RP-1 were to be stored in permanent storage facilities adjacent to the launch pads, the separation distance from launch site to fuel storage site will not meet safety requirements for future HLLV operations. Another advantage of barge transport is that the barge can be pulled away from the launch complex area after off-loading of RP-1.

2.2 LIQUID HYDROGEN

2.2.1 SOURCE. Reference to Table 1-4 shows that LH_2 consumption in the HLLV will be essentially the same as was LH_2 consumption in the Saturn V. Using a multiplication factor of three for LH_2 required for HLLV engine certification at SSC and assuming 26% LH_2 transfer losses based on shuttle data, some 9,071,680 lbs. (4,115 mt) or 15,358,354 gallons of LH_2 will be required for the eight planned HLLV launches per year. Production of hydrogen in the United States in 1990 amounted to approximately 148 billion cu. ft. (349,200 mt) (9). Preliminary figures indicate that hydrogen production for 1991 will remain essentially unchanged (10). Thus the annual consumption of LH_2 in future HLLV missions will amount to slightly over 1% of 1990 and 1991 LH_2 production levels in the United

States. However, as is discussed below, there will be a dramatic increase in production levels of LH_2 in the U.S. in the very near future.

Liquid hydrogen utilized at the KSC/CCAFS complex is produced in two plants operated by Air Products and Chemicals, Inc., New Orleans, Louisiana, each plant having a capacity of 32 mt of LH_2 per day. The annual production of these plants is 51,499,456 lbs. (23,360 mt), more than enough to meet future HLLV requirements. In the last year, there has been increased activity in the area of LH_2 production. Air Products and Chemicals, Inc., already the world's largest supplier of LH_2, plans to build, at a cost in excess of $15 million, a new LH_2 facility in Pace, Florida, near Pensacola, as a result of a cooperative agreement with the Spaceport Florida Authority. The plant, with a 30 ton daily production, is scheduled to go on-line in early 1994 (11,12). Besides the space programs, the Clean Air Act is stimulating growth of the hydrogen market (13).

A proposal is also under consideration for the construction of a government-owned LH_2 plant at the KSC/CCAFS complex. The rationale for building such a facility is that LH_2 is currently obtained from private industry by direct contract as distinct from RP-1, which is obtained through DAF. Other than the government wishing to produce its own LH_2 for economic reasons, future HLLV operations would not appear to be limited by LH_2 availability.

2.2.2 TRANSPORTATION. As already noted, the HLLV design used as the basis for this study will essentially consume the same amount of LH_2 as did the old Saturn V vehicles. During the early days of the Saturn projects, LH_2 was barged from Louisiana directly to Launch Complex 39A at KSC. As previously noted, this was the reason the barge channel was constructed to pad 39A. As was done later in the Saturn program, tank trucks or rail tank cars could be used to transport LH_2 from production plants to KSC. NASA owns four LH_2 tank trucks. The older tank trucks have a capacity of 13,000 gallons whereas the newer units have a capacity of between 14,000 and 16,000 gallons. NASA also owns four LH_2 rail tank cars of 34,000 gallon capacity. Considering the fact that new LH_2 production facilities are being planned in Florida, the continued use of tank trucks or rail tank cars for LH_2 transport appears to be even more attractive.

2.2.3 STORAGE. The LH_2 storage facilities at Launch Complex 39A and 39B consist of one 900,000 gallon spherical storage tank at each location. As with the Saturn program, these LH_2 storage facilities will be suitable for HLLV missions except for their present location with respect to future HLLV vehicle launch operations (see Section 3.3 of this report).

2.3 LIQUID OXYGEN

2.3.1 SOURCE. Reference to Table 1-4 shows that, unlike the situation with regard to LH_2, the proposed HLLV will consume more than three times the amount of LOX that was consumed in Saturn V launches. Again using a factor of three to account for LOX requirements for engine testing and certification at SSC and assuming 60% LOX transfer losses based upon shuttle data, some 1,159 million lbs. (525,780 mt) or 121.7 million gallons of LOX will be required for eight HLLV launches per year. Fortunately, as with LH_2, supply of LOX will be no problem. In 1990, the United States produced 462 billion cu. ft. (17,359,000 mt) of oxygen

(9,10). Preliminary indications are that this production figure was slightly exceeded (~2%) in 1991. The proposed HLLV missions would consume annually 3% of all the oxygen that was produced in the U.S. in 1990. Oxygen ranks fourth in total production of all the chemicals produced annually in the United States (10).

Today, most of the LOX utilized at the KSC/CCAFS complex is produced by PRAXAIR (formerly Linde Air, Inc.) in Mims, Florida. This plant, which has since expanded, was constructed in support of the Saturn program and produces 40,000 gallons a day (62,914 mt) annually. Assuming that LOX required for engine testing and certification would come from a source outside of Florida and much closer to the SSC facility, the current LOX production facility at Mims, Florida, would support less than four HLLV launches per year. Fortunately, several LOX plants exist in Orlando, Florida. LOX manufacturing facilities also exist in Tampa and Jacksonville, Florida.

2.3.2 TRANSPORTATION. Because of the close proximity of Mims, Florida, to KSC and CCAFS, mobile tank trucks have always been used to transport LOX to these facilities. However, tank trucks may not be the most practical means for LOX transportation in future HLLV missions, particularly if it will be necessary to transport LOX to KSC from locations further away than Mims. A more practical means of transportation would be by rail tank cars. The volume capacity of a typical LOX rail tank car is dictated by weight and is approximately 19,750 gallons (telephone conversation with Frank Licari, Air Products, Inc., Allentown, Pennsylvania, June 25, 1992).

The argument could be made that considering the quantities of LOX that will be involved in future HLLV missions, barge transfer of LOX from the Mims, Florida, plant to Launch Complex 39A be considered. However, this presents a number of complications. First, the capacity of the Mims plant would need to be more than doubled in order to meet proposed annual HLLV requirements. Since Mims, Florida, is very close to the west bank of the Indian River, LOX could conceivably be barged from Mims south on the Indian River via the Intracoastal Waterway, around Merritt Island and then north via the Banana River and through existing channels to Pad 39A complex. Although the relative economics of barging versus using rail tank cars would have to be made, a safety problem immediately becomes apparent. RP-1 and LOX barges would be using the same channels, a potentially dangerous situation in the event of an accident. Another possible LOX barge route from Mims would be northeast on the Intracoastal Waterway, through Haulover Canal, the southeast away from the Intracoastal Waterway, through Mosquito Lagoon and marshes to Launch Complexes 39B and 39A. However, this route would involve digging of new channels through environmentally sensitive wetlands and would probably never be allowed. All factors considered, the use of rail car transport would appear to be the most practical method for LOX transport. The Florida East Coast Railway provides rail service to the area with a main line through Titusville, Cocoa, and Melbourne. Spur rail lines from the main line at Titusville to Launch Complexes 39A and 39B already exist.

2.3.3 STORAGE. Taking into consideration transfer losses, some 3,800,941 gallons of LOX will be required for each HLLV launch. At the present time, each launch pad has one 900,000 gallon spherical LOX storage tank. To the HLLV launch pad will need to be added at least three and preferably four more 900,000 gallon LOX tanks. However, as pointed out in Section 3.3 below, the LOX as well as the LH_2 storage tanks will need to be moved further away from the HLLV lift-off site.

III POTENTIAL HAZARDS

3.1 RP-1 EMERGENCY DUMP

Two RP-1 concrete-lined holding ponds exist at each Launch Complex, 39A and 39B. The ponds, constructed for the Saturn V program, were designed to retain spilled RP-1 and discharge water. The dimensions of the pond are 150 feet by 250 feet with a water depth of two feet (14). The two ponds at each launch pad are capable of retaining some 1,122,000 gallons of RP-1, five times the RP-1 capacity of the Saturn V. In order to retain all of the RP-1 from an emergency HLLV dump, the depth of the existing holding ponds will need to be increased by six feet to a total depth of eight feet if we apply the same overdesign factor. This overdesign factor is justified because most certainly spilled RP-1 will be mixed with rainwater in the ponds. Environmental restrictions demand that the petroleum/water mixture be isolated from the environment until the ponds can be pumped out and proper RP-1/water separation processes undertaken.

3.2 ACOUSTIC EFFECTS

Sound pressure levels generated by high-thrust booster engines must be considered. Overall sound pressure levels of 120 to 135 decibels (dB) are important noise levels considered in formulating zoning restrictions. For protection of public property, 120 dB (intermittent) is considered the maximum overall sound pressure level to which the public should be exposed. At 135 dB (intermittent), ear protection is required and some damage to conventional structures may be expected. Sustained exposure to 90 dB will result in hearing damage (15).

According to the KSC Master Plan File for 1972 (conference with Merle D. Buck, Facilities Master Planning Office, Facilities Engineering Directorate, KSC, Florida, July 7, 1992), the Saturn V booster stage produced 135 dB at 4,000 feet, which decreased to 120 dB at 19,000 feet from the launch site. The Saturn V first stage booster was powered by five F-1 engines, whereas the HLLV will employ seventeen F-1A engines. Linear extrapolation gives a calculated 120 dB radius for the HLLV of 64,600 feet. Although large, this number is still considered to be rather modest because the F-1A engines in future HLLV's will be 20% more powerful than the old F-1 engines. In Figure 3-1, the 120 dB level radius associated with a HLLV launch from Complex 39A is shown superimposed (broken line) on a map of the KSC/CCAFS area. Also shown for comparison is the 120 dB radius for the Saturn V (inner broken line). Not only does the 120 dB limit for the HLLV come very close to the City of Titusville, but essentially all of the KSC and CCAFS operational facilities fall within this noise area. Similar calculations show that the 135 dB level for HLLV's will occur at approximately 13,600 feet. Although not shown in Figure 3-1, this level falls just short of the VAB area.

Noise associated with rocket booster lift-offs may be characterized as brief, intense, and predominantly low frequency. In surrounding communities to KSC/CCAFS, launch vehicle noise is usually perceived as a distant rumble. Based on the current launch environment, noise generated by launches, at worst, is considered to be an infrequent nuisance and does not pose a potential health risk

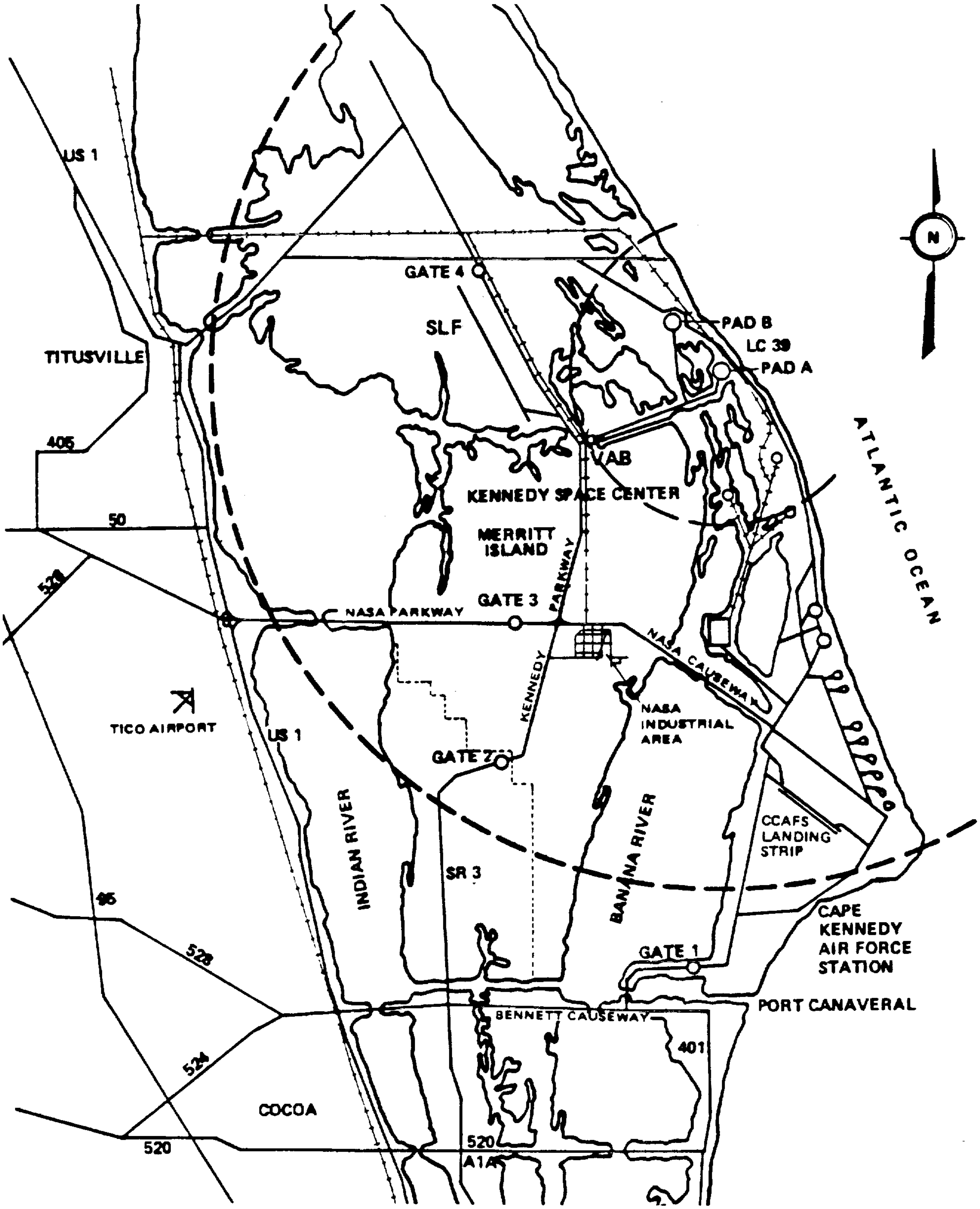

Figure 3-1. 120 dB Noise Level Radii for HLLV (Outer Broken Line) and Saturn V (Inner Broken Line) Superimposed on Map of the KSC/CCAFS Complex. Launches from Pad 39A.

to on- or off-site populations (16). However, this preliminary study suggests that noise associated with future HLLV launches will be more than an infrequent nuisance and may very well pose a potential health risk to both on- and off-site populations. It is almost certain that appropriate noise-abatement measures will need to be incorporated into future HLLV design plans.

3.3 FIREBALL AND BLAST EFFECTS

Studies of hazards associated with liquid propellant explosions must include both blast effects and the thermal environment. Liquid propellant explosions are characterized by a sudden release of a large volume of hot gases, often accompanied by pressure shock. These explosions are considered to be low-order detonations followed by deflagration (burning of the rocket above the launch pad in the event of an accidental failure or deliberate activation of the vehicle destruct system) (17).

Such a study was made for the Saturn V in which was described the thermal environment (the fireball) derived from empirical data and correlation with analytical results (18). For this study, it was assumed that: (1) all the fuel on the Saturn V is consumed in the fireball formation; (2) the fireball expands by deflagration rather than detonation or conflagration (burning of the rocket on the launch pad); and (3) the fireball shape is spherical.

In Figure 3-2 are presented the maximum diameters of fireballs from some experimental tests and missile failures. The following equation was derived by a least squares regression analysis of the data (19):

$$D = 9.82\ W^{0.320} \tag{1}$$

where D - maximum diameter, ft., and W - weight of propellant, lb.

The fireball duration, derived in a manner similar to that for diameter, is illustrated in Figure 3-3. The least squares fit to the data is as follows:

$$Duration = 0.232\ W^{0.320} \tag{2}$$

where duration is in seconds.

Using a total HLLV propellant weight of 20.6 million pounds, a maximum fireball diameter of 2,150 feet and a duration time of 51 seconds were calculated from Equations (1) and (2), respectively. These points have been added to Figures 3-2 and 3-3.

Of particular interest in these studies is the observation that both fireball diameter and duration are functions of total propellant mass only and not of the type of propellant.

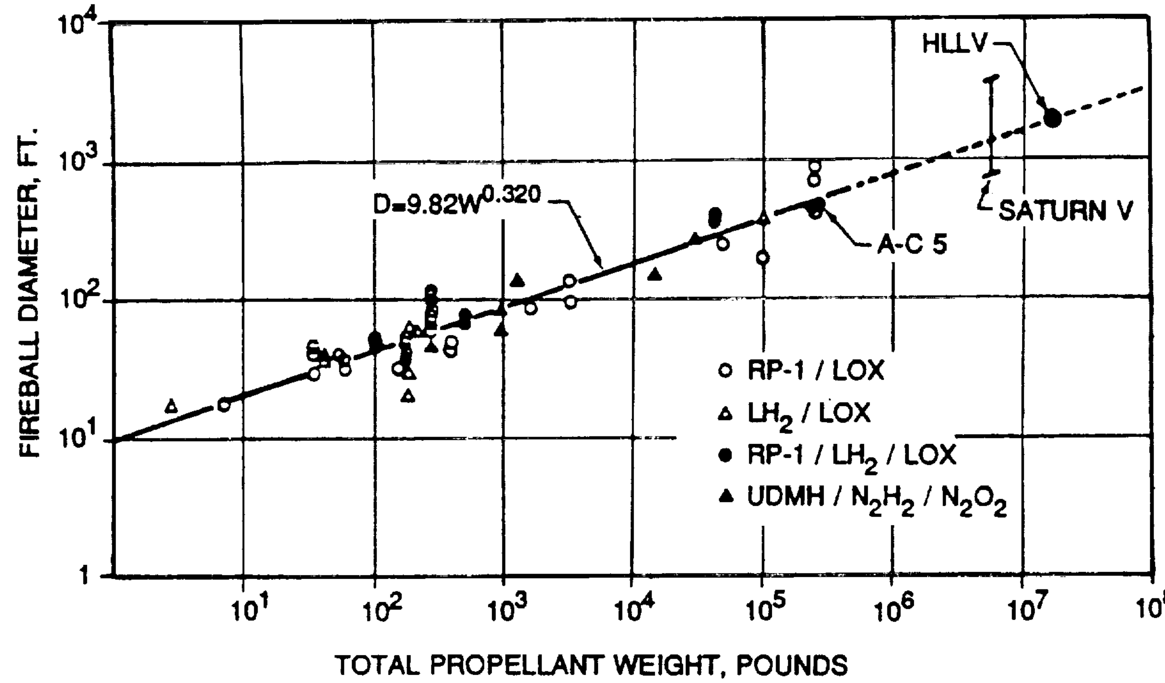

Figure 3-2. Fireball Diameters for Various Weights and Types of Propellants.

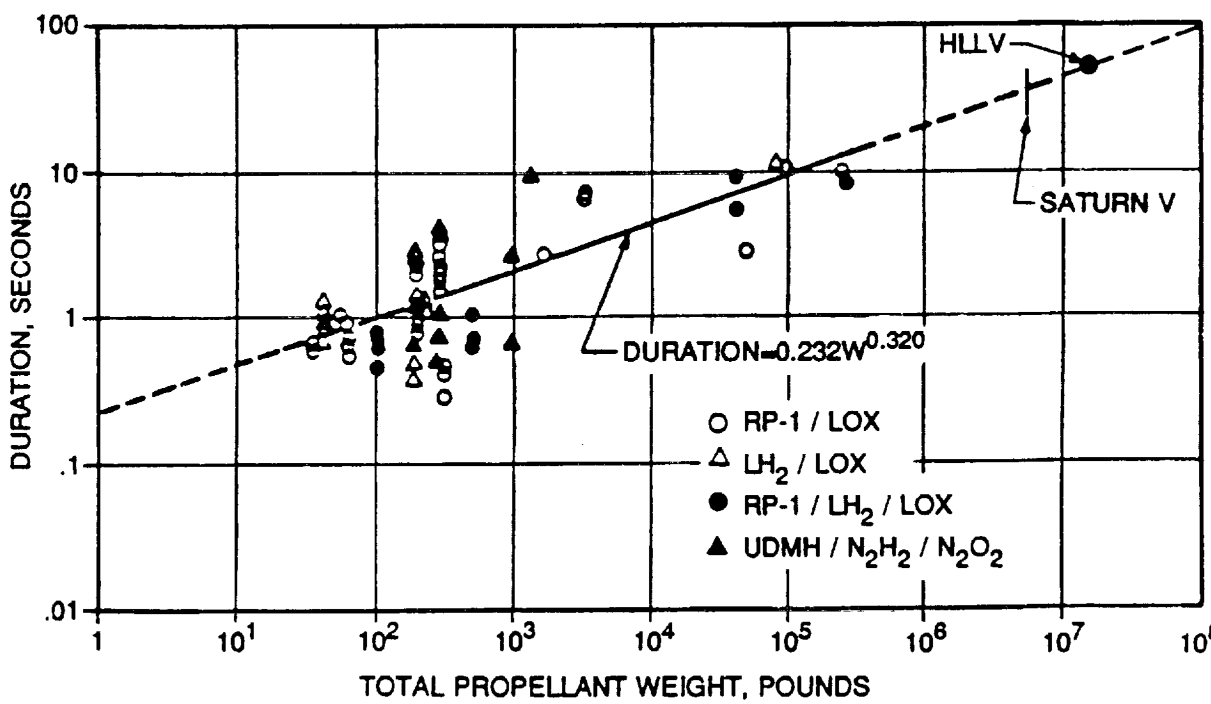

Figure 3-3. Fireball Duration for Various Weights and Types of Propellants.

The effective area covered by the HLLV fireball is shown as a broken circle in Figures 3-4 and 3-5, which are drawings of Launch Pads 39A and 39B, respectively. Inspection of Figures 3-4 and 3-5 shows that the HLLV fireball would come very close to propellant storage facilities on both pads and would spread over most of the maintenance and service operations buildings adjacent to the launch sites. As part of the SEI, various designs are being considered for upgrading and extending the launch pads at 39A and 39B for future HLLV missions. Such reconstruction should also include the relocation of maintenance and service operations buildings considerably outside the sphere of a possible HLLV deflagration.

The complete Saturn V/Apollo configuration contained the explosive equivalent of 1,193,227 lbs. of TNT (1). Based upon relative quantities of total propellants, the HLLV will have a TNT equivalent three times greater (and more than ten times greater than the space shuttle). The KSC Master Plan File for 1972 also outlined safety criteria regarding blast effects. It was determined that at 7,000 feet from a Saturn V detonation, the overpressure resulting from the blast would be 0.65 pounds per square inch (psi). This is the maximum allowable overpressure that ordinary windowless building construction can withstand without damage. All KSC ordinary buildings are designed to withstand a minimum overpressure of 0.28 psi. For the HLLV, this overpressure limit would be extended to 21,000 feet, approximated by the circle indicating the 120 dB noise level radius for Saturn V in Figure 3-1. The VAB area falls just within this limit. It was established that the maximum allowable overpressure to which the Saturn V rocket could be subjected was 0.40 psi. This established the launch danger radius or vehicle protection distance. Launch Complex Pads 39A and 39B are separated at a distance of approximately 8,700 feet, which complies with this criterion. If it is assumed that the 0.40 psi overpressure limit applies to the HLLV as well, then in order to comply with the safety criteria, HLLV's could not be on Pads 39A and 39B at the same time.

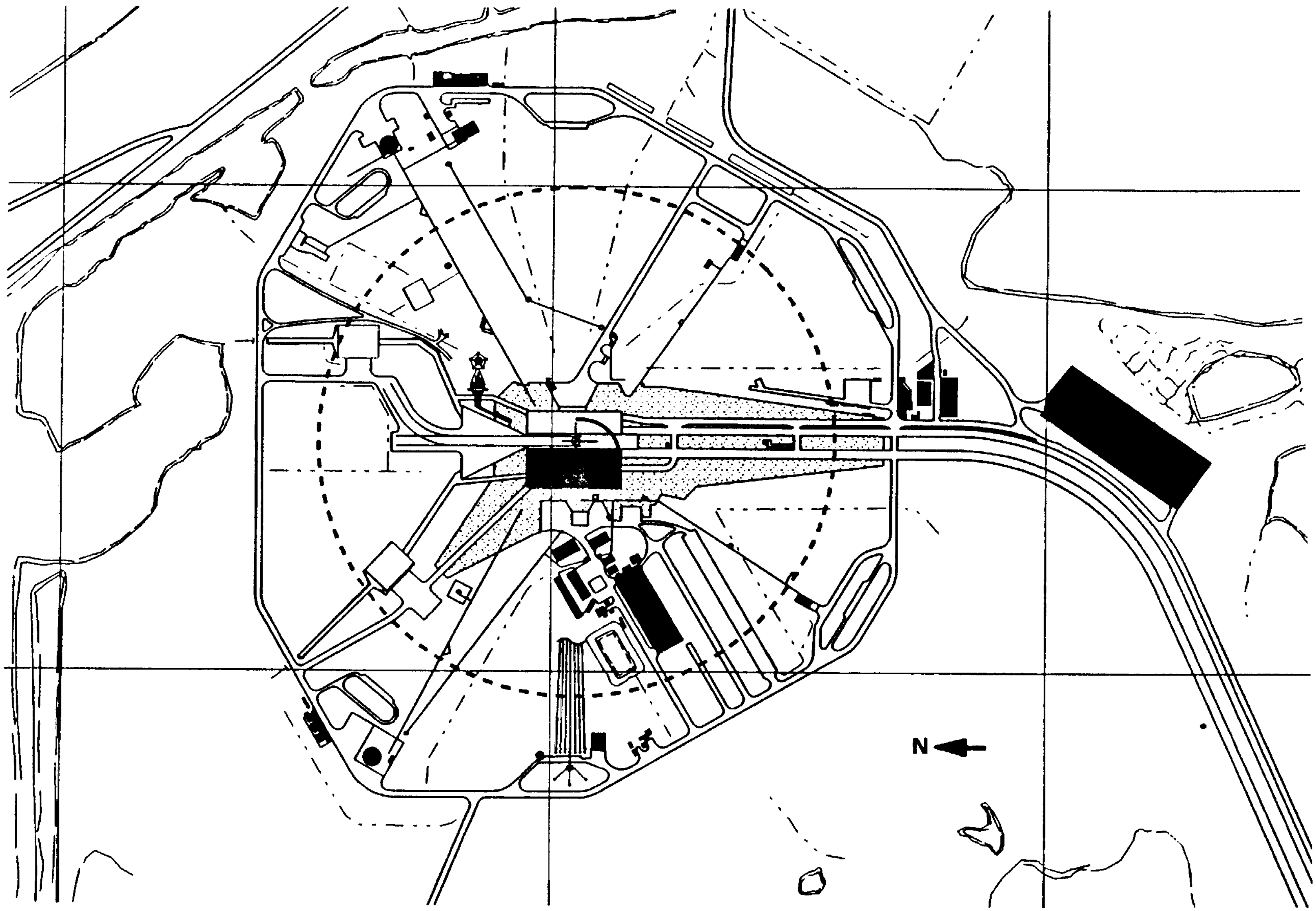

Figure 3-4. Area Covered by HLLV Fireball on Launch Complex 39A.

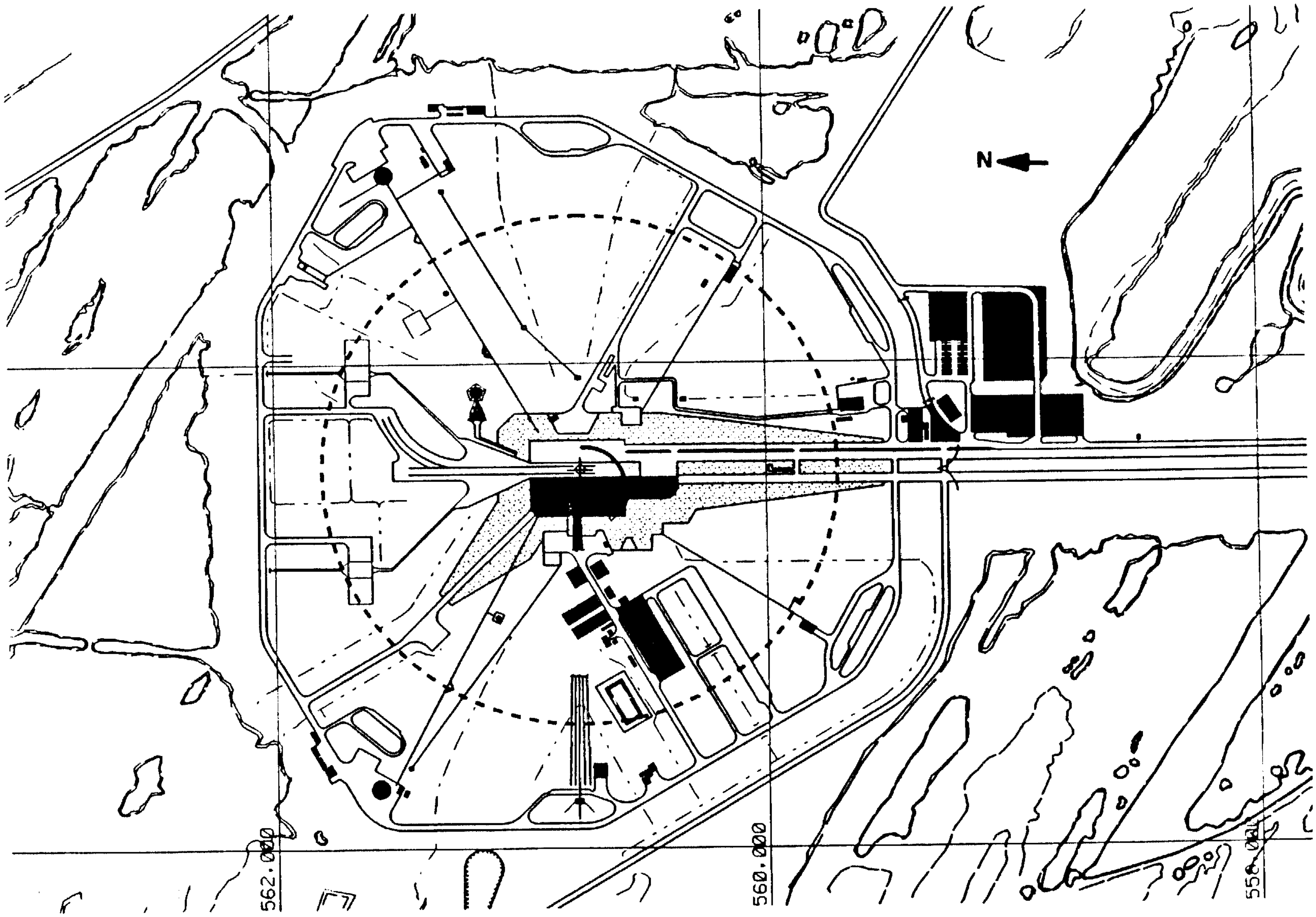

Figure 3-5. Area Covered by HLLV Fireball on Launch Complex 39B.

IV CONCLUSIONS

It is concluded from this study that no major problems should arise with regard to the logistics of securing, transporting, and storage of large quantities of propellants which will be required in future HLLV missions. At the same time, the handling of such large quantities of fuels and LOX should have no serious effect on the KSC infrastructure and, in fact, will be facilitated by reactivation of facilities already present at KSC. Some changes will be necessary, however. The location of some critical facilities, such as operations buildings, RP-1, LH_2, and LOX storage tanks, etc., will need to be relocated further away from the HLLV launch site than they are now in order to avoid a hostile thermal environment (fireball) or blast damage associated with either a HLLV deflagration or detonation.

With regard to specific HLLV propellants, the following conclusions can be drawn:

- Supply of RP-1 should pose no problem. However, the HLLV will require four times (by volume) as much RP-1 as Saturn V, so transportation of RP-1 by either commercial mobile tankers or rail tank cars is not deemed practical. Barge transportation appears most attractive, particularly since a barge channel to Pad 39A already exists. Such a barge could also serve as the storage site since no suitable RP-1 storage facilities exist as KSC today.

- The HLLV will utilize slightly more LH_2 than did the Saturn V. Certainly the supply of LH_2 should pose no problem, particularly since new facilities for LH_2 production are either now under construction or being planned. Since at least one of the new plants will be in Florida and closer to KSC, the continued use of mobile tankers (and possibly rail tank cars) is feasible. Storage of LH_2 is no problem except for the relocation problem discussed above.

- Unlike Saturn V, the HLLV will consume large quantities of oxygen, approximately 3% of the annual production in the United States. Overall this should create no problem, except for the fact that the LOX plant in Mims, Florida, would have to be increased by at least 100% in order to meet future HLLV requirements. However, if necessary, LOX manufacturing facilities in Orlando, Tampa, and Jacksonville could be utilized. Considering the closeness of LOX facilities to KSC, rail tank cars appear to be the most practical means of transportation. Barge transport of LOX from Mims to Launch Pads 39A and/or 39B would either involve LH_2 and LOX barges using the same channels, a potentially dangerous situation, or digging of new channels specifically for LOX barges, an environmentally unacceptable solution.

- Launch pad storage facilities for LOX will have to be increased substantially. At least four additional 900,000 gallon LOX storage tanks (in addition to the 900,000 gallon tank now located adjacent to each pad) will be required for future HLLV missions. Existing tanks must, of course, be relocated.

The one technical problem which must be solved will be that of noise associated with HLLV launches. Unlike previous Saturn V launches or even space shuttle launches today, future acoustic effects associated with the HLLV will be more than just a temporary nuisance. Noise-abatement measures must, and certainly will, be found.

V RECOMMENDATIONS FOR FUTURE WORK

Time constraints did not permit an analysis of either the environmental impact or cost analysis of future HLLV missions. Certainly environmental issues when handling this quantity of propellants must be considered. During the past three decades, new and increasingly stronger regulatory policies for the handling and clean-up of hazardous materials have been promulgated.

Specific objectives which would be addressed in future work are as follows:

- o Become cognizant of all standards and regulations: governmental (EPA, OSHA, State of Florida, etc.), non-governmental (ANSI, ASTM, etc.), military and industrial relating to petrochemical-based fuels, LH_2, and LOX.

- o Become familiar with the state-of-the-art with respect to RP-1 detection and clean-up techniques.

- o Review updated medical data which may have been obtained during the past thirty years with respect to the toxic effects of RP-1.

- o Undertake an overall environmental assessment for the HLLV program.

Recently, in compliance with the National Environmental Policy Act of 1969 and the regulations of the President's Council on Environmental Quality, an environmental assessment has been prepared for General Dynamics Space Systems Division for their commercial Atlas IIAS program (16). The results of this study showed that the implementation of the Atlas IIAS program would have no significant environmental impact. It is hoped that the same will hold true for future HLLV projects.

A cost analysis will, of course, be required. A unique aspect of the HLLV propellant system (like Saturn V) is that RP-1, LH_2, and LOX are all derived from starting materials plentiful and inexpensive (petroleum and air). The major expense items are thus processing and transportation, the former item predominating (telephone conversation with Chet Roberts, Compressed Gas Association, Arlington, Virginia, July 7, 1992). The major processing expense is the cost of energy (11). In qualitative terms, the expense of HLLV propellants will be the cost of the energy necessary to extract RP-1, LH_2, and LOX from their starting materials plus the cost of transporting this chemical energy to the launch site. The cost of producing LH_2 and LOX is particularly energy-sensitive and reduction in propellant expense will come primarily through cheaper electrical power, although improved processing methods and more efficient means of transportation will also be important.

New propellant storage separation distances must be determined. Because of transfer losses, some 1.07 million gallons of RP-1, 0.480 million gallons of LH_2, and 3.80 million gallons of LOX will be required for each HLLV launch. These storage facilities cannot be located at existing sites on Pads 39A and 39B, which are 1,450 feet from the pad centers. The basis for calculating safety distances has been established for different classes of explosive, including rocket propellants (20,21).

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