STUDY TO IDENTIFY FUTURE CRYOGEN PAYLOAD ELEMENTS/USERS FOR SPACE SHUTTLE LAUNCH DURING PERIOD 1990-2000

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ABSTRACT

This study has made possible the creation of a current compilation of major cryogenic space payload users; also, the opportunity to explore their future unclassified needs, while conducting a survey of planned scientific, commercial and defense-oriented space payloads. Thus, this study has endeavored to provide a summary of future cryo payload users, their currently projected needs and reported planning for space operations over the next decade. The results of this study indicate that at the present, few users with payloads consisting of reactive cryogens, or any cryogen in significant quantities are contemplating the utilization of the Space Shuttle. Some members of the cryogenic payload community indicated an interest in flying their future planned payloads on the orbiter, versus an ELV, but are awaiting the outcome of a Rockwell study contract to define what orbiter mods and payload requirements are needed to safely fly chemically reactive cryogen payloads, and the resultant cost, schedule and operational impacts. Should NASA management decide in early 1990 to so modify orbiter(s), based on the results of the Rockwell study and/or changes in national defense payload launch requirements, then cryo payload customers such as SDIO and NASA experimenters will reportedly plan on utilizing the Shuttle orbiter vehicle in preference to an ELV. After surveying over 75 individual members of the cryo payload community, (representing a comprehensive cross-section of user areas), this study has resulted in the conclusion that within the scientific research and defense communities lies the most potential for possible future cryogenic space payloads for the Space Transportation System Orbiter fleet.

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I. Purpose

A need has existed to define unique reactive cryo payloads intended for launch aboard Space Shuttle orbiters during the next decade. In conjunction with this need has been a growing interest to identify current associated key contractors, agencies and commerical users. In pursuit of satisfying these needs, a study-search was conducted during the period April-October 1989 to acquire such information, form a current data base and to provide the summarizing study report presented herein. The primary focus of this study was to document planned and approved payloads/experiments that require chemically reactive cryogens.

II. Approach

To establish an orbiter payload bay reactive cryogen payload data base, the author found it necessary to investigate a number of potential user areas by means of conducting a general search for specific contacts. Unfortunately, no central or established data source for current actual/planned chemically reactive cryo payload suppliers or users was available. Necessity dictated that a broad-spanned (or blind) search be conducted, thus other future space cryo payloads were also identified. Key cryo payload suppliers and users, program managers and scientists, including payload manufacturing management were thereby identified and surveyed by the author. Consequently, information was collected for both chemically reactive and non-reactive payloads, whether proposed, planned, or approved, and in some cases actually funded, and design work already initiated. As the information was being processed, it became apparent that by comparison, few users were planning to fly reactive cryogen payloads on future orbiter flights. For the purpose of this study report, an effort was made to segregate and highlight the reactive cryo payloads being considered for potential future flights on-board an orbiter.

The specific approach taken to acquire the information needed and to generate the necessary data base was to seek-out principal cryogenic payload user areas, and contacts; cryogens currently planned for use on space payloads during the next decade; physical state(s) of such applied cryogens; and, typical space flight applications. Contacted members of this supplier-user community were further surveyed in regard to their plans for utilizing either an orbiter or an expendable launch vehicle (ELV) and if their programs were funded/or approved. These discusions included considerations pertaining to payload applications such as an experiment residing in the payload bay; deployment as a free-flyer, or a lower earth orbit (LEO) payload; and possible evolution as a geocentric earth orbiter (GEO) payload, via an upper stage vehicle.

The performance of this study has made possible the creation of a current compilation of most major cryo space payload community members. The latter information is presented by this study report as Section VI, with specific individuals contacted being delineated by Appendix A. The chemically reactive cryo payloads/experiments planned for launch aboard an orbiter during the 1990's are described by Chart A. This study report includes, as Attachment B, a sample listing of the better defined orbiter cryo payloads, along with associated key contacts; i.e., program scientist, managers, and contractors.

The intent of this study report is to identify only the general areas of consideration and to summarize those preliminary-type discussions conducted by the author with those contacts listed in Appendix A. As the reader will note, much related payload development efforts are being expended in various sectors of government and industry that should be collected and summarized for the cryo payload community. Due to the need to remain within the scope of this study report, only that information required to support the stated needs of the Space Shuttle management team have been included.

III. Background

Should it be decided that a need will exist for one or more orbiters to be modified to provide cryogenic services for payloads carried in the cargo bay, particularly if these cryogens are utilized as reactants, significant orbiter systems changes and development of new flight kits will be mandated. Other extensive changes and modifications will be required of facilities and GSE for payloads and launch processing, launch site servicing and recovery operations and post mission/abort deservicing operations. Typically, many orbiter and GSE systems will be required to service and control such cryo payload operations prior to launch; e.g., chilling, filling, circulating, purging, venting, deservicing, heating and instrumentation/sensors. In-flight controls will have to be provided for cryo payload unique operations that include: activation/de-activation, deployment/recovery, and possible overboard dump or payload jettisoning.

IV. Current Payload Bay Configurations For Centaur Type Payloads

After the January 1986 Challenger (OV-099) accident, the fueling and venting orbiter mods for the Centaur G' main propulsion system were almost completely removed from OV-103 and OV-104. The remaining modifications and permanent scarring consists of structural improvements, plumbing pentrations, supports, brackets and access doors. Similiar residual modifications remain that were provided for the Radioisotope Thermal-Nuclear Generators (RTG) GN_2 purge and coolant circulating plumbing. The RTG is employed to provide primary electrical power for the Centaur G' payload; e.g., GALILEO space probe.

Generally all orbiter, GSE and facility modifications peculiar to supporting and servicing the Centaur G' upperstage vehicle and associated payload RTG(s) were removed except for a few remaining changes underlying the payload bay liner surface. Attachment A is provided to summarize the current orbiter fleet configurations and an overview of coolant and GN_2 purge line installations relating to the use of RTG's for orbiter-carried payloads.

V. Typical Cryogenic Materials & Applications For Space Payloads

CRYOGEN	APPLICATION	APPROX. CRITICAL CONSTANTS FOR GASES AND FREEZING/TRIPLE POINT FOR LIQUIDS
A. Reactive Cryogens:		
1. Liquid Oxygen (LO_2)	Propellant Oxidizer Fuel Cell Reactant	154.78°K; 50.14 Atm.
2. Liquid Hydrogen (LH_2)	Propellant Fuel Fuel Cell Reactant	33.2°K; 12.797 Atm.
3. Liquid Nitrogen Trifluoride (NF_3)	Propellant Oxidizer	144.1°K
4. Solid Methane (CH_4)	Coolant	90.68°K; 0.099 Atm.
5. Solid Ammonia (NH_3)	Coolant	265.37°K; 111.5 Atm.
6. Slush Hydrogen (H_2)	Coolant	18°K (Solution of Solid And Liquid H_2)
7. Solid Hydrogen (H_2)	Coolant	13.96°K; 0.0711 Atm.
B. Non-Reactive Cryogens (Inerts) - Liquids:		
1. Liquid Nitrogen (LN_2)	Coolant Purge Fluid	126.1°K;33.5 Atm.
2. Liquid Neon (LN_e)	Coolant	44.4°K; 26.87 Atm.
3. Super Critical Helium (S.C. H_e)	Purge Fluid Pressurant	5.2°K; 0.435 Atm.
4. Helium I (LHe_2)	Coolant Purge Fluid Pressurant	He-4: 5.2°K; 0.229 Atm. He-3: 3.32°K; 1.15 Atm.
5. Helium II, Superfluid (LHe_4)	Coolant	2.171°K (Lambda Point); 0.050 Atm. 7.25 psia)
C. Non-Reactive Cryogens (Inerts) - Solids:		
1. Argon (Ar)	Coolant	83.85°K; 0.679 Atm.
2. Helium (He)	Coolant	He-4: 1.77°K; 29.7 Atm. He-3: 3.0°K; 29.3 Atm.
3. Nitrogen (N_2)	Coolant	63.15°K; 0.127 Atm.

D. Conversion Values For Absolute Zero Temperature:

On Kelvin Scale = 0°K (-273.15°C) Same degree graduations as for Celsius scale
On Rankin Scale = 0°R (-459.67°F) Same degree graduations as for Fahrenheit scale

NOTES:

(1) Refer to Attachment B For SAMPLE LISTING OF POTENTIAL ORBITER CRYO PAYLOADS.
(2) Figure 1 below provides a generalized explaination of phase equalibria, critical point, triple point, transition lines for changes in state.

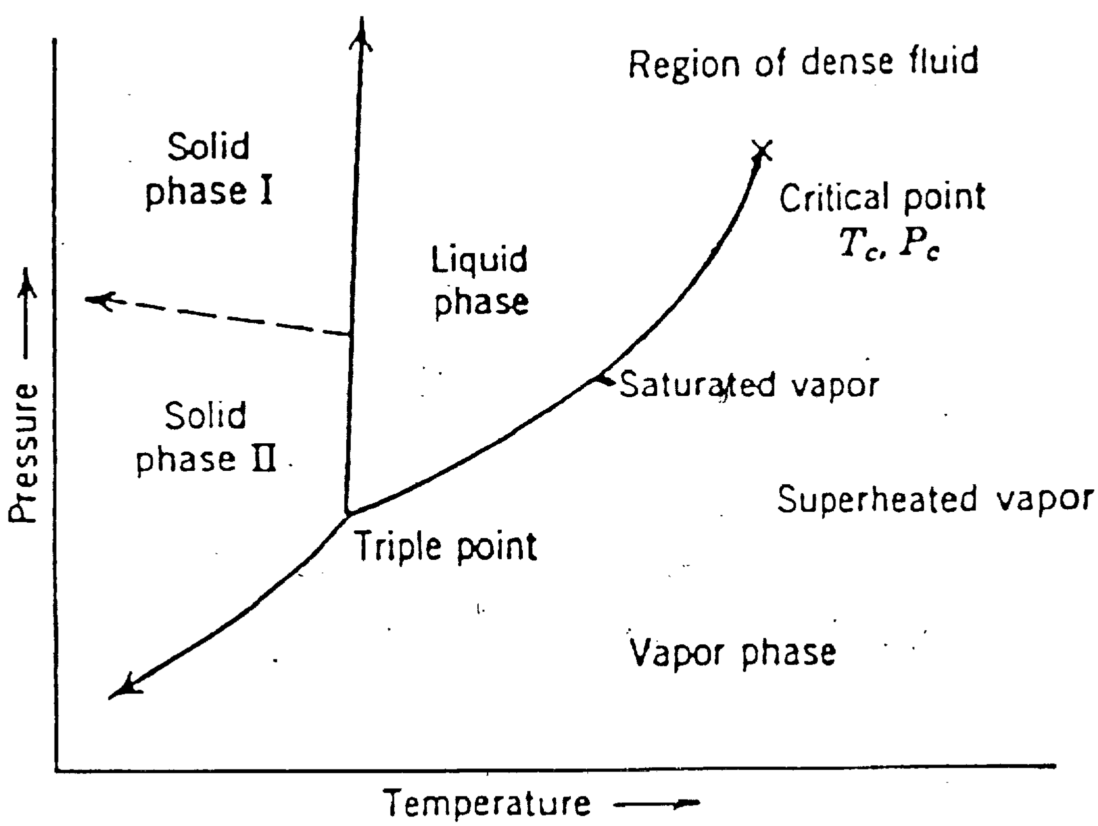


FIGURE 1

VI. Summaries of Cryogen Payload User Areas

A number of potential/known users were querried for each of the following nine cryo payload user areas. User contacts were asked a list of questions that included what cryo payload programs were in work, planning, or being proposed; if such programs were approved, funded or funding anticipated. Schedules, future growth, alternatives, applications, etc. were discussed at various levels of detail. Each contact was asked to indicate which means of flight was preferred, planned or anticipated; i.e., via ELV or as an orbiter payload/experiment. Contacts whose responses were most typical for each of the user areas are given below, along with a general summary for each area. The response from those in the same user area were generally consistant, thus any variances were only slight and not worthy of mention.

A. Space Material Sciences:

Summary: No known applications

B. Space Life Sciences:

1. Contact: Dr. Penny Firth/Lockheed Support, Code E, NASA HQ

Response: Bio-regeneration experiments might require LN_2 or solid CO_2 for rapid freezing of food grown in space.

Status: Test beds designed, awaiting incremental funding, earliest could be flown would be FY-90.

Summary: Tissue samples and/or plant specimens that are lost/sacrificed during in-space testing may require rapid-freezing with LN_2 or solid CO_2 to perserve their condition until further space/earth testing is possible.

C. Space Infrared Remote Sensing:

1. Contact: Mr. Robert Kelly/Lockheed Support Contractor to Code C, HQ, Stennis Space Center, MS.

Response: LN_2 is required for the Large Format Camera (LFC). Intended applications would be as pressurant and lens surface particle removal. Anticipate future infrared scanners on earth observable payloads that would also require LN_2 for sensor cooling.

Status: LFC will be flown several times in the orbiter and if used on the Space Station Freedom (SSF) resupply missions of LN_2 will be required.

2. Contact: Mr. Michael Nobel/Electro-optical and Cryogenics, Ball Aerospace Co.

Response: Cooling by solid H_2 will be required for infrared instrumentation (in the range of 10°K). Such payloads presently can be flown only on ELV's. Future designs can be adapted for any space vehicle.

3. Contact: Dr. Joseph Binsack/Center For Space Research, M.I.T.

Response: Millimeter wavelength experiments requiring cryogenic cooling are being developed. An example is the Space Infrared Telescope Facility (SIRTF) being developed by Ames Rsrch Ctr. that will require a Helium II cooling source.

Status: SIRTF was originally planned to fly on orbiter, but was changed to an ELV. Instead of utilizing a Space Lab Pallet, SIRTF will be launched on Titan IV-Centaur vehicle late in 1998.

Summary: Future space sensors operating in the infrared range will continue to require cooling by cryogenic sources such as Helium II for IR astronomy and can be designed to fly on most any type spacecraft/vehicle.

D. Space Physics Experiments: (See Attachment B)

1. Contact: Dr. Alan N. Bunner/EZC, High Energy Astrophysics, NASA HQ.

Response: The Advanced X-Ray Astrophysics Facility (AXAF) will require Helium II (liquid) Superfluid as a coolant. The Broad Band X-Ray telescope (BBXRT) will require the use of solid Argon (Ar.).

Status: The AXAF is planned for launch during 1997, and the BBXRT is scheduled for a STS-35 launch during 1990.

2. Contact: Dr. Edward J. Weiler/EZB, Ultra-Violet, Visible and Space Telescope, NASA HQ.

Response: The Near Infrared Camera Multi-Object Spectrograph (NICMOS) will use as a coolant a mixture of solid carbon dioxide (CO_2) and solid nitrogen (N_2). The NICMOS will be used with the Hubble Telescope as an add-on subsystem. The Advanced Scientific Instrument (ADVANSI) would have used solid Methane (CH_4). The ADVANSI, an infrared instrument subsystem used with the Hubble Telescope; i.e., for second generation investigations, has recently been combined with NICMOS.

Status: The NICMOS and the ADVANSI are planned for a 1995 flight.

3. Contact: Dr. Lawrence Caroff/EZF, Infrared and Radio Astrophysics, NASA HQ.

Response: The Cryogenic Interferrometer Spectrometer will require liquid Helium (H_e) as a coolant. The Large Deployable Reflector (LDR) will use Helium II (liquid) as the infrared sensor system coolant.

Status: Both of the above experiments will not be flown prior to the year 2005.

4. Contact: Dr. Bonnard J. Teegarden/661.0, Nuclear Astrophysics, NASA Goddard.

Response: The Nuclear Astrophysics Explorer (NAE) will require either a mechanical refrigeration system to cool the gamma ray detector

(Germanium crystal), or if microphonics should prove to be a problem for the sensor, the second choice will be a cryogen such as solid nitrogen (N_2) or solid methane (CH_4).

Status: The NAE launch target year is currently 1998.

Summary: After discussions with the representatives of the space physics area, it is apparent that their preference is to fly their experiments in the cargo bay of the NSTS orbiters. The cryogens intended for use are in most cases inert; e.g., Argon, Helium, Carbon Dioxide, Nitrogen. In one case, the selected cryogen is chemically reactive; i.e., Methane for the NAE experiment. In the case of an infrared sensor system, the selected sensor and frequency operating range will determine the optimum sensor temperature, therein the selected cryogen and physical state (i.e., liquid or solid) will be selected. Another solid reactive cryogen that is planned for such future payload experiments is ammonia (NH_3). The solid cryogen sublimes and produces a chemically reactive gas.

E. Cryogen Experiments Enabling Technical Development of Space Systems

1. Contact: Mr. E. Patrick Symons (Mail Code 6200)/Lewis Rsrch Ctr.

Response: Current plans call for flying the Cold-Sat Experiment (Cryogenic On-Orbit Liquid Depot-Storage and Transfer) as a remotely-operated spacecraft launched by an ELV. The prefered cryogen will be 600 pounds/150 cubic feet of LH_2. The purpose for Cold-Sat is to demonstrate storage and fluid transfer operations in preparation for STV (see V, F) flights during period 1998-99. An alternate possiblity would be use of the NSTS orbiter, with non-reactive LN_2 cryogen fluid, but this would result in an attendent loss of technology return (i.e., "G" forces, lack of stay time, fluid physical properties, etc.).

Status: A final decision is not likely until mid-1990, when RIC completes a study to identify orbiter mods, schedules and costs involved if orbiter(s) were to be equipped to safely carry cryogenic reactant payloads. The Cold-Sat flight is planned for late 1997, (See Chart A).

Summary: More empirical data may be needed to design cryogenic reactant transfer and management systems that can store and transfer large quantities of LH_2 and other cryogens while under microgravity conditions. The final configuration design of operational experiments such as Cold-Sat is dependent upon precursor experiments and selection of means for launching into a micro-gravity environment. Currently, the Lewis Research Center (LeRC) plan is to use an ELV such as the Delta II or an Atlas I.

CHART A

CHRONOLOGY OF POTENTIAL ORBITER PAYLOAD BAY REACTIVE CRYO EXPERIMENTS

	PLANNED LAUNCH YR.	USER	TYPE	PAYLOAD NAME/FUNCT. DESCRIPTION	CRYOGEN/REMARKS
1.	1992	SDIO	Fluid Mechanics & Mixing	Slush Hydrogen Coolant Sys.	Solution of Solid & Liquid Hydrogen (LH_2)
2.	1992-95	SDIO	High Power-Short Duration Fuel Cells, Open & Closed Cycle	High Mass Flow Rates & High Energy Density, Possible Electrolysis Reactor For Closed Cycle	Liquid Hydrogen (LH_2) Liquid Oxygen (LO_2) Gaseous H_2 & O_2 For Reactor Input & Supercritical Storage
3.	1993-94	NASA	Precursors For Design Of Cold-Sat & I-STV	Cryo Fluids Microgravity Mechanics & Dynamics	Liquid Hydrogen (LH_2)
4.	1997	SDIO	Hot Gas Turbine Driven Machinery For Power Supply	High Electrical Power Generation By Turbine-Alternator Fluid Mechanics & Emissions	Liquid Hydrogen (LH_2) Liquid Oxygen (LO_2)
5.	1998	NASA	Space Physics, Gamma Ray Detection	NAE (Reference: Attachment B, Item#15)	Solid Methane (CH_4) Solid Ammonia (NH_3)-Alternate

F. Upper Stages Employing Cryogen Propellants

1. Contact: Mr. Robert L. Porter/PD22, Marshall Space Flight Center

Response: A study is being conducted to develop a Space Transportation Vehicle (STV) that assumes the only available launch vehicle will be either a Titan IV (estimated availability of 1989), USAF's Advanced Launch Systems (ALS) (estimated availability of 1998-99), or the Shuttle C vehicle (estimated availability of 1995). The Shuttle C is the preferred launch vehicle. The Shuttle Orbiter is no longer being considered, however, the contracts issued to the two competing contractors, who are currently preparing conceptual designs, specifies that the Interim-Space Transporation Vehicle (I-STV) design will use LH_2 and LO_2 and be adaptable for use by STS, Shuttle C, or ELV transportation and use man-rated safety factors, including man scarring where necessary. The I-STV must be flown several years prior to the full STV; i.e., 1998-99.

2. Contact: Mr. Donald R. Saxton/PT31, Marshall Space Flight Center

Response: Mr. Saxton, the STV Program Manager at MSFC identified several STV contractor studies in work. The MSFC approach for an I-STV conceptual design includes vehicle study contracts with Boeing Aerospace and Martin-Marietta. These competing designs for an I-STV will incorporate man-rated safety factors and provisions/scarring for installation of STV hardware peculiar for use with an STS orbiter; i.e., should the use of an orbiter be later required. The primary intent for these I-STV conceptual designs is to be configured for launch by a Shuttle C vehicle, with adaptability for an ELV, or an orbiter. These designs will also include considerations pertaining to on-orbit disassembly and recovery of vehicle elements, permitting orbiter crews to return with parts from an I-STV. At NASA Headquarters, Code M, has an infrastructure study contract with General Dynamics to provide an overall evaluation and recommendations regarding the NASA's National Space Transportation System (NSTS), by addressing various launch vehicles, Orbiter Maneuvering Vehicle (OMV) and future required support facilities. Another contractor study let by Headquarters is for Boeing Aerospace to look into the design requirements for a Mars Transfer Vehicle (MTV).

Summary: Present program planning efforts for launching cryogenic upper stage vehicles seems to be limited to small pre-I-STV flight experiments, I-STV's and SBSTV's. In each case, the reactive cryogens are LH_2 and LO_2 and the payloads are now being designed to fly only on an ELV or the Shuttle C vehicle, except the MSFC design for an I-STV which could also fly on an orbiter if circumstances should later dictate. It should be noted that the LeRC has been considering the use of an Upgraded Centaur vehicle as an I-STV. The LeRC approach is currently in the definition phase and calls for a 1995 launch to LEO aboard a Titan IV or IV-U.

G. Fuel Cell Development

1. Contact: Dr. Alton Patton,/Director, Center For Space Power and Space Research, Texas A&M University.

Response: Since 1987, while under a NASA HQ's contract, Texas A&M has been conducting research in the area of high energy density fuel cells utilizing LH_2 and LO_2. A solid oxide fuel cell and a solid polymer electrolyte fuel cell could be test flown on an ELV or in the payload bay of the orbiter. The latter being the preferred mode of flight testing.

Status: No technical papers have been turned-in yet, but an intent to soon file a NASA Form 1628 (request for flight) was reported.

2. Contact: Dr. Raymond Askew/Director, Auburn University Space Power Institute.

Response: They are presently working on methods of demonstrating heat transfer properties with LH_2/LO_2 advanced fuel cells. Electrical power conditioning and controls that will be required by commercial users for space materials processing are also being investigated. A new electrode structure for producing fuel cells with high mass flow rates is undergoing development. Dr. Askew expects to tie-in with U.T.C. for fabrication of some related hardware items. One of their institute's primary goals is to develop an advanced fuel cell system that produces high power output for short-term needs, while using own dedicated cryo system; and be first used aboard the Shuttle as some sort of supplemental electric power source system. Future payload applications are also possible.

Status: The advanced fuel cell project is yet in the early developmental stage and conceivably could fly in 3-years, but no schedule has been established. The electrode structure for high mass flow is expected to be built and tested about 12 months from now.

3. Contact: Mr. David Bueden/Power & Power Conditioning, SDI Office

Response: SDI experiments will continue to utilize LH_2 and LO_2 powered fuel cells, but all payloads have been moved over from Orbiter flights to those on ELV's.

4. Contact: Mr. O.E. Bassett/Power and Conditioning, SDI Office

Response: Fuel cells utilizing LH_2 and LO_2 that operate within a closed cycle system, producing about 1 Megawatt of output power for short bursts of energy are subjects of planned future space experiments. The system will include a small reactor to hydrolyze the fuel cell effluent (H_2O and H_2) back into the gaseous form (O_2 and H_2); also a storable cryogenic source to chill these gases down to supercritical cryo state for storage and eventual reuse in the fuel cell. Experimental fuel cells of this type must be tested on-orbit and the SDIO would prefer to use the space shuttle as the launch vehicle.

Status: Closed-loop fuel cell systems are in the early stages of development, but will be required for SDIO future payloads. Presently, conceptual designs are being prepared to fly as experiments early-to-mid 1990's. Should the STS orbiter fleet offer the capability to safely carry such proposed payloads, then the flight hardware will be designed to meet STS requirements.

Summary: A number of universities and aerospace manufacturers have in work various research and development programs to produce improved fuel cell systems. It's too soon to determine the outcome of pending research, nor when requests for space flights might materialize. Either the Shuttle or an ELV could be used to launch these fuel cells, but the orbiter is preferred in all cases by the experimenters.

H. Turbine Drive Alternator Power Supply Systems

1. Contact: Mr. O.E. Bassett/Power and Power Conditioning, SDI Office

Response: SDIO will require the generation of many megawatts of electrical power for short durations by the utilization of turbo-machinery to drive electrical energy generating alternators. Such a power system requires cryogenically stored LH_2 and LO_2 for use as combustion reactants, the products being water vapor and gaseous hydrogen (used as the propellant for driving the turbine); or hydrogen alone as the working fluid after being heated (in a nuclear reactor or due to combustion).

Status: An associated water vapor and GH_2 effluent capturing experiment is being planned for an orbiter flight during the mid-1990's, followed by a possible orbiter flight of an experimental turbine powered by combustion of GH_2 with GO_2. Cryogenically stored reactants for powering turbo-machinery are planned for extensive use to provide electrical power for SDI systems planned for operation during the late 1990's.

Summary: Turbine-derived electrical power for future SDIO payloads is an important component of planned SDIO payload capabilities. The effluent capturing experiment planned for the mid 1990's will require a source for heated water vapor and GH_2 to be captured by the experimental equipment being evaluated. The possible follow-on experiment will require the combustion of GH_2 with GO_2 to drive the turbo-machinery. The SDIO desires to perform such testing while utilizing an orbiter payload bay as the local environment. If the STS orbiter fleet should include such capabilities as required for the proposed combustion phase testing of the turbo-machinery, then the SDIO designs will meet those requirements imposed by the NSTS.

I. Slush Hydrogen Experiments

1 Contact: Dr. Jerry Beam/National Aerospace Plane, USAF Wright Research Development Center (WRDC)

Response: The WRDC has issued a "Procurement of Research & Development Acquisition" (PRDA) for contractor work to develop the conceptual designs and associated technology for utilizing slush hydrogen (solution of liquid H_2 with chunks of solid H_2 present) to cool equipment for SDIO that would be positioned on a future space platform. Slush hydrogen is favored because of the temperatures/thermal energy levels it provides, (Approximately 12°K colder than LH_2 or 18°K versus 30°K). On-orbit experiments will be required once flight experimental hardware becomes available.

Status: The successful bidder has not been selected by WRDC yet, who are still reviewing submitted proposals. No choice has been made yet if such experiments will be flown on an orbiter or an ELV.

Summary: Dr. Beam has indicated that the STS orbiter would probably provide the best space platform for such proposed experiments. Apparently, he will soon be discussing such a possibility with NASA Goddard representatives in the thermal management area.

VII Listing Of Potential Reactive Cryogen Payload Users Contacted

The individuals contacted at the following user organizations are identified in Appendix A.

A. U.S. Government Agency Organizations

1. NASA

a. Commerical Development Division, Headquarters (HQ)
b. Flight Projects Div., Headquarters (HQ)
c. Advanced Transportation Program Development, HQ
d. Transp. Services Office, HQ
e. Customer Services, Div., HQ
f. Transportation Services, HQ
g. Shuttle Systems Div., HQ
h. Office of Space Science & Applications, HQ
i. Propulsion, Power, & Energy Div., HQ
j. Astrophysics Div., Office of Space Science & Applications, HQ
k. Defense & Intergovernmental, Relations Dir., Office of External Relations, HQ
l. Space Technology Div., Goddard Space Flight Center (GSFC)
m. Cosmic Radiations Br., Laboratory for High Energy Astrophysics Div.,GSFC
n. Orbiter Engineering Office, Johnson Space Center (JSC)
o. Customer Service, Br., Customer Integration Office, JSC
p. Power Generation, Propulsion & Pwr Div., JSC
q. Systems Branch, Propulsion & Pwr Div, JSC
r. Vehicle Propulsion & Fluids BR., Propul. & Pwr Div, JSC
s. Project Engineering Office, Orbiter Engrg Office, JSC
t. Cargo Engineering Office, JSC
u. Space Science Lab, Marshall Space Flight Center (MSFC)
v. Advanced Systems Office, MSFC
w. Propulsion Lab, MSFC
x. Structural & Thermal Analy Br., Advan. Projects Office, Program Development Directorate, MSFC
y. Star Lab Mission, Mission Project Office, Payloads Project Office, MSFC
z. Space Propulsion Br., Propulsion Lab, MSFC
aa. Program Development, Advan. Transp Office, MSFC
ab. Science & Engineering Directorate, MSFC
ac. Cold-Sat Project, Cryo Fluids Technology Office, Lewis Rsrch Ctr.
ad. Advance Space Analy. Office, Lewis Rsrch Ctr.
ae. National Aerospace Plane Program, WPAFB
af. Payload Support Office, Payloads Project Mgmt.,Kennedy Space Center (KSC)
ag. Fluids & Propul. Sys Section, STS Payloads Ops., KSC
ah. External Relations Office, Moffett Field, Ames Rsrch Ctr.
ai. Advanced Technology & SS Plan Office, Moffett Field, Ames Rsrch Ctr.

2. USAF

   a. Upper Stage Office, USAF, Space Sys. Div.
   b. Space Flt Sys Div. US Air force Directorate For Space & SDI Programs
   c. Space Test Programs, U.S. Air Force Directorate For Space & SDI Programs
   d. Space Launch Planning Div, USAF Space Sys.
   e. Advanced Space Concepts, U.S. Air Force Space Systems Div.
   f. National Aerospace Plane, Wright Research Development Center

3. Space Defense Initiative (SDI) Office

   a. Power & Power Conditioning, Key Technologies Directorate, SDIO
   b. Directed Energy Directo~~rate~~, SDIO
   c. Sensors & Intercepters Technology Directorate, SDIO

B. Domestic Commercial Sector Aerospace Companies

   1. Electro-Optical & Cryogenics, Space Sys Div., Ball Aerospace
   2. NASA-Code C Support, McDonnell-Douglas
   3. NASA-Code M Support, McDonnell-Douglas
   4. NASA-Code C Support, Lockheed Space Co.
   5. NASA-Code E Support, Lockheed Space Co.
   6. Advanced Programs, Astronautics Div, Lockheed Space & Missile Co.
   7. EDO Project & Orbiter Payload Cargo Integration, STS Div., Rockwell Int'l Corp.
   8. Hamilton Standard, UTC
   9. National Aerospace Plane, P&W, UTC
   10. Upper Stages Engines, P&W, UTC
   11. Int'l FuelCells/UTC Pwr Systems Div
   12. Advanced Technology Div, TRW
   13. Space System Div, General Dynamics
   14. Research Mechanical Dept., Sundstrand
   15. Aerospace & Electronics Div., Boeing
   16. Advanced Programs, NASA Space Systems, Astronautics Gp., Martin-Marietta
   17. STV Program, Strategic Systems, Martin-Marietta

C. Domestic Universities

   1. Center of Space Research, MIT
   2. Center For Space Power, Texas A&M Univ.
   3. Space Power Institute, Auburn, Univ.
   4. Center For Advanced Space Propulsion, Univ. of TN

VIII. Summation of Study Findings

A review of the data obtained while surveying those users representing the nine cryogenic payloads areas (Section VI.), led to the conclusion that only three should be further scrutinized. Each of the three presented a potential for future orbiter reactive cryogen payloads. A key factor that will influence such possibiliites will be the products of a current RIC study to determine existing and recommended orbiter design limitations for safely carrying cryo payloads. The following presents brief summations of the RIC orbiter modifications study and the three potential user areas.

A. Current Space Shuttle Modification Studies For Accommodating Reactive Cryogenic Payloads

As earlier mentioned by this study report, future planning by a number of intended/potential reactive cryo payload users will be significantly influenced by the outcome of current studies, (Refer to Chart A). Studies are currently in work by the Rockwell International Corp. (RIC). In June, 1989, the NASA Johnson Space Center (JSC) initiated a Level II 9-month study by RIC to determine what orbiter design modifications would be required to safely provide orbiter reactive cryo payload mission capabilities. The anticipated results of this RIC study include: orbiter conceptual designs and specifications necessary for cryo payloads prelaunch testing, servicing, purging and venting; recovery after launch abort, or return from flight; inflight dumping/purging; and, contingency operations associated with various mission abort modes. Other products of the RIC study will include: expected costs, schedules, weight and manpower impacts for RIC recommended design modifications; along with resultant levels of orbiter operational capabilities. Subsequent to such studies, NASA will determine if any orbiter chages are required, relative to establishing future policy pertaining to possible flight of reactive cryo payloads.

B. Planned Experiment Payloads For STV Space Cryo Technology Development

In the area of advanced upper stage planning for the development of NASA's STV capability, on-orbit cryo fluid experimentation is regarded as an essential element for completing the design phase for the initial or interim STV (I-STV) and the space-based STV (SBSTV). The two leading NASA centers on the STV effort are the Lewis Research Center (LeRC) and the Marshall Space Flight Center (MSFC).

The planned cryo experiments will consist of two major technological areas: pressure controls for tanks (venting and maintaining subcritical pressures); and liquid acquisition (fluid settling). The LeRC is the lead center for the first area and MSFC is for the second. In both cases, the cryogen would be preferably LH_2, but LN_2 could also be used as a less desirable alternate cryogen, (See Chart A). The smallest size cryo tanks being considered for both areas are about 7-cubic feet in volume and the largest about 18-20-cubic feet (tanks will be shaped cylinderical with eliptical ends). These precursor technological experiments are planned for orbiter flights occuring during the period 1993-94. The real (versus theorectical) modeling data obtained will be utilized by both centers for final designs for the I-STV; SBSTV; cryo fluid depots (located at LEO, on the lunar surface, and/or low Martian orbit); the Martian Propulsion Vehicle (manned fast version-14 months from moon to Mars and the slower cargo version); and, if time permits, for the LeRC Cold-Sat Experiment.

The MSFC is also planning for a possible cryogen transfer experiment for LH_2 technology experiments that could fly as early as 1996-97. This MSFC experiment would be intended to represent an option for the LeRC's Cold-Sat Experiment, but instead would fly in the orbiter cargo bay, possibly as free-flyer. This experiment for low "G" on-orbit resupply experimentation is being proposed by MSFC as a joint effort with Le RC (See Chart A).

C. Space Experiments For Defense Related Power Supply Systems

Recent technical interface meetings (TIMS) with representatives of SDIO have indicated that SDIO space experiments will continue to depend on the use of LH_2 and LO_2 as reactants for on-going experiments for new fuel cell technologies. The new fuel cells will be capable of producing high power output for short periods of time by employing high mass flow rates through experimental type fuel cells with solid oxide electrodes and solid polymer electrolyte. Some of these systems will operate within closed cycles, thus will require cryogenic sources to cool and supercritically store recovered fuel cell effluent for future reuse. Presently, these proposed fuel cell experiments are being planned for launch aboard an ELV, but SDIO would much prefer to use an orbiter instead. As an experiment operated in the payload bay of the orbiter, or as a free-flyer, increased scientific test data would be realized sooner than if flown aboard an ELV. The use of an orbiter (versus an ELV) would permit human interaction with experiments and payload on-orbit repair/returnability of hardware for modifications and re-use. Such experiments are planned for flight during the period 1993-95. If an orbiter reactive cryogen payload carrying capability were to soon become available, then SDIO would reportedly design their experiments to fly on the orbiter, versus an ELV (Refer to Chart A).

A similar case is true for SDIO proposed experiments involving the use of turbine machine operated alternator power supplies to generate short bursts of high power output. The SDIO has firm plans to fly during the mid-1990's a turbine machine exhaust collection experiment onboard an orbiter to recover water vapor and gaseous hydrogen.

The follow-on experiment will utilize GH_2 and GO_2 from a cryo storage system to fuel the turbine. This second experiment could also be flown on an orbiter, versus an ELV; i.e., if such an orbiter capability should become available.

D. Space Physics And Sensor Experiments

By reference to Attachment B, ~~there~~ are at the present 11-space physics cryogenic-type experiments planned to fly on an orbiter between the period 1990 and 2005, of which none will employ (as a coolant), a chemically reactive cryogen. Other reactive cryo payloads have either been cancelled or re-planned for launch on an ELV. During all discussions with representatives of this cryo payload user area, the general response has been uniformly in favor of using the cargo bay of an orbiter, rather than an ELV, (Refer to Chart A). The preference for use of an orbiter is similar to that earlier mentioned by Item C (i.e., human inter-action and hardware returnability). Infrared sensor systems will require the cryogen and physical state that best suits the selected sensor and optimum frequency operating range. Thus, future such sensor systems will probably require solid methane (CH_4), ammonia (NH_3) and/or slush hydrogen (LH_2). Therein lies the possibility of a number of future space experiments requiring such coolants.

E. General Summary of Study Report

To recapitulate the findings of this study report, it is apparent that most users in the areas of SDIO, space physics, sensors and technology enabling experiments have expressed uncertancies regarding the possibility that program approval and funding will be attainable for their planned/proposed cryo experiments for the 1990's, but have indicated a preference for flying their experimental type payloads on an orbiter, versus an ELV. If the STS management should decide to provide an orbiter with an approved capability to carry chemically reactive cryogens and/or significant quanities of cryogen as payloads, then it appears that most experimenters would make every effort to have their planned/approved payload designed for and flown on an orbiter, instead of an ELV. If follows that this scientific activity could induce future needs for such space experimentation.

IX. Conclusion and Recommendations

It is noted that the planning time tables for cryo payload users mentioned in this study report may be adversely effected by decisions driven by budget authorizations. This study report can only address the facts as present conditions dictate. At this time there are few firm recommendations possible.

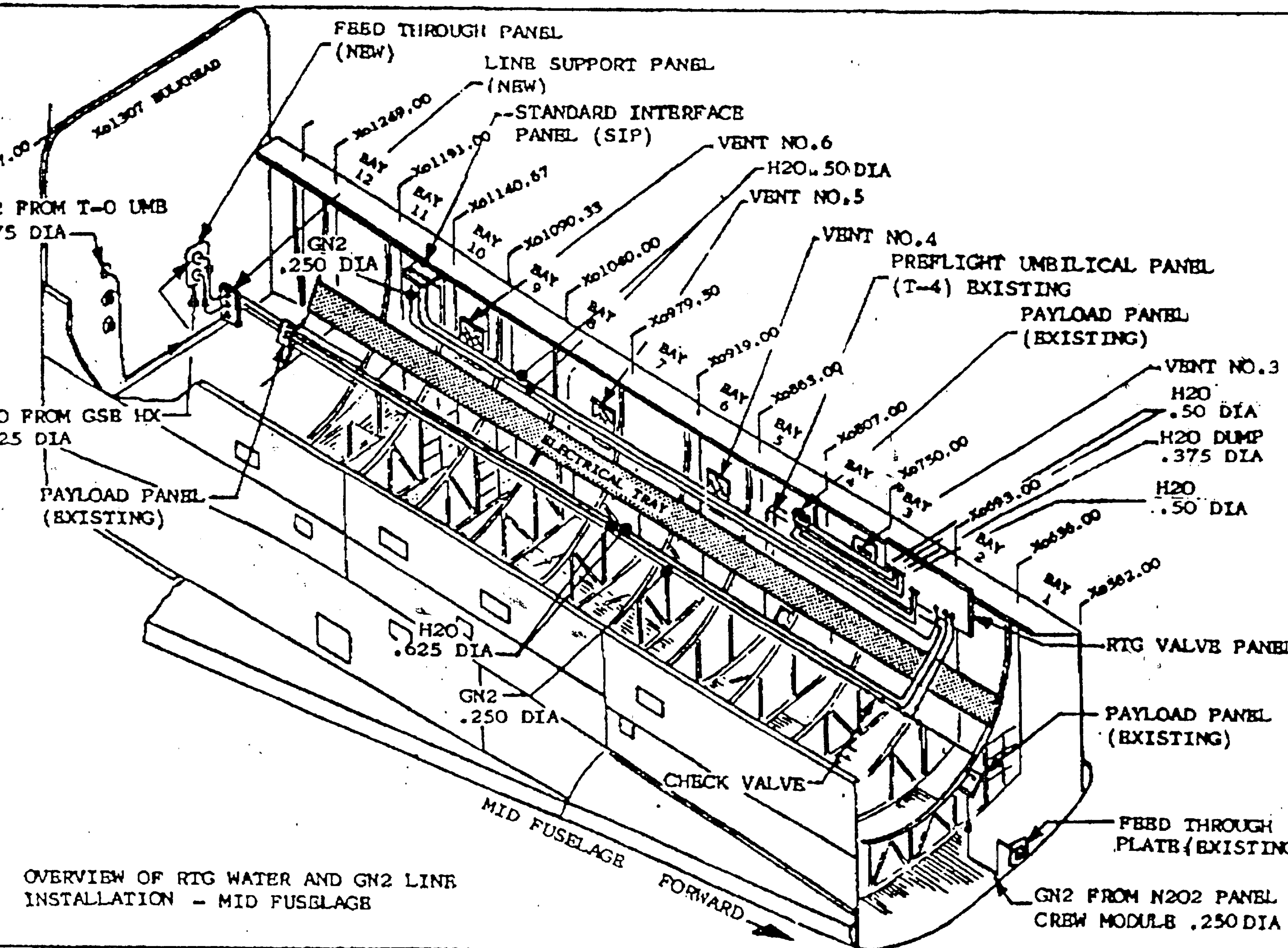
Thus, it is recommended that in the near future potential payloads/experiments identified herein should be closely tracked for continuance and changing schedular needs. Chart A is provided to summarize the key reactive cryo space experimental programs, and Attachment B to present an aggregate sampling of potential cryo payloads, that could, if approved, require or would greatly benefit from use of an orbiter as the launch vehicle. Parallel to this period, the Rockwell study will be completed and the NASA will be deciding if any, or what, orbiter modifications will be performed to permit the safe carrying of future reactant cryo payloads/experiments.

The final recommendations set forth by this study report are first, there is an apparent need to revisit and update the status relating to many of the cryo user concerns and trends; possible changes in their plans, technology development, and U.S. space program goals. Second, that such an update could be performed in a manner similiar to the one derived for conducting this survey-type study. If such a future study should be required, then it would be most appropriate within a 3-4 month time frame; i.e., following completion of other studies mentioned herein that will help define future capabilities and payload requirements for the orbiter fleet.

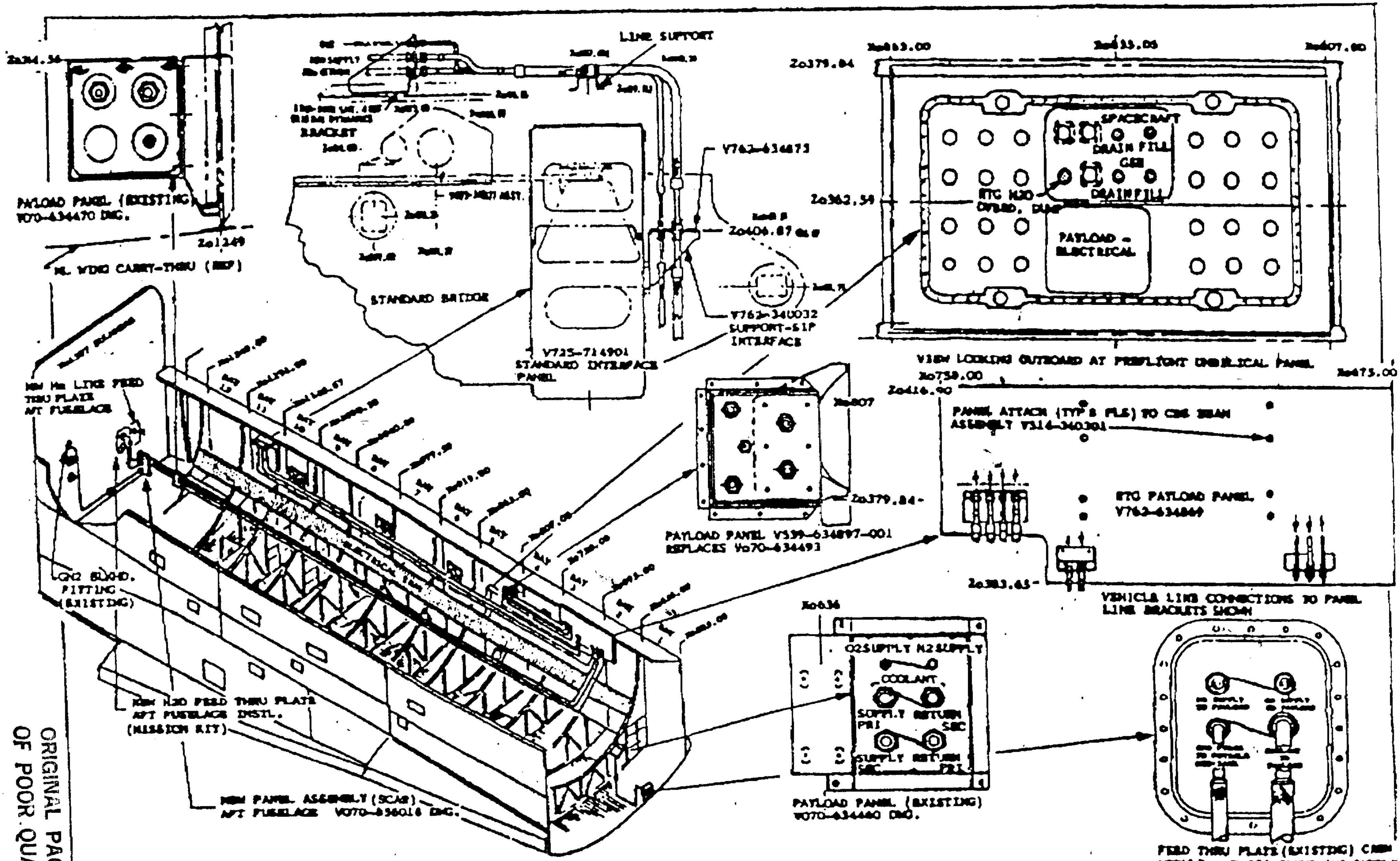
In conclusion, although this study report can only address general areas of consideration and probable near-term trends, it is intended to provide NASA Space Transporation System management with updated reactive cryo payload user status and technical areas summaries. Hopefully the findings reported herein will support the decision making process that will effect the future use of our important natural resource, the Space Shuttle System.

CONFIGURATION OF ORBITERS FOR CENTAUR TYPE PAYLOADS

- SUMMARY ORBITER CURRENT CONFIGURATIONS:
  - OV-102 (COLUMBIA): NO RELATED MODS INSTALLED
  - OV-103 (DISCOVERY): STRUCTURAL STRENGTHENING MOD KITS, CUT-OUTS & COVER PANELS INSTALLED
    NOTE: KITS INSTALLED WERE THOSE NOT INSTALLED OV-099 & BALANCE WERE RE-MFG KITS UNIQUE TO OV-103
    ADDITIONAL MODS INSTALLED AFTER STS-29 INCL. PROVISIONS FOR PAYLOAD RTG COOLING (LINE SUPORTS, BRACKETS, & ACCESS DOORS FOR COOLING LOOP CONNECTION TO GSE VIA PORT-AFT HEAT EXCHANGER)
  - OV-104 (ATLANTIS): ORIGINALLY CONFIG FOR GAILIO-CENTAUR G' PAYLOAD, NOW ONLY KITS FOR STRUCTURAL STRENGTHENING & VENTING REMAIN INSTALLED; KIT INSTALLATION EFFORT FOR PAYLOAD RTG COOLING LOOPS @ KSC
  - OV-105 (PALMDALE, CA): PRELIMINARY RPTS INDICATE STRUCTURAL STRENGTHENING MODS INSTALLED



OVERVIEW OF RTG WATER AND GN2 LINE INSTALLATION - MID FUSELAGE



MID FUSELAGE PANEL INSTALLATION REQUIRED TO SUPPORT LINE MOCKUP, INSTALLATION IN THE MID FUSELAGE

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SAMPLE LISTING OF POTENTIAL ORBITER CRYO PAYLOADS

ITEM	ACRONYM	PAYLOAD/ EXPERIMENT NAME	CRYOGEN(S)	PHYSICAL STATE	APPROX. VOL (LITERS)	PLANNED MISSION	LAUNCH DATE	USER	REMARKS
1	ADVAN SI	Advanced Scientific Instrument	Methane (CH_4)	Liquid	200	T.B.D	1995	NASA	IR Instrument Used with Hubble Space Telescope After 5yrs in Space for 2nd Generation Investigations. Program Scientist: E.J. Weiler, NASA HQ (202) 453-1469; Contractors: Ball Aerospace, U. of AZ. Note: Now Combined w/NICMOS
2	NICMOS	Near IR Camera Multi-Object Spectrograph	Nitrogen & Carbon Dioxide (N_2 & CO_2)	Solid Solid	Combined in 200gm mass	T.B.D	1995	NASA	Used with Hubble Space Telescope Program Scientist: E. J. Weiler, Program Mgr.: D. Broome NASA HQ (202) 453-1469 Contractor: Bal Aerospace, U. of AZ.
3	AXAF	Advanced X-Ray Astro-Physics Facility	Helium II Superfluid (H_e.)	Liquid	200-400	T.B.D	1997	NASA	Planned for 15 years On-Orbit. Program Scientist: A.N. Bunner, NASA HQ (202) 453-8547 Program Mgr: A. J. Fuchs, NASA HQ (202) 453-1450 Contractor: TRW
4	ASTROMAG	Particle Astrophysics Superconduct-ing Magnet Facility	Helium II Superfluid (H_e.)	Liquid	3,100 to 6,000	T.B.D	1999	NASA	Joint NASA-ASI Facility. Super-conducting Magnet used on SSF for High Energy Astrophysics Experimentation (Cosmic charged Particles/Photons) Resupply of He. II optional Program Scientist: W.V. Jones, NASA HQ Program Mgr.: R. Howard, JPL/NASA HQ (202) 453-1514

SAMPLE LISTING OF POTENTIAL ORBITER CRYO PAYLOADS

ITEM	ACRONYM	PAYLOAD/ EXPERIMENT NAME	CRYOGEN(S)	PHYSICAL STATE	APPROX. VOL (LITERS)	PLANNED MISSION	LAUNCH DATE	USER	REMARKS
5	BBXRT	Broad Band X-Ray Telescope	Argon (Ar.)	Solid	184 kgm	STS-35	1990	NASA	Sealed System Built Under MSFC, Flown Under goddard Space Flt. Center on ASTRO -1 Space Lab for Several Missions. Program Scientist: A.N. Bunner, NASA HQ Contractor: MSFC/Ball Aerospace
6	CPPF	Critical Point Phenomena Facility	Helium II Superfluid (He.)	Liquid	200-400	T.B.D	1994-96	NASA	Used On SSF. Helium Lampda Point Super-Fluid Experiment Program Scientist: R.K. Crouch, NASA HQ (202) 453-1490 Program Mgr.: F. Lemkey, NASA HQ (202) 453-1490 Contractor: T.B.D.
7	CIRRIS	Cryo IR Radiance Instrument for Shuttle	Helium II Superfluid (He.)	Liquid	350	T.B.D	1990	DOD-SDIO	Palletised on SPAS Program Scientist: T.B.D. Program Mgr.: M. Harrison, SDIO (202) 695-8825 Contractor: MBB
8	COLD-SAT (originally CFME & CFMFE)	Cryogenic On-Orbit Liquid Depot-Storage & Transfer	Hydrogen (H_2.)	Liquid	600 lbs.	Currently Planned to Fly on ELV	1996	NASA	Flown Under Ames Research Ctr. Program Scientist: T.B.D Program Mgr.: E.P. Symons, NASA Ames (216) 433-2853 Contractor: Bidding Phase
9		Cryogenic Inter-ferrometer Spectrometer	Helium (He.)	Liquid	2,000	T.B.D	2005	NASA	Program Scientist: L. Caroff, NASA HQ (202) 453-1466

SAMPLE LISTING OF POTENTIAL ORBITER CRYO PAYLOADS

ITEM	ACRONYM	PAYLOAD/ EXPERIMENT NAME	CRYOGEN(S)	PHYSICAL STATE	APPROX. VOL (LITERS)	PLANNED MISSION	LAUNCH DATE	USER	REMARKS
10	GP-B	Gravity Probe-B	Helium Ii Superfluid (He.)	Liquid	1,500-1,600	Currently Planned to Fly on ELV (Delta II)	1993-94	NASA	Currently Unfunded, Under MSFC Program Scientist: Francis Everritt Prrogram mgr.: D.A. Gilman, NASA HQ (202) 453-1467 Contractors: Standord Univ./Lockheed Space Co.
11	IBSS	Infrared Background Signature Survey	Helium I (He.)	Liquid	300	STS-39		DOD-SDIO	Palletised on SPAS Program Scientist: T.B.D. Program mgr.: M. Harrison, SDIO (202) 695-8825 Contractor: MBB
12	LPE	Lampda Point Experiment (Thriple Point)	Helium Ii Superfluid (He.)	Liquid	200	T.B.D.	1995	NASA	Palletised on MPESS & Space Lab Ii Pallet Reflight Of Dewar Program Scientist: John Lipa Stanford Univ. (415) 723-4562 Program Mgr.: Warren Hodges, NASA HQ (202) 453-1490 Contractor: JPL
13	LDR	large Deployable Reflector	Helium Ii Superfluid (He.)	Liquid	7,000	T.B.D.	2005	NASA	Submillimter IR Astronomical Observations Requires Resupply (1 per yr.) Program Scientist: Larry Caroff Program Mgr.: Larry Caroff NASA HQ (202) 453-1466 Contractor: J.P.L.
14		Planetary IR Telescope	Helium Ii Superfluid (He.)	Liquid	500	T.B.D.	1999	NASA	Program Scientist: T.B.D. Program Mgr.: H.C. Brinton, NASA HQ (202) 453-1597
15	NAE	Nuclear Astrophysics Explorer	Mech Refrig or Nitrogen (N_2) or Methane (CH_4)	Solid	800 kgm or 1,000 Liters	Currently Planned to Fly On ELV (Delta II)	1998	NASA	Gamma Ray Intensity Counter by Germanium crystal Program Scientist: Bonnard J. Teegarden NASA Goddard (301) 286-5277

LISTING OF INDIVIDUALS CONTACTED FOR STUDY INPUTS

U.S. Government Agency Organizations, Contractors And Universities Awarded Study Grants

A. NASA:

1. Commercial Development Div, Headquarters (HQ) - Richard H. Ott/CC	(202) 453-1890
2. Flight Projects Div, HQ - John C. Loria/RX	-2838
3. Propulsion, Power, & Energy Div., HQ - Maria Lopez-Tellado/RP	-2856
4. Advanced Transportation Br, Advan. Program Develop Div., Advanced Transporation Program Development, HQ - Barbara S. Askins/MD	-9226
5. U.S. Civil & Int'l Payloads Branch, Transporation Services Office, HQ - Robert L. Tucker/ MC	2151
6. Flight Requirements & Analy Branch, Transporation Services Office HQ - Randy K. Herington/MC	-1912
7. Customer Services Div, HQ - Frank B. Pipkin/MC	-1916
8. Shuttle Systems Div, HQ - Witalij Karakulko/MES	-2547
9. Astrophysics Div, Office of Space Science & Applications, HQ - Lawrence Manning/EZF	-1472
10. Astrophysics Div, Office of Space Science & Applications, HQ - Edward J. Weiler/EZB	-1469
11. Astrophysics Div, Office of Space Science & Applications, HQ - Alan N. Bunner/EZC	-8547
12. Astrophysics Div, Office of Space Science & Applications, HQ - Lawrence Caroff/EZF	-1466
13. Defense & Intergovernmental Relations Div., Office of External Relations, HQ - Richard G. Annas, Lt. Col. USAF/XD	-8427
14. Space Technology Div, GSFC - Stephen H. Castles/7-109	(301) 286-8986
15. Cosmic Radiations Br., Laboratory for High Energy Astrophysics Div,. GSFC -Bonnard J. Teegarden/661.0	-5277
16. Customer Service, Customer Integration Office, JSC - John H. Temple/TC-12	(713) 483-1341
17. Orbiter Engineering Office, JSC - Dwayne Weary/VE	-1386
18. Orbiter Engineering Office, JSC - Robert R. Rice/VE-4	-8396
19. Vehicle Propulsion & Fluids Br., Propulsion & Power Div, JSC - John W. Griffen/EP-4	-9003
20. Propulsion & Power Power Div, JSC - Kenneth R. Kroll/EP-4	-9011
21. Cargo Integration Office, JSC - Lawrence Bell/TJ	-1235
22. Space Science Lab, MSFC - George L. Fichtl/ES01	(205) 544-5506
23. Advanced Systems Office, MSFC - James A. Fountain/PS05	-0644
24. Propulsion Lab, MSFC - John P. McCarty/EP01	-6999
25. Science & Engineering Directorate, MSFC - Lee W. Jones/EP53	-7094
26. Science & Engineering Directorate, MSFC - John M. Cramer/EP53	-7090
27. Structural & Thermal Analy Br, Advanced Projects Office, Program Development Directorate, MSFC - Robert L. Porter/PD-22	-2652
28. Star Lab Mission, Mission Mgmt. Office, Payload Projects Office, MSFC - Robert C. McAnnally/JA-21	-1925
29. Advanced Transportation Office, MSFC - Donald Saxton/PT-31	-5035
30. Cold-Sat Project, Cryo Fluids Technology Office, Lewis Research Center (LeRC) - E. Patrick Symons/MS6200	(216) 433-2853
31. Cold-Sat Project, Mission Mgmt. Office, Payload Projects Office,LeRC - Irv Sumner/ MS-6200	-2853
32. Advanced Space Analysis Office, LeRC - Joseph Nieberding/501-6	-5418
33. CIRRUS Launch Site Support Management, Payloads Support Office, Payloads Project Mgmt., KSC - Dean C. Zimmerman/CP-PSO-A	(407) 867-3183

34. STS Payload Operations, Payloads Processing Div.,STS Payload Ops.,KSC- Craig M. Baker/CS-PPD-22 -4787
35. External Relations Office, Ames Research Center, Moffett Field - Lawrence Milov/DXR (415) 694-4044
36. Advanced Technology & Space Station Planning Office, Ames, Moffett Field William E. Berry/DS -4930
37. NASA Principle, National Aerospace Plane Program, WPAFB - Harold Wright/ AFSC/NA (513) 255-9405

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1. Electro-Optical & Cryogenics, Space Systems Div., Ball Aerospace - Michael Noble/EOC (303) 939-4880
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3. Center For Electro-Chemical & Hydrogen Research, Texas A&M University - John Appleby 845-5571
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5. Center For Advanced Space Propulsion, University Of Tennessee - George Garrison (615) 454-9294
6. Center For Advanced Space Propulsion, University Of Tennessee - Basil Antar (615) 455-0631 Ext.471