

CONTRACT NAS8-31844

PHASE B-FINAL DEFINITION AND PRELIMINARY DESIGN STUDY FOR THE INITIAL ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL) - A Spacelab Mission Payload

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LABORATORY. REQUIREMENTS REVIEW Final
Definition and Preliminary Design Study
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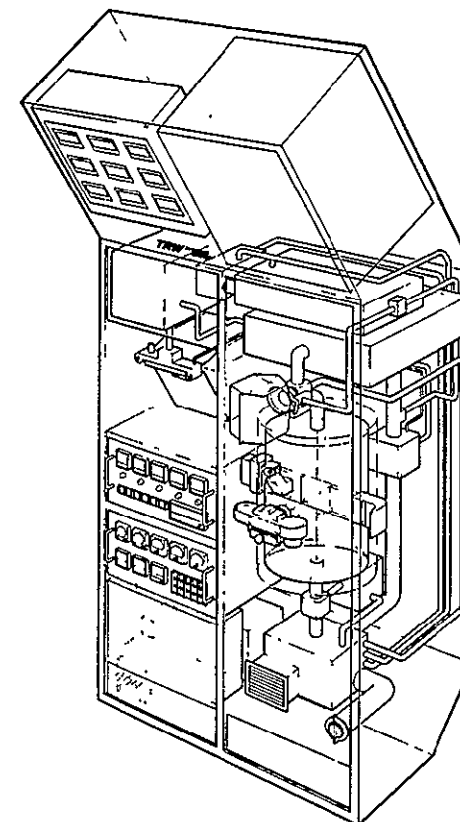
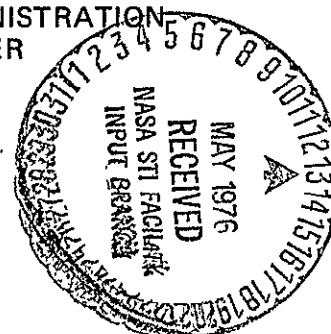
REQUIREMENTS REVIEW (DR-MA-03)

APRIL 15, 1976

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

By
ACPL PROGRAM TEAM
O.W. Clausen, Program Manager



TRW

DEFENSE AND SPACE SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

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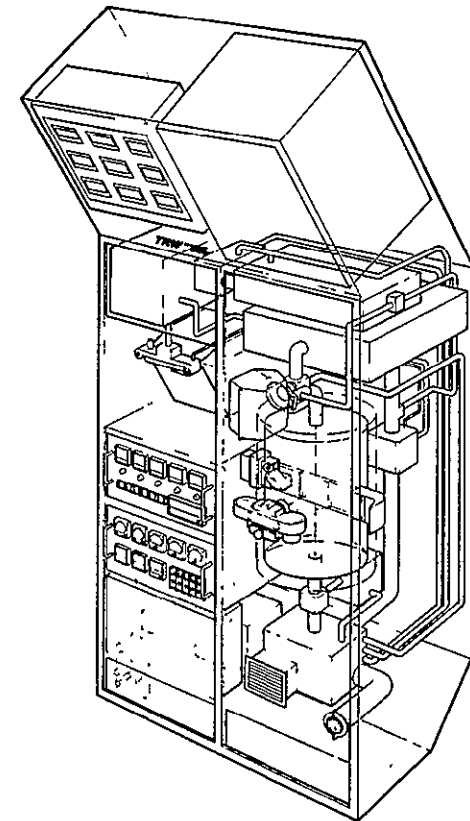
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AGENDA

NASA REMARKS

STUDY OVERVIEW

SPACELAB RESOURCE ALLOCATIONS

ENGINEERING ANALYSES AND TRADES

SCIENTIFIC REQUIREMENTS

LUNCH

SCIENTIFIC REQUIREMENTS - CONTINUED

STUDY OVERVIEW

BILL CLAUSEN

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The Requirements Review has been structured to present TRW's progress in engineering of the ACPL with the objective of soliciting comments and suggestions on the work. Another, more pressing, objective is to discuss specific science requirements to be used for the remainder of the study in as much detail as possible.

MEETING OBJECTIVES

- TO DESCRIBE THE RESULTS OF THE ENGINEERING ANALYSES AND TRADES ACCOMPLISHED TO DATE.
- TO SOLICIT COMMENTS ON THE PRELIMINARY ACPL CONFIGURATION, AND ON THE DIRECTION OF PLANNED WORK.
- TO BETTER UNDERSTAND ACPL SCIENCE REQUIREMENTS AND THEIR BASIS.
- TO IDENTIFY PRIMARY LABORATORY SCIENCE DRIVERS.
- TO PROVIDE A FORUM FOR DISCUSSION AND ADOPTION (OR REJECTION) OF SPECIFIC SCIENCE REQUIREMENTS.

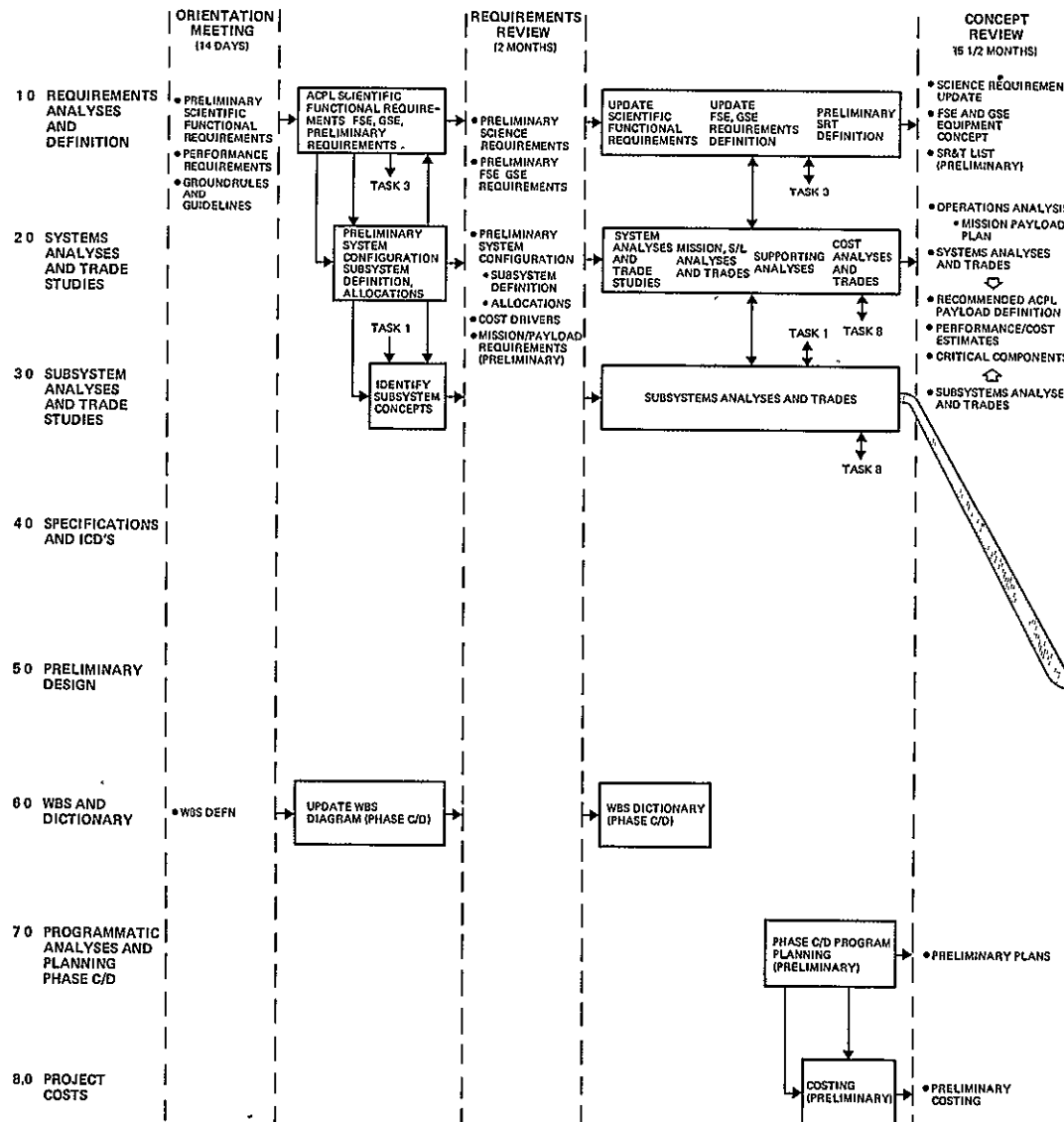
The facing page presents an overview schedule for the ACPL Phase B Study. Because of the one month delay in the date of the Requirements Review, the time before Concept Review has been reduced to approximately thirteen weeks. This fact emphasizes the need to establish ACPL science requirements as quickly as possible. Conceptual analyses and trades have been underway since February and are based on the preliminary sets of science requirements provided.

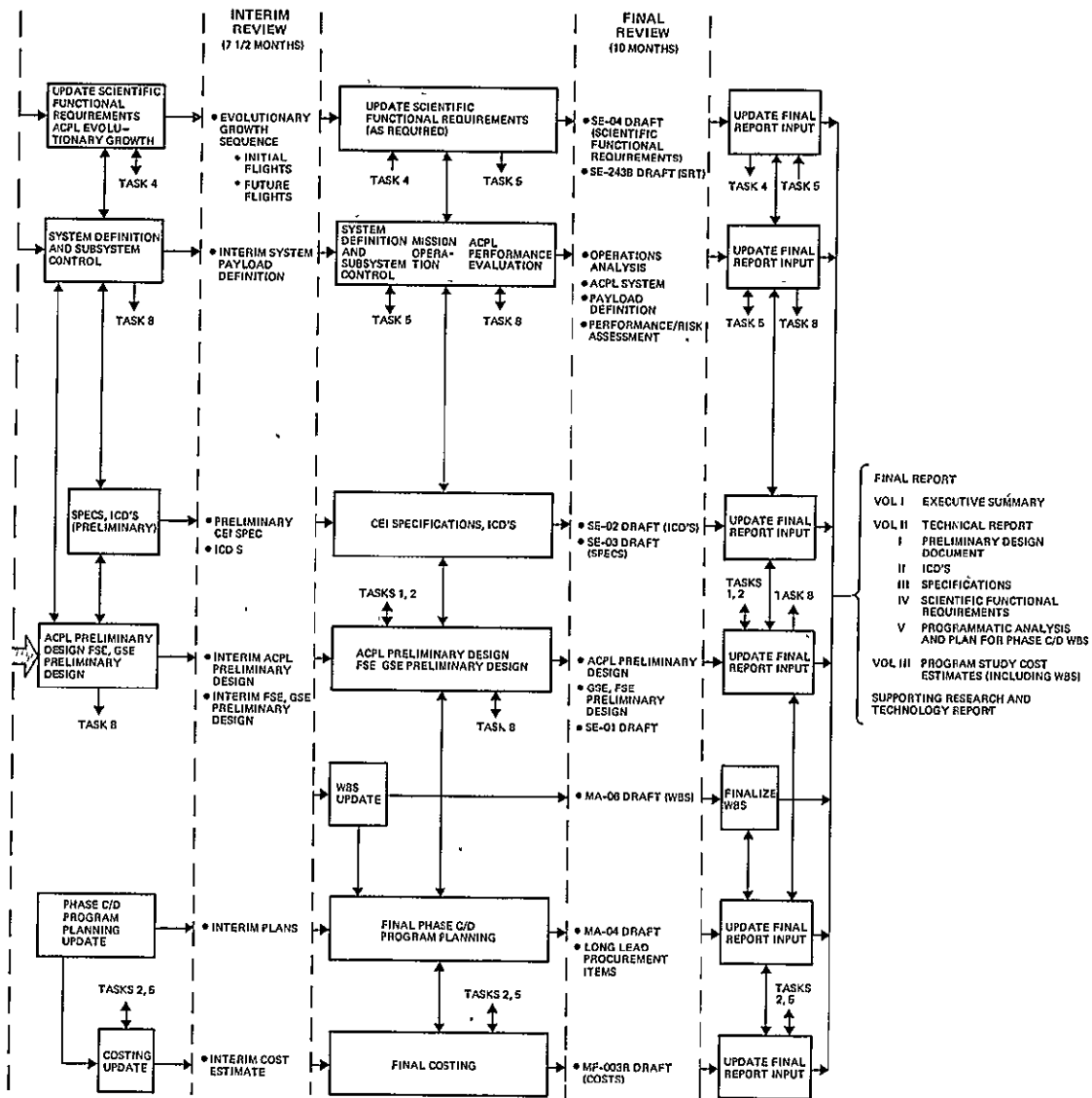
ACPL PROGRAM SCHEDULE

ACTIVITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	JAN
REQUIREMENTS ANALYSIS				∇	REQUIREMENTS REVIEW								
CONCEPT ANALYSES AND TRADES							∇	CONCEPT REVIEW					
PRELIMINARY DESIGN							FINAL REVIEW ∇						
PHASE C/D PLANNING													
FINAL REPORT													

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APRIL 15, 1976

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In addition to supporting the activity for establishing the ACPL science requirements, TRW has initiated those System and Subsystem analyses and trades necessary to select the laboratory concept to be used for preliminary design. Particular emphasis was put on identification and allocation of the major Spacelab resources, and on establishing baseline design concepts for the Fluids and Thermal Systems.

MAJOR TECHNICAL ACTIVITIES

- EVALUATION OF ENGINEERING IMPLICATIONS OF PROPOSED SCIENCE REQUIREMENTS.
- ALLOCATION OF MAJOR SPACELAB RESOURCES (MASS, VOLUME, ELECTRICAL POWER, THERMAL LOAD).
- INITIATION OF ENGINEERING ANALYSES AND TRADES FOR EACH SUBSYSTEM.
- FORMULATION OF BASELINE FLUID SYSTEM CONCEPTUAL DESIGN.
- IN-DEPTH STUDY OF THERMAL CONTROL SYSTEM REQUIREMENTS. FORMULATION OF CONCEPTUAL DESIGN BASELINES.
- SEARCH FOR COMMERCIALY AVAILABLE COMPONENTS.

Marshall Space Flight Center provided an initial set of ACPL science requirements at contract initiation (these were discussed at the Orientation Meeting), and an updated version (titled Annex A) in early March. Primarily, this latter set has been used by TRW for the analyses and trades described in this briefing package. A third set, resulting from the 18-19 March 1976 meeting of key cloud physicists in Rolla, Missouri, was provided informally and is discussed in a preliminary way.

The facing page identifies what we feel are the major science drivers for the Annex A and Rolla requirements sets. Certain of these are based on relatively specific requirements (e.g., expansion chamber control and operating range, specific humidity accuracy, CFD accuracy and operation). Others (e.g., particle generation) more properly represent concerns since their specific requirements have not been established at this time. Engineering implications of these drivers are discussed in subsequent sections.

MAJOR SCIENCE DRIVERS

MSFC REQUIREMENTS (ANNEX A)

- EXPANSION CHAMBER – CONTROL AND OPERATING RANGE
- SPECIFIC HUMIDITY ACCURACY REQUIREMENTS
- CFD ACCURACY AND OPERATIONAL REQUIREMENTS
- AEROSOL GENERATION
- AEROSOL STORAGE

ROLLA MEETING

- VERY-LONG-TERM EXPERIMENTS
- PARTICLE/CLOUD POSITIONING
- EXPERIMENT AIR CLEANLINESS
- SAMPLE COLLECTION AND RETURN

SPACELAB RESOURCE ALLOCATIONS

RALPH SCHILLING

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We have established ACPL resource budgets in four areas: volume, mass, electrical power and thermal load. In each case, we have derived what we feel are realistic goals for the ACPL using data contained in the current edition of the Spacelab Payload Accommodation Handbook (May 1975). We anticipate some changes when the next edition of this document is published (late May or early June 1976) and our resource budget goals will be reevaluated at that time.

In order to establish the preliminary budgets, we identified a strawman ACPL configuration consisting of the major pieces of equipment listed on the facing page. Resource requirements have been estimated for each subsystem with the exception of thermal control. In that case, major options are still being evaluated and a baseline concept has not been selected.

ACPL SUBSYSTEM DICTIONARY
MAJOR EQUIPMENT

- 1) FLUID
 - HUMIDIFIER
 - FLUID CONTROL COMPONENTS
- 2) GAS CLEANING
 - CO₂ ABSORBER
 - ACTIVATED CHARCOAL
 - PARTICLE FILTERS
- 3) PARTICLE GENERATOR
 - SOLUBLE NUCLEI (NaCl)
 - PHOTOLYSIS (H₂SO₄)
 - STORAGE BAG
 - PARTICLE INJECTOR
- 4) PARTICLE COUNTER
 - OPTICAL PARTICLE COUNTER
 - ELECTRICAL AEROSOL ANALYZER
 - ELECTROSTATIC AEROSOL SAMPLER
- 5) CONTINUOUS FLOW DIFFUSION CHAMBER
 - CHAMBER
- 6) EXPANSION CHAMBER
 - CHAMBER
 - EXPANSION DEVICE
- 7) STATIC DIFFUSION LIQUID CHAMBER
 - CHAMBER
- 8) THERMAL CONTROL
 - THERMAL CONTROL COMPONENTS
- 9) CONTROL AND DATA
 - CONTROL UNIT
 - CONTROL PANEL
- 10) OPTICAL AND IMAGING
 - EXPANSION CHAMBER ASSEMBLY
 - SDL CHAMBER ASSEMBLY
- 11) CONSOLE
 - DOUBLE RACK
 - ELECTRICAL POWER COMPONENTS

The Spacelab pressurized module will be used in two configurations. The short module includes only a core segment while the long module includes a core segment and an experiment segment. Each segment can accommodate four double racks and two single racks. In the core segment, however, one double rack is allocated to the Spacelab subsystem control and display station and one double rack is replaced by a workbench. Thus, the short module can accommodate six rack widths (two double and two single) of experiment equipment and the long module sixteen rack widths (six double and four single).

A set of experiment hardware that occupies a double rack requires 1/3 of the space available inside the short module and 1/8 of the long module. The corresponding fractions for a three-rack set are 1/2 and 3/16. For the short module, the ACPL volume clearly has a major impact on the Spacelab resources. On this basis, the goal of fitting the ACPL into a double rack has been established.

The gross volume inside a double rack is approximately 1.75 m^3 . Because of the rack shape, it is difficult to fully utilize this volume. The worst-case lower limit occurs if all equipment is packaged in rectangular nineteen-inch rack-mounted enclosures. For that case, a double rack has a usable value of about 1.3 m^3 (75% of the gross volume). Since the ACPL can readily utilize a large triangular volume and several smaller volumes not included in the worst case calculation, we are estimating the usable volume of the double rack to be 1.6 m^3 .

SPACELAB RESOURCES

VOLUME

- SHORT MODULE ACCOMMODATES TWO DOUBLE RACKS AND TWO SINGLE RACKS OF EXPERIMENT EQUIPMENT
- LONG MODULE ACCOMMODATES SIX DOUBLE RACKS AND FOUR SINGLE RACKS OF EXPERIMENT EQUIPMENT
- GROSS VOLUME INSIDE DOUBLE RACK IS 1.75 m^3 , WORST CASE USABLE VOLUME IS 1.28 m^3
- DOUBLE RACK SET OF EQUIPMENT OCCUPIES $1/3$ OF SHORT MODULE OR $1/8$ OF LONG MODULE
- THREE-RACK SET OF EQUIPMENT OCCUPIES $1/2$ OF SHORT MODULE OR $3/16$ OF LONG MODULE
- GOAL: ACPL SHOULD FIT IN DOUBLE RACK (1.6 m^3)

The volume budget appears to be comfortable, with sufficient room remaining for the thermal control subsystem and reasonable contingency allowance.

ACPL RESOURCE BUDGET

VOLUME (m³)

1)	FLUID	0.314
2)	GAS CLEANING	0.150
3)	PARTICLE GENERATOR	0.190
4)	PARTICLE COUNTER	0.114
5)	CONTINUOUS FLOW DIFFUSION CHAMBER	0.049
6)	EXPANSION CHAMBER	0.216
7)	STATIC DIFFUSION LIQUID CHAMBER	0.009
8)	THERMAL CONTROL	TBD
9)	CONTROL AND DATA	0.056
10)	OPTICAL AND IMAGING	0.023
11)	CONSOLE	<u>0.039</u>
	TOTAL	1.160
	GOAL	1.6

The fundamental structural limitation on mass is the load carrying capability of the Spacelab floor. The floor design provides for a load of 500 kg/m of rack width. A double rack is 1.05-m wide, so the gross mass allowed is 525 kg. The mass of the rack structure is 58 kg, so the net mass of the ACPL should not exceed 467 kg.

From a total Spacelab viewpoint, the individual structural limitations are not the dominant effect for all configurations. For the long module with one or more pallets, the total structural capability exceeds the landing mass limitation and, thus, the Spacelab structural capability could not be completely allocated to experiment hardware.

It is unlikely that the structure would ever be fully loaded, because of center-of-mass limitations and other practicalities. Since the structural limitation dominates for the majority of configurations, and the landing mass limitation may never be the determining factor for the other configurations, we should assume that a 525 kg mass allocation is a justifiable choice for the ACPL.

SPACELAB RESOURCES

MASS

- FLOOR DESIGNED TO CARRY LOAD OF 500 KG/M RACK LENGTH
- DOUBLE RACK GROSS MASS LIMIT IS 525 KG
- MASS OF DOUBLE RACK STRUCTURE IS 58 KG
- STRUCTURAL CAPABILITY FOR CERTAIN CONFIGURATIONS EXCEEDS LANDING MASS LIMITATION
- GOAL: ACPL MASS SHOULD NOT EXCEED 525 KG

The mass budget appears to be comfortable, with sufficient capability remaining to accommodate the thermal control subsystem and a reasonable contingency allowance.

ACPL RESOURCE BUDGET

MASS (KG)

1)	FLUID	105
2)	GAS CLEANING	40
3)	PARTICLE GENERATOR	14
4)	PARTICLE COUNTER	41
5)	CONTINUOUS FLOW DIFFUSION CHAMBER	35
6)	EXPANSION CHAMBER	30
7)	STATIC DIFFUSION LIQUID CHAMBER	5
8)	THERMAL CONTROL	TBD
9)	CONTROL AND DATA	31
10)	OPTICAL AND IMAGING	8
11)	CONSOLE	<u>73</u>
	TOTAL	382
	GOAL	525

The electrical power available for experiment hardware and mission-dependent equipment is consistent with the thermal control capability of Spacelab. The average power available ranges from 3.8 to 4.0-kW at 28V DC \pm 4V DC, and the peak power limits are set by the thermal control subsystem capability. The maximum energy available ranges from 391 to 422-kWh. The variation in limits is a function of the Spacelab configuration being used.

All voltages (AC and DC) other than 28V DC is provided by inverters or converters, and the power requirements of those pieces of mission-dependent equipment must be subtracted from the above capabilities if other than 28V DC is used by the payload. In addition, the 600-watt consumption of the experiment computer must be subtracted. Assuming the experiment computer is powered for the entire 6.5-day nominal Spacelab operating period on orbit, it will consume 94-kWh. This leaves a maximum energy of between 297 and 328-kWh for experiment hardware. This would provide a continuous average power of about 2-kW for the entire mission. The limiting factor appears to be the energy available. We have set a goal of 50-kWh which is equivalent to 340 watts average for 6 days of continuous operation.

SPACELAB RESOURCES
ELECTRICAL POWER AND ENERGY

- 4-KW AVERAGE POWER AVAILABLE IS CONSISTENT WITH THERMAL LOAD CAPABILITY
- MAXIMUM ENERGY AVAILABLE IS ABOUT 400 kWH
- SPACELAB EXPERIMENT COMPUTER AND CRT CONSUMES 94 kWH IN 6.5 OPERATING DAYS.
- ENERGY AVAILABLE FOR EXPERIMENT EQUIPMENT IS ABOUT 300 kWH - EQUIVALENT TO AVERAGE POWER OF ABOUT 2 kW FOR 6.5 OPERATING DAYS
- GOAL: MAXIMUM ACPL POWER SHOULD NOT EXCEED 1.7 kW
 MAXIMUM ACPL ENERGY SHOULD NOT EXCEED 50 kWH

The electrical power budget is a potential problem area with respect to the continuous power required to maintain the ACPL in a stable stand-by condition between experiments. Two major factors presently contribute to this situation: 1) the consumption estimates are based on the use of existing commercially available equipment designed for ground-based use, and 2) the 340 watt allocation was derived from an energy consumption goal assuming 6 days of continuous operation. The use of aircraft-type components (e.g., pumps) may reduce the consumption and a reduction in the duration of continuous operation increases the power available (for a fixed energy usage goal).

ACPL RESOURCE BUDGET

ELECTRICAL POWER (WATTS)

		CONTINUOUS	PEAK
1.	FLUID	360	460
2.	GAS CLEANING	0	0
3.	PARTICLE GENERATOR	0	100
4.	PARTICLE COUNTER	0	250
5.	CONTINUOUS FLOW DIFFUSION CHAMBER	0	0
6.	EXPANSION CHAMBER	0	160
7.	STATIC DIFFUSION LIQUID CHAMBER	0	0
8.	THERMAL CONTROL	TBD	TBD
9.	CONTROL AND DATA	275	275
10.	OPTICAL AND IMAGING	0	50
11.	CONSOLE	<u>55</u>	<u>55</u>
	TOTAL	690	1040 WORST CASE
	GOAL	340	1700

The heat produced inside the module by the experiment hardware and the mission-dependent subsystem equipment combined cannot exceed 4-kW average or 8-kW peak for 15-minute intervals every three hours. (The peak load capability is only available if the freon loop used to cool pallet-mounted equipment is not installed.) This heat removal capability is distributed among three loops. The cabin air cooling loop can accommodate average loads up to 1-kW, the avionics cooling loop (internal to the racks) up to 3-kW, and the experiment heat exchanger liquid loop up to 4-kW (peak loads are TBD in all cases).

The above limitations are based on a heat rejection capability of 8.5-kW provided to Spacelab by the Orbiter. This is the maximum capability achieved on orbit and may be reduced on some missions due to unusual operating conditions.

The heat produced by mission-dependent subsystem equipment must be subtracted from the above figures to determine what heat rejection capability is available for allocation to experiment hardware. The Spacelab experiment computer, along with its CRT display, dissipates about 600 watts, so in general, there will be a maximum of 3.4-kW of capability available. As goals, a heat load of 1.7-kW average during full operation of the ACPL would consume 50% of this maximum heat rejection capability and a standby or equilibrium state of the ACPL dissipating 340 watts would require 10% of the heat rejection capability.

SPACELAB RESOURCES

THERMAL LOAD

- AVERAGE LOAD CAPABILITY
 - CABIN AIR COOLING LOOP, 1 kW
 - AVIONICS AIR COOLING LOOP, 3 kW
 - EXPERIMENT HEAT EXCHANGER LIQUID LOOP, 4 kW
 - LIMITATION FOR ALL THREE COMBINED, 4 kW
- ADDITIONAL PEAK LOAD CAPABILITY OF 4 kW FOR 15 MINUTES EACH 3 HOURS
 - AVAILABLE ONLY IF PALLET FREON LOOP NOT INSTALLED
- USE OF MISSION DEPENDENT SUBSYSTEM EQUIPMENT REDUCES THESE ALLOCATIONS
 - SPACELAB EXPERIMENT COMPUTER AND CRT REQUIRES 0.6 kW
- MAXIMUM CAPABILITY FOR EXPERIMENT EQUIPMENT IS 3.4 kW AVERAGE
- GOAL: MAXIMUM ACPL LOAD SHOULD NOT EXCEED 1.7 kW
 TYPICAL ACPL LOAD SHOULD NOT EXCEED 0.34 kW

The thermal load budget is a potential problem area with respect to the peak load. The worst case peak consumption occurs when the expansion chamber and its optical and imaging assembly are operating in addition to the continuous load of the other ACPL subsystems. However, we have presumed in this budget that no load leveling is used. By including thermal capacitance in the ACPL, we can spread the load in time and greatly reduce the peak requirement shown here.

ACPL RESOURCE BUDGET

THERMAL LOAD (WATTS)

	CONTINUOUS	PEAK (NO LEVELING)	
1. FLUID	360	490	
2. GAS CLEANING	10	95	
3. PARTICLE GENERATOR	0	100	
4. PARTICLE COUNTER	0	250	
5. CONTINUOUS FLOW DIFFUSION CHAMBER	0	40	
6. EXPANSION CHAMBER	0	1020	
7. STATIC DIFFUSION LIQUID CHAMBER	0	5	
8. THERMAL CONTROL	TBD	TBD	
9. CONTROL AND DATA	275	275	
10. OPTICAL AND IMAGING	0	50	
11. CONSOLE	<u>55</u>	<u>55</u>	
	TOTAL	700	1855 WORST CASE
	GOAL	340	1700

ENGINEERING ANALYSES AND TRADES

RALPH SCHILLING

BRUCE MARCUS

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Block diagrams for the control and data, electric power and fluid systems are presented on the pages immediately following. The alternatives for the thermal system will be presented in conjunction with discussions of analyses and trades for major pieces of ACPL equipment.

ACPL SYSTEM ANALYSES AND TRADE STUDIES

- BASELINE BLOCK DIAGRAMS AID IN EVALUATING ALTERNATIVE CONCEPTS
 - ESPECIALLY USEFUL IN STUDYING ACPL/SPACELAB AND ACPL INTERNAL INTERFACES
- INITIAL BLOCK DIAGRAMS ESTABLISHED FOR CONTROL AND DATA AND ELECTRICAL SYSTEMS
 - REQUIREMENTS ARE STRONGLY DEPENDENT ON FLUID AND THERMAL SYSTEM IMPLEMENTATION
 - SPECIFIC FACTORS HAVE BEEN CONSIDERED AS PART OF FLUID AND THERMAL TRADES BUT BLOCK DIAGRAMS HAVE NOT BEEN REVISED
- REVISED BLOCK DIAGRAM ESTABLISHED FOR FLUID SYSTEMS
 - A NUMBER OF TRADE-OFFS HAVE BEEN EVALUATED AND UPDATED BLOCK DIAGRAM IS CLOSE TO FINAL
- BLOCK DIAGRAMS REPRESENTING MAJOR ALTERNATIVES ESTABLISHED FOR THERMAL SYSTEM
 - A NUMBER OF TRADE-OFFS ARE BEING EVALUATED BUT BASELINE SYSTEM HAS NOT YET BEEN SELECTED

The requirements for the control and data system are significantly affected by the specific implementation of the fluid and thermal system controls. Because of this, detailed tradeoffs have been deferred until those requirements are established. We present here the initial block diagram representing the baseline system approach to be used in examining the tradeoffs.

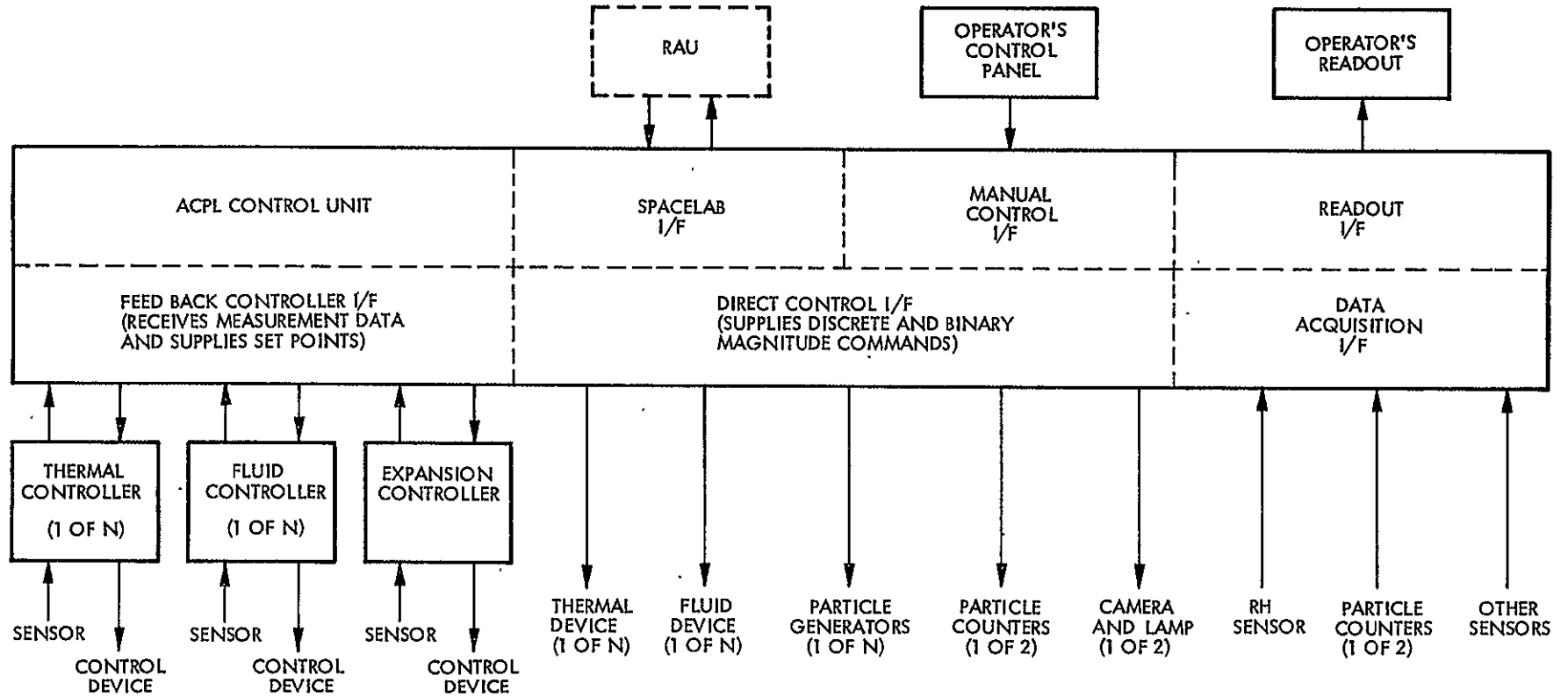
CONTROL AND DATA SYSTEM

- MAJOR OPTIONS
 - ACPL CONTROL UNIT CAN BE IMPLEMENTED WITH HARD WIRED LOGIC OR PROGRAMMABLE LOGIC (USING FIRMWARE OR SOFTWARE)
 - FEEDBACK CONTROL LOOPS CAN BE CLOSED IN DEDICATED CONTROLLER, IN ACPL CONTROL UNIT, OR IN THE SPACELAB EXPERIMENT COMPUTER
 - OTHER TYPES OF CONTROL FUNCTIONS CAN BE OPERATED BY DIRECT MANUAL CONTROLS, BY THE ACPL CONTROL UNIT AND PANEL, OR BY THE SPACELAB COMMAND AND DATA MANAGEMENT SYSTEM (CDMS)
- MAJOR FACTORS TO BE CONSIDERED
 - SPACELAB CDMS TIMELINE REQUIREMENTS
 - CONTROL FUNCTION RESPONSE TIME REQUIREMENTS

The ACPL Control and Data System shown here would use modular subassemblies transferring control and measurement data on a single common data highway.

The Remote Acquisition Unit (RAU) is Spacelab mission-dependent equipment. It would be GFE and would be installed in the ACPL double rack. The RAU will be the main interface with the Spacelab Command and Data Management Subsystem.

CONTROL AND DATA SYSTEM BLOCK DIAGRAM



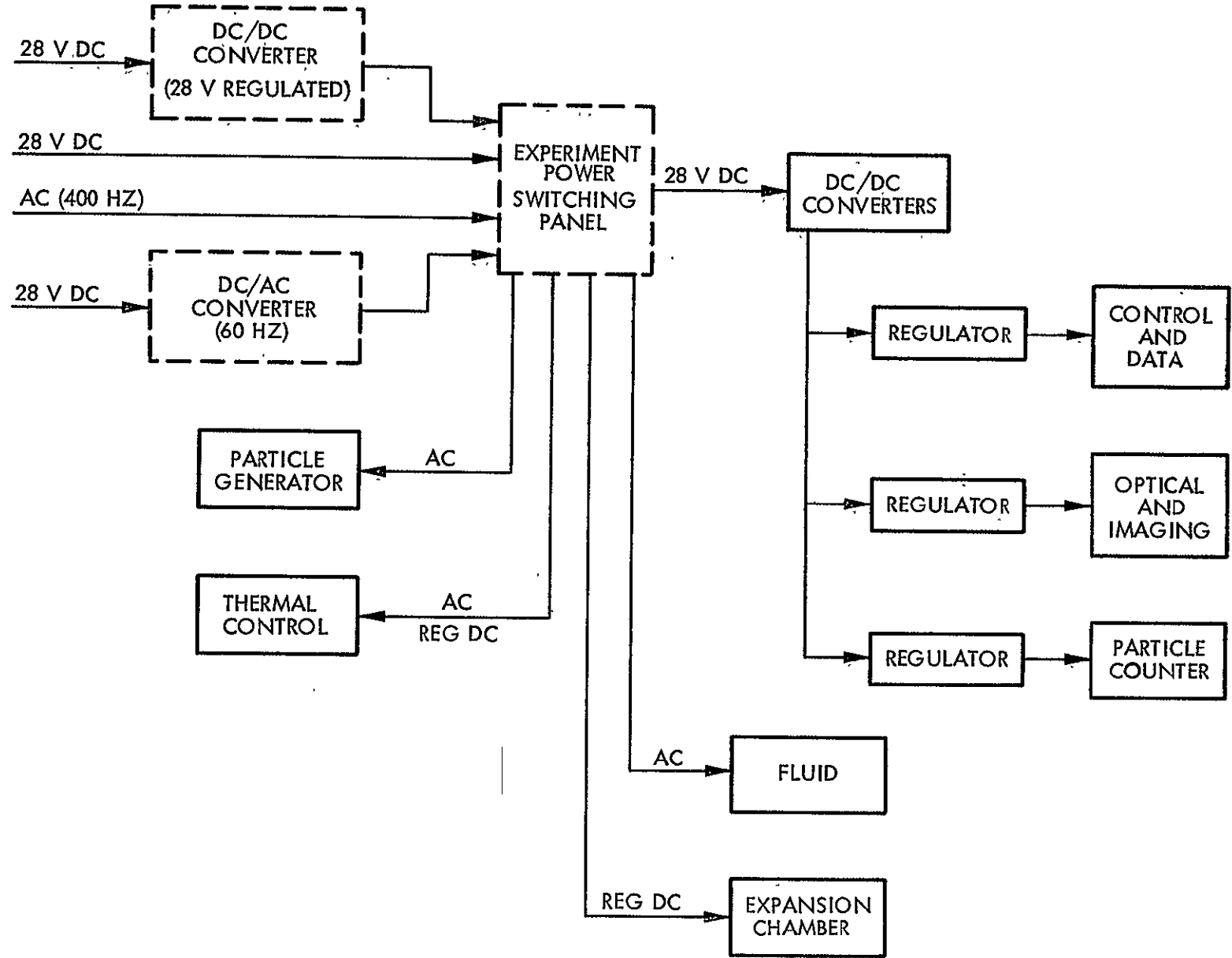
The equipment shown as dashed boxes is Spacelab mission-dependent equipment. These items would be GFE and would be installed in the ACPL double rack. We plan to use the experiment power switching panel since it defines the interface with the Spacelab Electrical Power and Distribution Subsystem. Use of the converter and inverters will be considered in trade studies for the console subsystem.

ELECTRIC POWER SYSTEM

- MAJOR OPTIONS
 - USE OF SPACELAB CONVERTERS/INVERTERS
 - USE OF CENTRALIZED OR DISTRIBUTED REGULATORS
- MAJOR FACTORS TO BE CONSIDERED
 - AVAILABILITY OF SPACELAB-MISSION-DEPENDENT EQUIPMENT (GFE)

Similar to the control and data system, detailed trade-offs for the electric power system have been deferred until the requirements arising from the other systems have been more firmly established. An initial block diagram of the baseline concept is presented here.

ELECTRICAL POWER SYSTEM BLOCK DIAGRAM



A significant number of system level trades have been conducted in order to derive the fluid system schematic presented here. Detailed subsystem tradeoffs are now being performed, but we do not anticipate major changes to the system concepts shown here.

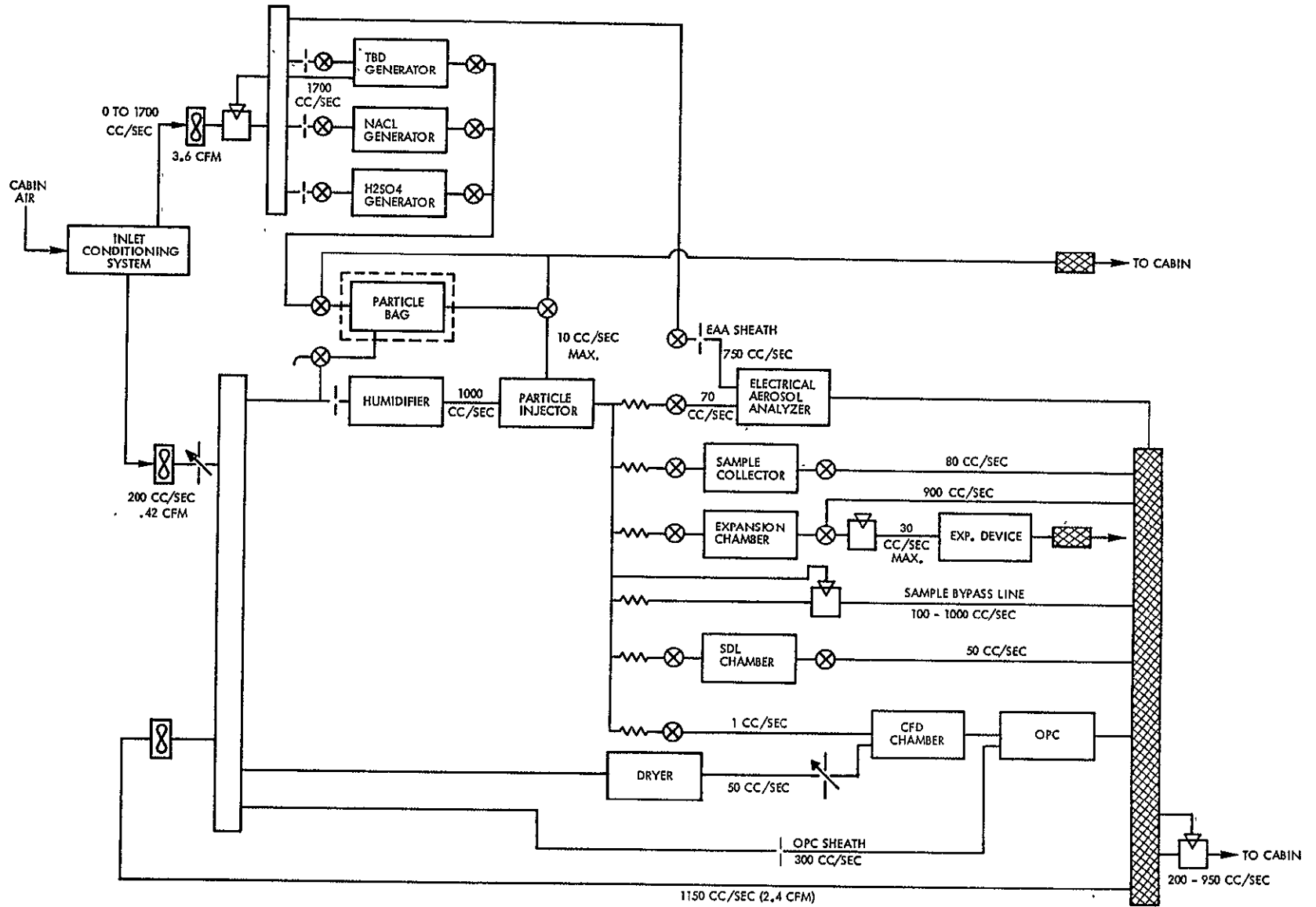
FLUID SYSTEM

- MAJOR OPTIONS
 - COMPLETE EXCHANGE OF AIR WITH SPACELAB CABIN
 - PARTIAL EXCHANGE OF AIR WITH SPACELAB CABIN
 - CLOSED-LOOP RECIRCULATION OF AIR
- MAJOR FACTORS CONSIDERED
 - CLEANLINESS REQUIREMENTS FOR INTAKE AND EXHAUST AIR
 - WATER SUPPLY AND REMOVAL REQUIREMENTS
 - ISOLATION FROM CABIN PRESSURE CHANGES

The fluid system shown here accommodates the strawman set of ACPL major equipment used to prepare the resource allocation budgets. In addition, we have included a provision for an experimenter supplied aerosol generator. As a worst case requirement for flow rate, we have assumed a vibrating orifice generator that requires a 1700 cc/sec flow for the evaporation column. In order to accommodate low duty cycle peak requirements for this type of generator and a sheath flow for an electrical aerosol analyzer, we have split the system and included a separate high flow rate pump which operates intermittently, on demand, to meet these requirements.

The low flow rate portion of the system includes recirculation of the humidified air to reduce the load on the humidifier. A partial exchange with the SpaceLab cabin is used to control the humidity of the recirculated air stream. The bypass line compensates for the varying flow requirements of the experiment equipment supplied by the humidifier so that the humidifier load remains constant.

FLUID SYSTEM SCHEMATIC DIAGRAM



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Other features of the fluid system include: 1) the placement of the active control elements outside of the critical path between the humidifier and particle injector and the experiment chambers; 2) isolation of the ACPL pressure from cabin fluctuations by use of pressure controlled plenums; 3) adjustable carrier flow to the CFD to permit residence time variation.

FLUID SYSTEM

- KEY FEATURES
 - NO ACTIVE CONTROL ELEMENTS BETWEEN HUMIDIFIER AND EXPERIMENT CHAMBERS
 - ACPL PRESSURE ABOVE CABIN AMBIENT AND ISOLATED FROM CABIN PRESSURE FLUCTUATIONS
 - HUMIDIFIER OPERATED AT CONSTANT LOAD
 - CFD CARRIER FLOW ADJUSTABLE
 - ACTIVE CONTROL ELEMENTS MINIMIZED
 - PUMP POWER REQUIREMENTS OPTIMIZED

Those ACPL components which drive the design of the Thermal Control Subsystem are shown on the facing page. These components and their thermal control requirements will be dealt with first so that a basis will exist for discussion of the TCS.

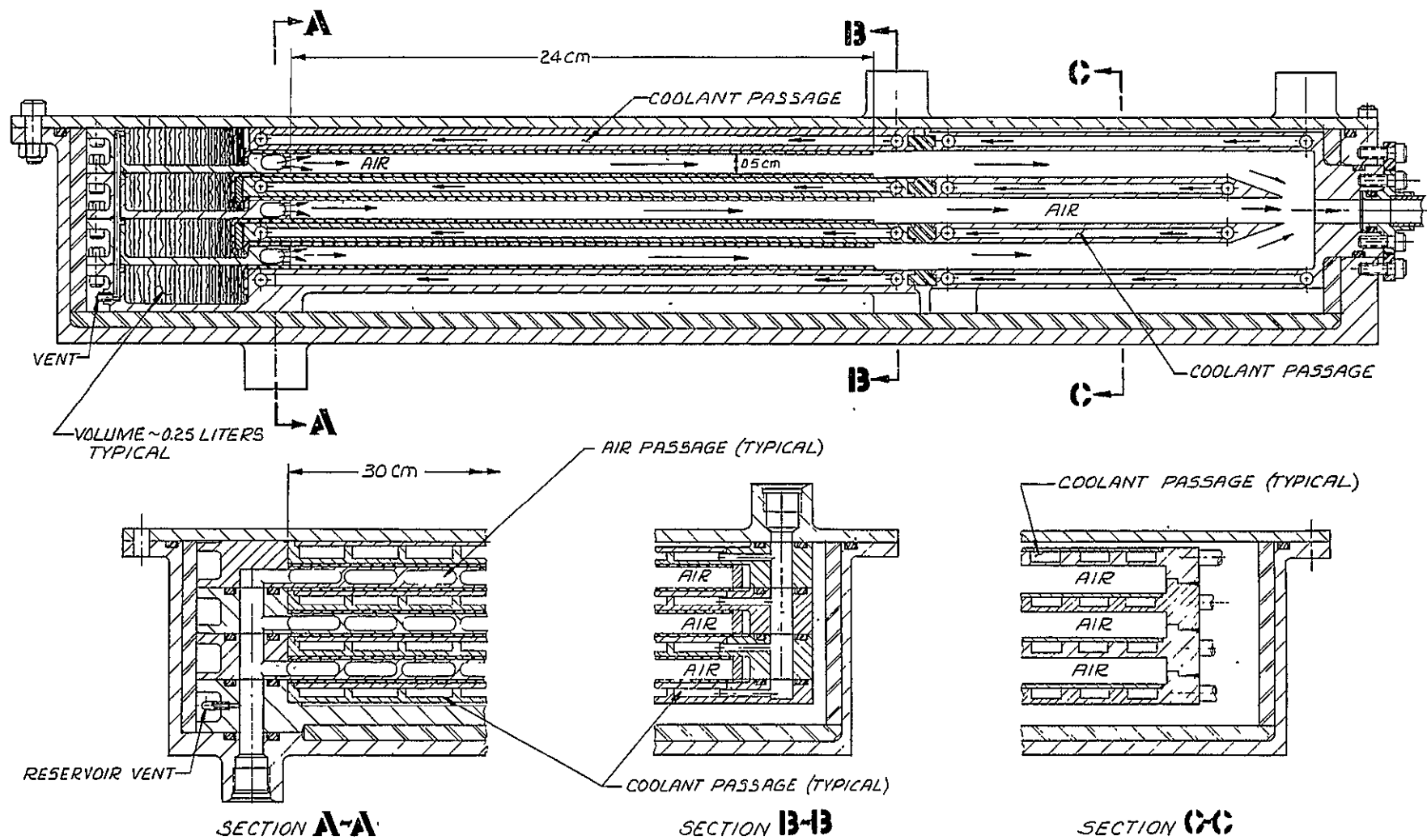
ACPL COMPONENTS WITH MAJOR IMPACT ON
THERMAL CONTROL SUBSYSTEM

- HUMIDIFIER.
- EXPANSION CHAMBER
- CFD
- SDL

The humidification concept is to saturate air in flow over temperature controlled, wetted surfaces and then reheat it over dry surfaces to lower the relative humidity and prevent subsequent condensation.

Our baseline design concept incorporates several key features to assure accurate humidification and simplified operation.

- The air flow is through three high aspect ratio (30 cm x 0.5 cm) rectangular ducts. This geometry lends itself to accurate analysis and design.
- The design incorporates a capillary-pumped water distribution system which passively maintains the surfaces wet while preventing entrainment of water droplets. The channel surface wicks draw water from self-contained storage reservoirs sized, if possible, for continuous operation over a six-day period with a single initial fill.
- Temperature control is provided by a pumped coolant in counter-flow to the air stream. This yields maximum control in the critical downstream end of the humidification region where the evaporative thermal load is very low.



HUMIDIFIER

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HUMIDIFIER DESIGN FEATURE

WELL DEFINED GEOMETRY PERMITS ANALYTICAL CALCULATION OF REQUIRED SATURATION LENGTH.

- BASED ON CLOSE CONTROL OF SURFACE TEMPERATURE AND PRECISE KNOWLEDGE OF VAPOR PRESSURE - TEMPERATURE RELATIONSHIP
- CONCERN OVER CONTAMINATION OF WICKS CAUSING REDUCED VAPOR PRESSURE - ESPECIALLY IF AEROSOL INTRODUCED UPSTREAM
- INTRODUCING AEROSOL DOWNSTREAM LIMITS DILUTION RATIO TO >100 FOR REQUIRED ACCURACY IN HUMIDITY (0.01%)
- REQUIRES RH MEASUREMENT OF AEROSOL STREAM TO 1% ACCURACY

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The humidifier concept includes self-contained water storage reservoirs. Mission operations will be simplified if these reservoirs can be designed large enough to supply water over an entire mission with a single filling. The required reservoir size can be kept small by minimizing the water consumption rate. Perhaps more important, minimizing the water consumption rate also minimizes the evaporative thermal load. This simplifies the thermal control problem as discussed later.

The water consumption rate is a function of the humidifier operating temperature, the air flow rate and the inlet air humidity or dew point. Thus, partial recirculation of the humidified air stream will increase the inlet humidity and reduce consumption. Care must be taken, however, to accommodate those components which require relatively dry inlet air. For example, the carrier air flow to the CFD must have a dew point below the cold plate temperature to avoid transient supersaturations. Such requirements either limit the degree of humidified air recirculation permissible or necessitate the inclusion of local dehumidification (e.g., desiccant drying).

HUMIDIFIER DESIGN FEATURE

SELF CONTAINED WATER STORAGE RESERVOIRS ALLOW CONTINUOUS OPERATION WITH A SINGLE FILL AT START OF MISSION.

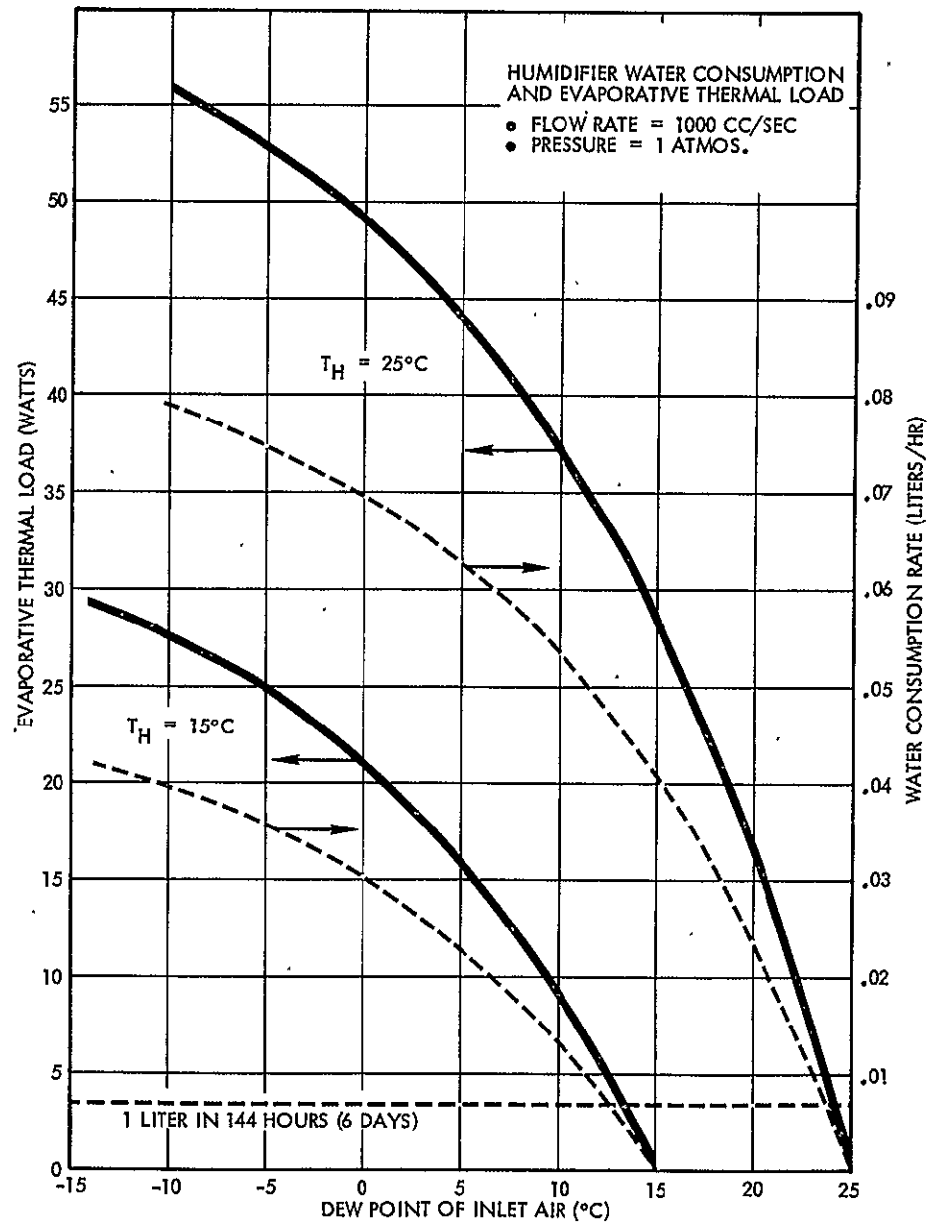
- MINIMIZING WATER CONSUMPTION RATE MINIMIZES SIZE OF RESERVOIRS, ALSO MINIMIZES EVAPORATIVE THERMAL LOAD
- WATER CONSUMPTION RATE IS A FUNCTION OF OPERATING TEMPERATURE, FLOW RATE AND INLET HUMIDITY
- CONSUMPTION IS REDUCED BY PARTIAL RECIRCULATION OF HUMIDIFIED AIR, INCREASING INLET HUMIDITY
- CERTAIN COMPONENTS REQUIRE RELATIVELY DRY INLET AIR (E. G., CFD CARRIER FLOW). THIS EITHER LIMITS DEGREE OF RECIRCULATION OR REQUIRES LOCAL DRYING.

The facing page shows the evaporative thermal load and water consumption rate as a function of inlet air dew point. Curves are shown for humidifier operating temperatures of 15°C and 25°C (the required operating range is 0.5°C - 25.0°C).

Both thermal load and water consumption decrease dramatically as the dew point of the inlet air approaches the operating temperature (inlet R.H. approaches 100%). Too close an approach must be avoided, however, for fear of condensation due to pressure or temperature variations elsewhere in the flow system.

Note that a flow system with no humidified flow recirculation, coupled with a potential requirement to include an activated charcoal bed at liquid nitrogen temperature in the Gas Cleaning Subsystem, would result in a very low inlet air dew point. The water consumption rate and evaporative thermal load for such a system would be very difficult to accommodate.

Our preliminary humidifier design stores approximately one liter of water. The consumption rate corresponding to one liter in six days of continuous operation is shown on the graph. Depending on operating temperature, this consumption rate permits an inlet air dew point at least 1.5°C below the humidifier operating temperature and a maximum evaporative load of 6 watts.



Precise temperature control of the humidifier plates, particularly in the downstream portion of the humidification region, is required to establish the outlet specific humidity with sufficient accuracy. Humidification to 99.95% or 99.99% R.H. corresponds to plate temperature control of 0.010°C and 0.002°C, respectively.

Since the humidifier evaporative load is maximum at the air inlet region and asymptotically approaches zero near the outlet region, thermal control of the latter with a temperature controlled pumped coolant is enhanced by having the coolant in counterflow with the air. Even with counterflow, maintaining the necessary plate temperature uniformity under the prevailing thermal loads requires nearly constant coolant temperature throughout and, consequently, very high coolant flow rates.

Detailed thermal modeling of the humidifier plates is currently underway to establish the maximum permissible variation in coolant temperature corresponding to the plate temperature uniformity requirements. By way of example, however, consider the case of a 1 liter/sec air stream with an inlet R.H. of ~92% and an operating temperature of 25°C. This yields an evaporative thermal load of 6 watts. If the coolant (water) temperature variation is limited to 0.010°C, the required mass flow rate is on the order of 500 kg/hr. Such large coolant flow rates have a major impact on the design of the Thermal Control Subsystem, as will be discussed later.

HUMIDIFIER DESIGN FEATURE

THERMAL CONTROL FLUID IN COUNTERFLOW TO AIR STREAM MAXIMIZES TEMPERATURE CONTROL IN CRITICAL DOWNSTREAM REGION.

- PRECISE PLATE TEMPERATURE CONTROL LIMITS ALLOWABLE COOLANT TEMPERATURE VARIATION, REQUIRING HIGH COOLANT FLOW RATES.
- CURRENTLY ANALYZING PLATE TEMPERATURE PROFILES IN DETAIL TO ESTABLISH MAXIMUM PERMISSIBLE COOLANT TEMPERATURE VARIATION.
- IF COOLANT TEMPERATURE VARIATION LIMITED TO 0.010°C AND EVAPORATIVE LOAD EQUALS 6 WATTS ($\sim 92\%$ R.H. INLET, 25°C OPERATING TEMPERATURE), COOLANT MASS FLOW MUST BE ~ 500 KG/HR. SUCH LARGE FLOW RATES HAVE MAJOR IMPACT ON THERMAL CONTROL SUBSYSTEM.

Based on the expansion chamber geometry presented at the Orientation Meeting (30 cm diameter X 45 cm height), and an average flushing velocity of 1cm/sec, the chamber flushing and stilling times have been estimated at ~9 minutes and <10 minutes, respectively.

However, considerations pertaining to thermal control of the sensitive experiment volume (SEV) as well as maintaining a laminar flushing flow pattern suggest a shorter chamber with a larger diameter. Such a change would have several additional implications. To maintain a 1 cm/sec average flushing velocity, the larger diameter would require a larger flow rate with an attendant decrease in flushing time and increase in humidifier water consumption rate and evaporative thermal load. In addition, the larger diameter would increase the stilling time which varies with the square of the radius.

EXPANSION CHAMBER SUBSYSTEM

- FLUSHING TIME:
 - ANALYSIS AND MSFC TESTS INDICATE 10 -12 VOLUMES REQUIRED
 - AVERAGE FLUSHING VELOCITY OF 1 CM/SEC REQUIRES
~ 9 MINUTES FOR 12 VOLUMES

- STILLING TIME:
 - ANALYSIS INDICATES THAT FOR INITIAL AVERAGE VELOCITY OF
1 CM/SEC, LESS THAN 10 MINUTES IS REQUIRED FOR VELOCITY
TO DECAY TO 0.1 MM/SEC.

The requirements on the expansion chamber having the largest impact on the Thermal Control Subsystem are the operating range, maximum cooling rate and temperature uniformity in the Sensitive Experiment Volume (SEV). The facing page identifies our present understanding of their specific values. Of the candidate approaches to satisfy these requirements, direct mounted thermoelectric modules (TEM's) have the most directly related ground-based laboratory experience and offer the potential of localized control and rapid response. On the other hand, this concept requires large electrical inputs and must reject even larger thermal loads to the Spacelab experimental heat exchanger. The electrical power and heat rejection limitations imposed by Spacelab are investigated in subsequent view-graphs.

The pumped loop approach, while it is larger and heavier than direct mounted TEM's and will need a supplementary refrigerator to achieve the desired range of temperatures, has the important attribute of being able to time average the heat rejection and electrical power loads thereby reducing their peak requirements. Preliminary analysis indicates the pumped loop approach to be a feasible concept.

EXPANSION CHAMBER SUBSYSTEM

THERMAL CONTROL

DRIVING REQUIREMENTS

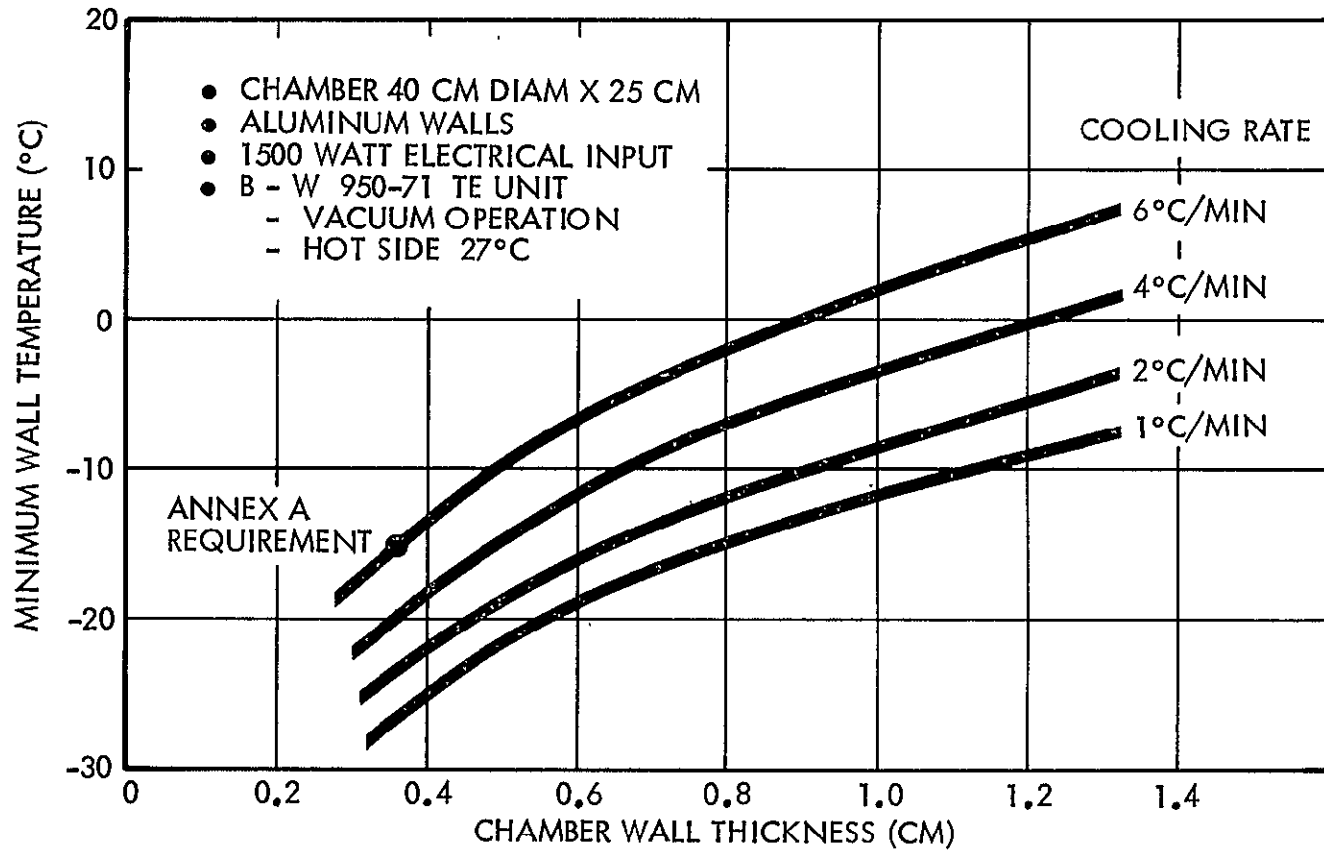
- OPERATING RANGE: -25 TO +25 °C
- MAXIMUM COOLING RATE: 6 °C/MIN
- TEMPERATURE UNIFORMITY IN SEV: 0.002 TO 0.010 °C

CANDIDATE APPROACHES

- DIRECT MOUNTED THERMOELECTRIC MODULES
 - EXTENSIVE GROUND-BASED LABORATORY EXPERIENCE
 - RAPID RESPONSE; POTENTIAL FOR LOCALIZED CONTROL
 - EXPENSIVE; DELICATE TO SHOCK AND VIBRATION
 - LARGE ELECTRICAL INPUTS
 - LARGER HEAT REJECTION (NECESSITATES SUPPLEMENTARY PUMPED LOOP SYSTEM)
- PUMPED LIQUID LOOP
 - POSSIBLE TO TIME AVERAGE ELECTRICAL AND HEAT REJECTION DEMANDS
 - MAXIMUM FLEXIBILITY FOR EVOLUTIONARY GROWTH
 - LIMITED LOCALIZED TEMPERATURE CONTROL (WALL HEATERS)
 - LARGER VOLUME, WEIGHT; REQUIRES SUPPLEMENTARY REFRIGERATOR

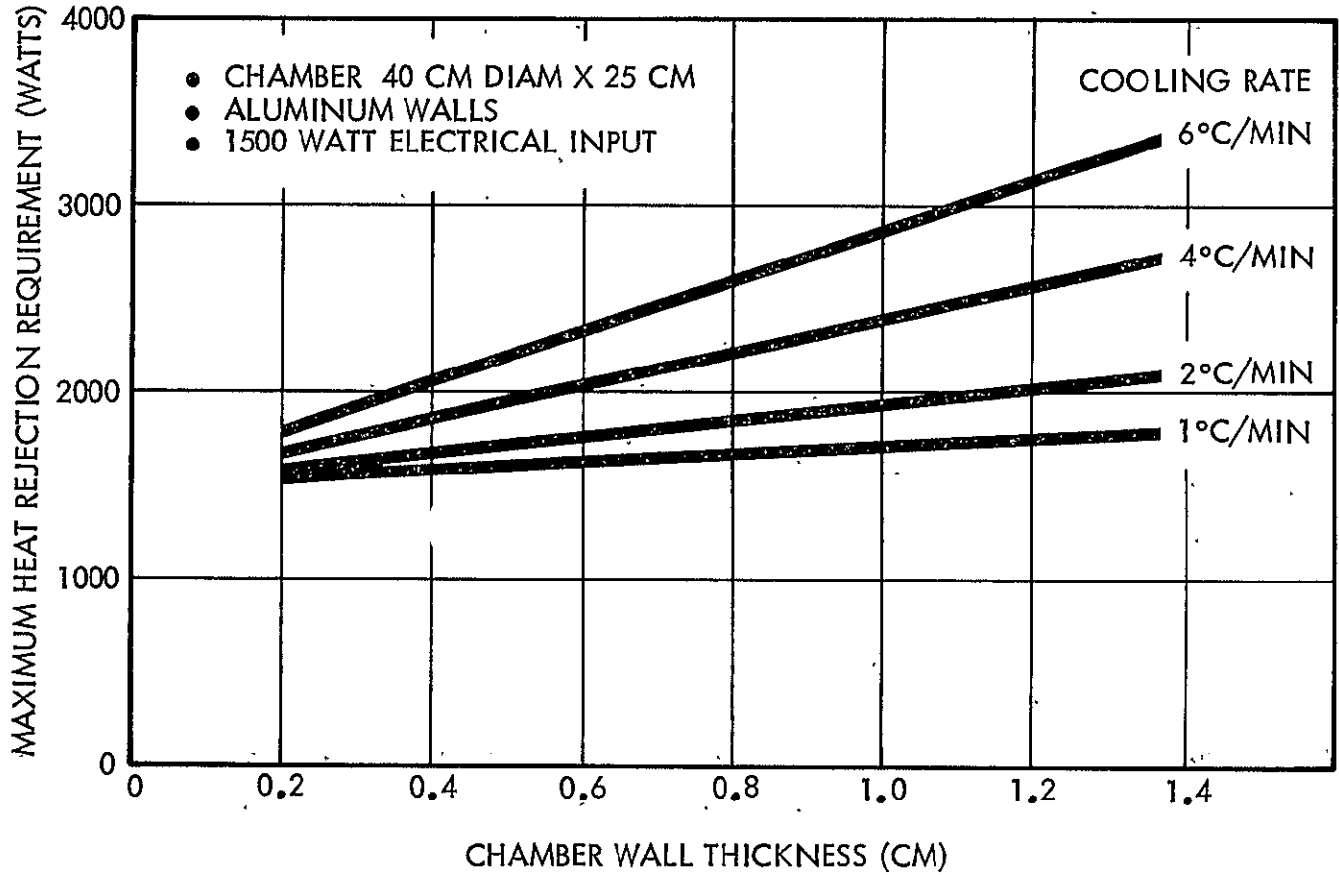
Direct mounted thermoelectric modules (TEM's) can be used to provide Expansion Chamber wall cooling. Their application is severely limited, however, by electrical power limitations imposed by Spacelab. The plot on the facing page shows the minimum wall temperature achievable for different cooling rates as a function of chamber wall thickness (properties for the Borg Warner 950-71 TE unit were used in the calculation). Assuming a 1500 watt electrical power limitation, the 6°C/minute cooling requirement down to -15°C can only be satisfied for wall thickness of 0.35 cm or less ($\bar{.14}$ in.).

MAXIMUM EXPANSION CHAMBER WALL TEMPERATURE
DIRECT MOUNTED THERMOELECTRICS



The application of direct mounted TEM's is also constrained by limitations imposed by Spacelab on heat rejection. Since the electrical input as well as the cooling load must be dissipated, the requirements on the Spacelab heat rejection loop are greater than those on the electrical system. The plot on the facing page shows the rejection requirement for different cooling rates and wall thicknesses. Assuming a 1500 watt electrical input and a 1700 watt heat rejection limitation, the system can meet the 6°C/minute requirement down to -15°C only for very small wall thicknesses (≤ 0.15 cm). Such small wall thicknesses would preclude achieving very uniform wall temperatures. The alternatives for a direct mounted TEM system are slower cooling rates and/or higher operating temperatures where TEM's are more efficient.

MAXIMUM EXPANSION CHAMBER HEAT REJECTION
DIRECT MOUNTED THERMOELECTRICS



The parallel flat plate CFD, following the design of Squires, et al, has been selected as the current baseline concept. Our objective here is to make maximum use of highly developed laboratory technology, with only those modifications necessary for 0-g operation. These relate primarily to the surface water distribution system.

When performing an experiment in the expansion chamber, it may be necessary to know the aerosol characteristics prior to beginning the expansion in order to establish the proper wall temperature cooling profile. Two viable options are to characterize the aerosol 1) during the flushing period by sampling part of the flushing stream, and 2) during the stilling period by storing a quantity of aerosol in a control bag after filling the chamber and drawing the sample from this bag. As indicated in the discussion of the expansion chamber, current estimates for the required flushing and stilling times are of equal magnitude (~10 minutes). Assuming the CFD characterization process can be completed in this time period, it is preferred to accomplish it during the flushing period since this minimizes equipment requirements and eliminates any uncertainties regarding aerosol changes in a control bag.

If characterizing the aerosol in the CFD requires longer time periods, the flushing period can be extended without additional expenditure of stored aerosol by decreasing the flow rate to the expansion chamber. Although this increases the duration of the experiment and introduces greater uncertainties due to aerosol decay, similar consequences would result from using a control bag and increasing the stilling time beyond that which is necessary. An incidental, but significant, benefit of lowering the flow rate to the expansion chamber would be a decrease of the water consumption rate and evaporative thermal load in the humidifier.

CFD SUBSYSTEM

CURRENT BASELINE

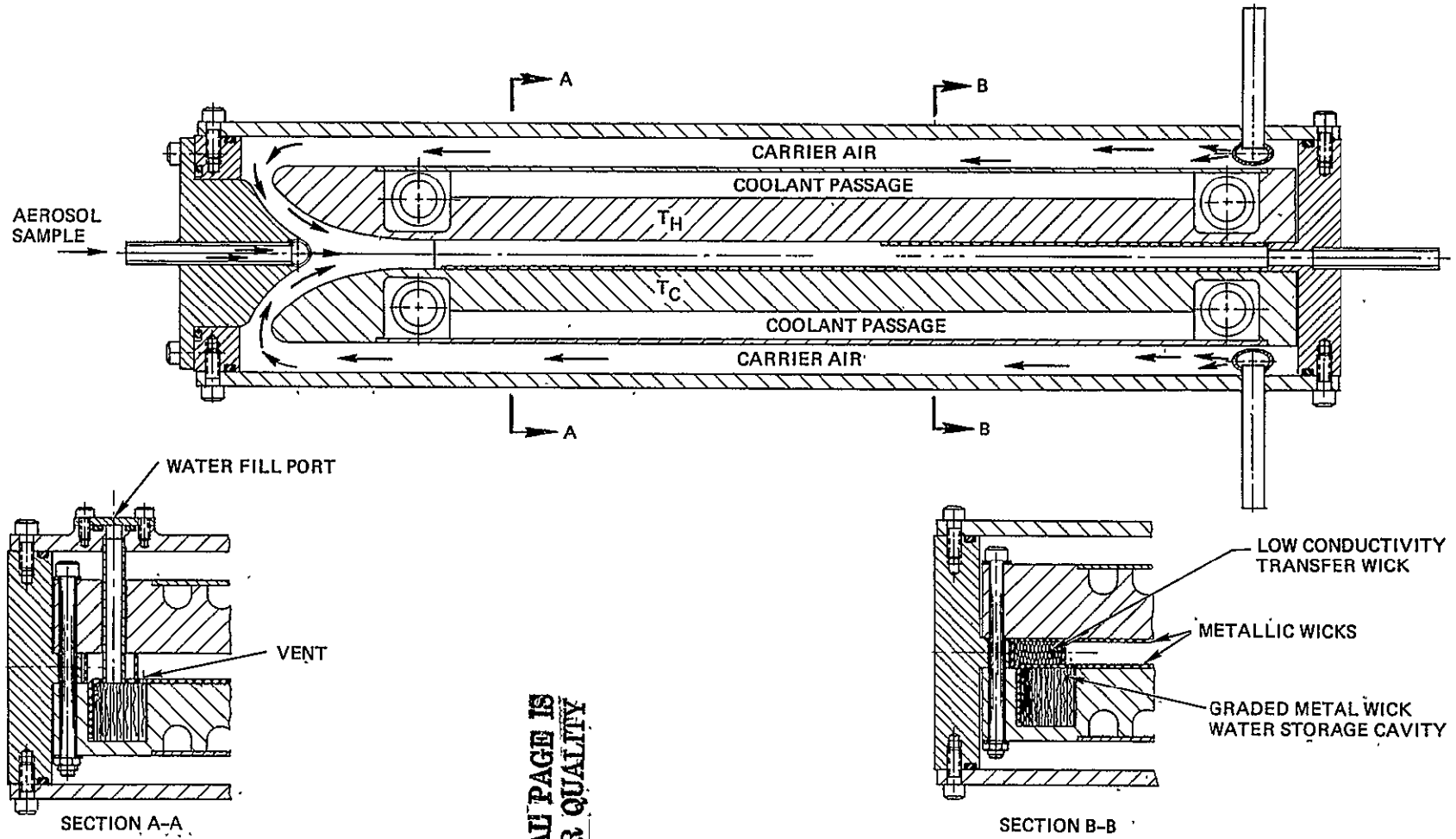
- PARALLEL FLAT PLATE CFD FOLLOWING DESIGN OF SQUIRES, ET AL.
- CHARACTERIZATION OF AEROSOL DURING EXPANSION CHAMBER FLUSHING PERIOD.

Preliminary layout of a parallel flat plate CFD following the design of Squires, et al.

Features:

- Similar to ground-based facilities
- Wicking system for control of water in both 0-g and 1-g horizontal operation
- Pumped-coolant temperature control. Coolant in counterflow to air stream provides maximum temperature control in most critical downstream region.
- Shaped reversal of carrier air flow path minimizes spreading of sample.

CONTINUOUS FLOW DIFFUSION CHAMBER



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The preliminary CFD layout shown on the preceding page has not yet been analyzed in detail with respect to the current requirements. However, it is clear that several of the requirements will have major engineering impact on the design.

First is the requirement for 1% accuracy in maximum supersaturation over the range 0.1% to 3.0%. The lower end of this range provides the most difficulty. Control and resolution of S_m to within 0.001% requires uniformity and control of the temperature difference between the plates to $\pm 0.008^\circ\text{C}$. This is in contrast to reported practice by Squires, et al. of $\pm 0.050^\circ\text{C}$. Along the lines of the discussion on temperature control of the humidifier, limiting the pumped coolant temperature variation in each plate to 0.008°C requires mass flow rates on the order of 250 kg/hr. Although smaller than for the humidifier (by virtue of lower thermal loads), these still represent very high flow rates and place major constraints on the options available for the Thermal Control Subsystem.

A second requirement calling for an extension in the state-of-the-art is that the aerosol sample be constrained to a humidity field within $0.99 S_m$. Physically, this means that the sample must be constrained to a thickness of ± 0.05 times the plate spacing, centered around the S_m plane. In this case, reported practice by Squires, et al, is for sample constraint to $0.90 S_m$ and ± 0.158 times plate spacing. The consequence of this more stringent requirement is to limit the maximum residence time of sample in the chamber before diffusion and phoretic velocities carry it beyond bounds, and to limit the sample/carrier air flow ratio. The feasibility of achieving this requirement in combination with the minimum residence time requirements also provided has yet to be analyzed.

IMPLICATIONS OF CURRENT CFD REQUIREMENTS

- 1% ACCURACY IN S_M OVER THE RANGE 0.1% TO 3.0%
 - REQUIRES CONTROL OF ΔT BETWEEN PLATES TO $\pm 0.008^\circ\text{C}$
 - (REPORTED PRACTICE BY SQUIRES, ET AL, EQUALS $\pm 0.05^\circ\text{C}$)
 - LIMITING COOLANT TEMPERATURE VARIATION TO 0.008°C
REQUIRES COOLANT FLOW RATE OF ORDER 250 KG/HR.
- SAMPLE MUST BE CONSTRAINED TO HUMIDITY FIELD OF $0.99 S_M$
 - SAMPLE MUST BE CONSTRAINED TO THICKNESS OF ± 0.05 X PLATE SPACING
 - (REPORTED PRACTICE BY SQUIRES, ET AL, IS ± 0.158 X PLATE SPACING FOR $0.90 S_M$)
 - LIMITS MAXIMUM RESIDENCE TIME BEFORE DIFFUSION AND PHORESIS CARRIES SAMPLE BEYOND LIMITS
 - LIMITS SAMPLE/CARRIER AIR FLOW RATIO

A third troublesome requirement calls for operation of the CFD with the plates vertical and the flow horizontal when on the ground, as is current laboratory practice.

It is recognized that this operating mode minimizes the effects of gravitational fallout and extends the terrestrial operating range of the CFD to longer residence times and lower supersaturations. However, this criterion will not exist in orbit and the need for vertical versus horizontal terrestrial certification (a matter of operating range in S_m) must be considered in light of the engineering implications.

The baseline CFD design utilizes a capillary pumped wick system. This system, based on suction, operates by the same physical mechanism when in 0-g or horizontal in 1-g. Theoretically, it is possible to design a capillary pumped water distribution system for vertical operation in 1-g also. However, this leads to very small-pore wicks with very high flow resistance. The high flow resistance, in turn, leads to very thick wicks, large wick temperature drops and a resultant loss in temperature control of the liquid surface.

Alternatively, vertical operation in 1-g can be accommodated with a supplementary water distribution system such as the gravity fed irrigation scheme currently used by Squires, et al. In this case, however, aside from the additional cost impact, performance achieved in 1-g vertical operation might not serve as an appropriate baseline for 0-g operation. Different water distribution systems, and potentially different degrees of temperature control, will be involved in the two cases.

IMPLICATIONS OF CURRENT CFD REQUIREMENTS
(CONTINUED)

- VERTICAL OPERATION IN 1-G FIELD
 - BASELINE CAPILLARY PUMPED WICK SYSTEM BASED ON SUCTION, OPERATES BY SAME MECHANISM WHEN IN 0-G OR HORIZONTAL IN 1-G.
 - VERTICAL OPERATION IN 1-G REQUIRES SUPPLEMENTARY WATER DISTRIBUTION SYSTEM. VERTICAL TERRESTRIAL TESTS MAY NOT SERVE AS A BASELINE FOR 0-G OPERATION.

There exists a great body of laboratory experience with SDL chambers and our baseline concept for this subsystem is patterned after these systems. The internal geometry of the chamber has the shape of a disc, nominally 15 cm in diameter and 1.5 cm high. The ultimate plate spacing represents a trade between the thickness of the Sensitive Experiment Volume and the rapidity with which the humidity field approaches equilibrium after the chamber is flushed and filled with the aerosol laden sample. The diameter of the chamber must be large compared with the plate spacing to minimize edge effects.

The Sensitive Experiment Volume, centered in the disc and nearly so between the plates, will be defined by an illuminating light beam and the camera imaging format across perpendicular diameters.

Our current understanding of the SDL supersaturation requirements are shown on the facing page. These translate to a temperature difference between plates of 0.5-13.0°C with uniformity and control to $\pm 0.042^\circ\text{C}$, somewhat less stringent than for the Humidifier and CFD.

The requirement that the SEV be constrained to $0.98 S_m$ limits its thickness to 2.2 mm for the 1.5 cm nominal plate spacing, and its volume requirement of $>0.1 \text{ cm}^3$ leads to an area in the S_m plane of $\sim 45 \text{ mm}^2$. This is a somewhat unfavorable geometry for photography across a diameter, but can be accommodated by allowing the image to fill only a small part of the film format.

Temperature control considerations for the SDL are similar to those for the Humidifier and CFD, but the relaxed uniformity requirements and smaller thermal loads result in lower (but still high) coolant mass flow rates.

STATIC DIFFUSION CHAMBER – LIQUID (SDL)

- BASELINE GEOMETRY:
 - DISC: 15 CM DIAMETER X 1.5 CM HEIGHT
 - ILLUMINATION AND IMAGING ACROSS PERPENDICULAR DIAMETERS
- REQUIREMENTS:
 - SUPERSATURATION: $0.01\% \leq S_M \leq 6.0\%$; ACCURACY $\pm 5\%$ FOR $S_M \geq 0.1\%$
REQUIRES ΔT BETWEEN PLATES OF 0.5 TO 13.0 °C WITH CONTROL
TO ± 0.042 °C
 - SENSITIVE VOLUME CONSTRAINED TO $0.98 S_M$
ILLUMINATION LIMITED TO ± 1.1 MM OF S_M PLANE
 - SENSITIVE VOLUME ≥ 0.1 CM³ RESULTS IN UNFAVORABLE SEV GEOMETRY
FOR IMAGING.
- THERMAL CONTROL
 - LIMITING COOLANT TEMPERATURE VARIATION TO 0.042 °C REQUIRES
COOLANT FLOW RATE OF ~ 50 KG/HR.

The facing page indicates the nature of the temperature control requirements imposed by key components of the ACPL. As discussed previously, the humidifier, CFD, SDL and expansion chamber all have stringent temperature uniformity requirements to achieve their respective accuracy specifications. Similarly, they all have equivalent temperature stability requirements when at steady state conditions. In addition, the expansion chamber and CFD have requirements for rapid temperature changes. The expansion chamber must be cooled at precisely controlled rates up to 6°C/min during the expansion process. The temperature difference between the CFD plates must be ramped or stepped through a sequence of steady state values rapidly enough to characterize the aerosol during the expansion chamber flushing (or stilling) period. Depending on how the SDL is used, it may have temperature change requirements similar to the CFD. However, this is not currently anticipated.

THERMAL CONTROL SUBSYSTEM

TEMPERATURE CONTROL REQUIREMENTS OF KEY COMPONENTS

	<u>HUMIDIFIER</u>	<u>CFD</u>	<u>SDL</u>	<u>EXP. CHAMBER</u>
TEMPERATURE UNIFORMITY	X	X	X	X
TEMPERATURE STABILITY	X	X	X	X
RAPID TEMPERATURE CHANGES		X	?	X

Temperature uniformity in the various chamber plates and walls can be achieved by fabricating them of thick, high thermal conductivity metals or as heat pipe vapor chambers. Massive metal walls also provide a fair degree of temperature stability, but at the price of high thermal loads for rapid temperature changes. Heat pipes, on the other hand, have low thermal mass and temperature stability must be provided through another mechanism.

Absolute temperature control for the chamber plates and walls can be accomplished with direct mounted thermoelectric modules, temperature controlled pumped fluid loops, and direct mounted sublimators or evaporators.

The latent heat expulsion concepts (sublimator and evaporator) are attractive in that they simultaneously provide temperature uniformity, stability and refrigeration (the expendable fluid) to accommodate high cooling loads with little power. However, they will be expensive to develop and fabricate, they suffer certain operational constraints, and they may lead to contamination problems exterior to the Spacelab.

Direct mounted thermoelectric modules with a pumped coolant as the heat sink is a viable approach when the temperature difference across the TEM's need not be too large. However, they are costly and have high electrical power requirements to accommodate rapid temperature changes involving high thermal loads.

Pumped fluid loops are state-of-the-art and, if they can meet the temperature control requirements, probably offer the lowest cost approach to thermal control. This has been selected as our baseline approach as discussed on the following pages.

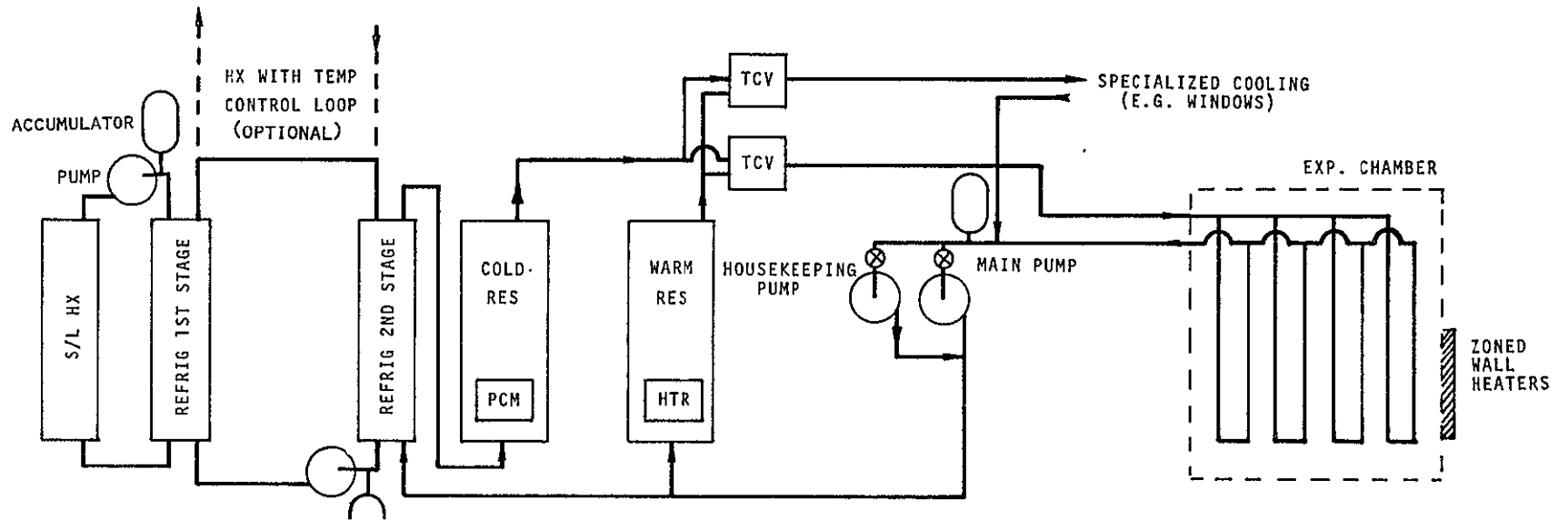
THERMAL CONTROL SUBSYSTEM
TEMPERATURE CONTROL CONCEPTS

CONCEPT	ADVANTAGES	DISADVANTAGES
MASSIVE, HIGH CONDUCTIVITY WALLS	<ul style="list-style-type: none"> ● PROMOTES UNIFORMITY AND STABILITY 	<ul style="list-style-type: none"> ● HEAVY ● HIGH THERMAL LOAD FOR RAPID TEMPERATURE CHANGES
HEAT PIPE (VAPOR CHAMBER) WALLS	<ul style="list-style-type: none"> ● GOOD UNIFORMITY ● LOW MASS MINIMIZES THERMAL LOAD FOR RAPID TEMPERATURE CHANGES 	<ul style="list-style-type: none"> ● PROVIDES LITTLE STABILITY ● EXPENSIVE ● NOT QUITE STATE-OF-THE-ART
DIRECT MOUNTED TEM'S WITH PUMPED COOLANT AS SINK	<ul style="list-style-type: none"> ● FAST RESPONSE ● LOW POWER REQUIRED AT STEADY STATE CONDITIONS 	<ul style="list-style-type: none"> ● UNIFORMITY DIFFICULT - COMPLEX CONTROL ● HIGH POWER NEEDED FOR RAPID TEMPERATURE CHANGES ● EXPENSIVE
PUMPED FLUID LOOPS HIGH FLOW RATE LARGE MASS (RESERVOIR) TEMPERATURE CONTROL BY MIXING HOT AND COLD STREAMS (COMMON LOOP) TEMPERATURE CONTROL BY HEATING OR COOLING STREAM TO EACH ELEMENT (MULTIPLE LOOPS)	<ul style="list-style-type: none"> ● PROVIDES UNIFORMITY ● PROVIDES STABILITY ● MINIMIZES HARDWARE (PUMPS, REFRIGERATORS, ETC.) ● PERMITS TIME-AVERAGING POWER WITH HOT AND COLD RESERVOIRS ● LOW POWER REQUIRED AT STEADY STATE ● MAXIMUM FLEXIBILITY 	<ul style="list-style-type: none"> ● HIGH POWER REQUIREMENT ● HIGH WEIGHT AND VOLUME ● NEED ACCURATE MIXING VALVES ● HIGH VOLUME AND WEIGHT OF RESERVOIRS ● HIGH POWER REQUIREMENT TO MAINTAIN HOT AND COLD STREAMS ● MAXIMIZES HARDWARE (PUMPS, REFRIGERATORS, ETC.)
DIRECT MOUNTED SUBLIMATOR	<ul style="list-style-type: none"> ● GOOD UNIFORMITY AND STABILITY THROUGH CONTROL OF UNIFORM PRESSURE ● LOW POWER 	<ul style="list-style-type: none"> ● SLOW RESPONSE FOR RAPID TEMPERATURE CHANGES ● OPERATIONAL CONSTRAINTS ON TRANSIENTS ● EXPENSIVE
DIRECT MOUNTED EVAPORATOR	<ul style="list-style-type: none"> ● GOOD UNIFORMITY AND STABILITY THROUGH CONTROL OF UNIFORM PRESSURE ● FAST RESPONSE ● LOW POWER 	<ul style="list-style-type: none"> ● POTENTIAL PROBLEMS WITH CONDENSATION AND CONTAMINATION ● EXPENSIVE

The schematic on the facing page shows the baseline pumped loop concept for thermal control of the expansion chamber. The Spacelab Experiment Heat Exchanger serves as the ultimate heat sink and two stages of refrigeration are used to provide low enough temperatures for -25°C operation. An optional flow path is shown for heat exchange with the temperature control loop serving the rest of the ACPL following the first stage of refrigeration.

A key feature of this concept is the use of hot and cold coolant reservoirs for leveling the thermal load of the expansion chamber. Low level refrigeration and heater power are applied continuously to establish the appropriate cold and hot reservoir temperatures, respectively. During a rapid expansion, the high cooling load at the chamber is accommodated with the refrigeration stored in the cold reservoir. Thermal control mixing valves (TCV's), with set points continually updated by the Control and Data Subsystem, are used to ratio the flow from the reservoirs so as to provide the appropriate cooling rate. TCV's with the required mixed stream accuracy have not yet been identified as available commercial equipment and may require development. However, presuming they become available, preliminary thermal modeling of the chamber has shown this concept to be potentially feasible with large, but manageable, coolant flow rates.

PUMPED COOLANT CONCEPT FOR THERMAL CONTROL
OF EXPANSION CHAMBER



The baseline concept for thermal control of the rest of the ACPL involves multiple pumped loops serving each system element requiring control to a specific temperature.

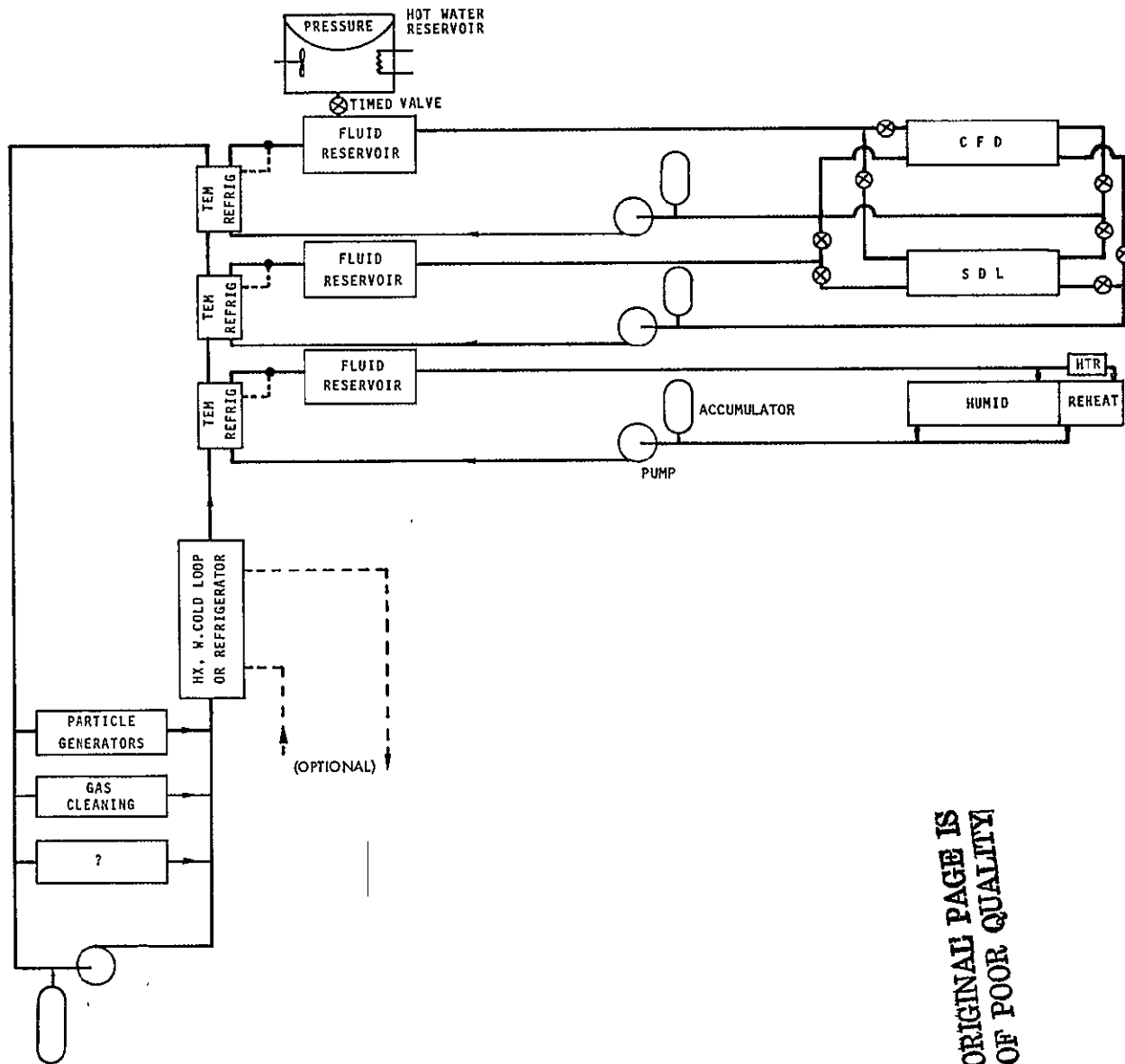
A primary loop, cooled by a refrigerator or in heat exchange with the first stage refrigerator of the expansion chamber loop, provides cooling for those components not requiring precise temperature control and serves as a heat sink or source for multiple TEM refrigerator/heat pumps in a series of temperature control loops.

Each ACPL element requiring precise temperature control is serviced by an independent temperature control loop, although a given loop may service multiple elements if they need not operate simultaneously. This has been assumed for the CFD and SDL which are shown serviced by the same two loops, one each for the hot and cold plates. Temperature control for each loop is provided by the TEM refrigerator/heat pump in reference to its outlet temperature, with fluid reservoirs serving to damp out fluctuations and provide stability.

An additional hot water reservoir is provided for the loop serving the hot plate of the CFD. The requirement for rapidly stepping the ΔT between CFD plates will be met by maintaining the cold plate constant and increasing the hot plate temperature. By injecting a controlled quantity of hot water into the flow loop, accommodated by the accumulator, the loop enthalpy and plate temperature are rapidly increased without a large electrical load on the system. As with the expansion chamber, this reservoir provides a time-averaging or load-leveling feature to the system.

This multiple loop concept accommodates the high coolant flow rates required for temperature uniformity of the critical components with maximum thermodynamic efficiency. Furthermore, it provides a high degree of flexibility for evolutionary growth. Its major disadvantage is that it maximizes the hardware requirements (pumps, refrigerators, etc.).

MULTIPLE LOOP PUMPED COOLANT CONCEPT FOR THERMAL CONTROL OF SUBSYSTEMS



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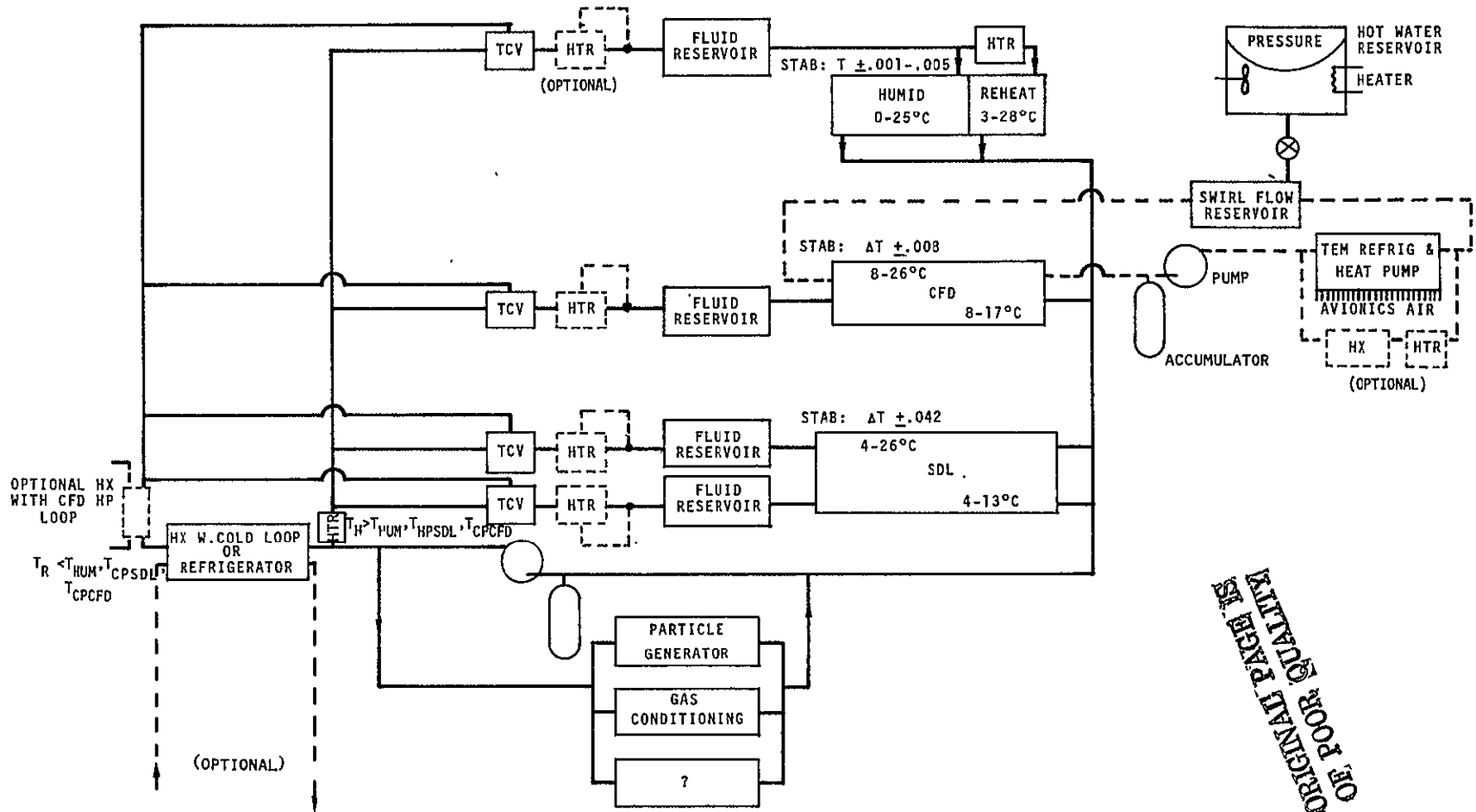
An alternative concept for temperature control of the critical ACPL components, which minimizes hardware requirements, is shown on the facing page. In this case, a common loop is used to control many of the key elements by mixing hot and cold streams with thermal control mixing valves (TCV's). Thus, a series of TCV's replace many of the pumps and refrigerators.

Temperature control is nominally provided by the TCV and temperature stability by the fluid reservoirs. However, depending on the control capability of the TCV's, it may be necessary to include heaters for temperature trimming.

Two major problems have been identified with this concept, both related to the very high coolant mass flow rates necessary for temperature uniformity in the critical components.

- 1) Mixing hot and cold streams, and then using refrigeration and heat to reestablish them is thermodynamically inefficient. The heating and cooling requirements depend on the temperature difference between the hot and cold streams and the loop mass flow rates.
- 2) Commercially available TCV's have relatively poor temperature control capability ($\pm 1^\circ\text{C}$) and will require supplementary heaters for temperature trimming. Heater power becomes excessive at high mass flow rates.

Unless higher performance TCV's become available, the simultaneous operating temperature range of the system is reduced, and uniformity requirements are relaxed or other methods found to lower the coolant mass flow rates, this minimum hardware temperature control concept will not be practical.



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Particle generation is very closely tied to scientific functional requirements which, at this point, are not yet fully defined.

The table on the facing page is offered as a preliminary classification of types of particles to be generated, potential generating techniques and their relative advantages and disadvantages.

PARTICLE GENERATOR CONCEPTS

PARTICLE SIZE MICRONS	COMPOSITION	GENERATION TECHNIQUE	ADVANTAGES	DISADVANTAGES
<.01	SULFURIC ACID - SULFATES	<ul style="list-style-type: none"> • EXPOSURE OF CONTAINER TO SUN • ARTIFICIAL UV RADIATION 	<ul style="list-style-type: none"> • NO POWER REQUIRED • STANDARD TECHNIQUE; EASY TO CALIBRATE 	<ul style="list-style-type: none"> • REQUIRES USE OF AIR LOCK • HIGH POWER REQUIRED
.01 - .1	SALTS	<ul style="list-style-type: none"> • EVAPORATION-CONDENSATION - MULTI-STAGE <li style="padding-left: 20px;">- SINGLE STAGE • EVAPORATION (FROM ATOMIZER OR SPRAY NOZZLE) • BUBBLING 	<ul style="list-style-type: none"> • GOOD SIZE DISTRIBUTION CONTROL; MAX PARTICLE PURITY • LOW POWER, SIZE, HEAT DISSIPATION; MAX PARTICLE PURITY • SIMPLE, LOW POWER OPERATION • MAY BE REPRESENTATIVE OF NATURALLY OCCURRING AEROSOLS 	<ul style="list-style-type: none"> • HIGH POWER AND HEAT DISSIPATION REQUIRED • POOR SIZE DISTRIBUTION CONTROL • POOR SIZE DISTRIBUTION CONTROL; CONTAMINATION PROBLEMS • NOT WELL CHARACTERIZED; POSSIBLE ZERO-G ADAPTION PROBLEMS
>.1	LATEX TEFLON	<ul style="list-style-type: none"> • ENTRAINMENT THROUGH ATOMIZATION • POWDER DISPERSION 	<ul style="list-style-type: none"> • GOOD PARTICLE SIZE CONTROL; USEFUL FOR OPC CALIBRATION • DESIRABLE SUBSTANCE FOR SOME EXPERIMENTS 	<ul style="list-style-type: none"> • SURFACE CONTAMINATION, NUMBER DENSITY NOT EASILY CONTROLLED • POOR SIZE DISTRIBUTION CONTROL

Pending further definition of the requirements, the baseline Particle Generator Subsystem has been defined to include two generators, the particle storage bag and the particle injector.

The first generator uses a single stage evaporation-condensation technique for producing salt nuclei. A pure salt sample in a quartz tube will be evaporated and the vapor condensed in a dilution air stream. This approach provides high particle purity and has low thermal, power, volume and mass requirements. However, it produces a polydisperse aerosol with poor size distribution control. If required, better size distribution control can be obtained with multiple evaporation-condensation stages, but at additional costs in all resources.

The second generator employs the photolysis technique for producing sulfuric acid or sulphate nuclei. The UV irradiation process will be performed directly in a storage bag through exposure to sunlight using the Spacelab airlock. This concept, which eliminates all power requirements, has apparently occurred to others as well as TRW, according to Dr. W. Davis' summary notes on the recent science requirements meeting at Rolla, Mo. Dr. W. Kocmond has also suggested that this approach might provide the basis for an independent experiment as well as an aerosol source for other experiments.

PARTICLE GENERATOR SUBSYSTEM

CURRENT BASELINE

- SINGLE STAGE EVAPORATION – CONDENSATION GENERATOR
- PHOTOLYSIS IN STORAGE BAG USING SPACELAB AIRLOCK FOR DIRECT EXPOSURE TO SUNLIGHT
- STORAGE BAG
- PARTICLE INJECTOR

The current aerosol storage, stability and density requirements, shown on the facing page, appear to represent a major problem in design of the ACPL.

First, preliminary calculations indicate that diffusion to the surface of the storage bag (assuming a 65 liter sphere) precludes meeting the stability requirement for particles smaller than about 10^{-6} cm. Much larger storage bags will be required to handle 10^{-7} cm particles with the required stability.

Furthermore, coagulation of a monodisperse aerosol appears to limit the storage density in the bag to the order of 10^4 particles/cc, using the same stability requirement. But if we combine this with a minimum dilution ratio of ≥ 100 to achieve the necessary humidifier accuracy with downstream injection and no secondary aerosol humidifier, we can only provide particle densities $\leq 10^2$ particles/cc to the experiments. This suggests a secondary humidifier (or upstream injection) may indeed be necessary, presuming the contamination problems discussed earlier can be overcome, in order to lower the dilution ratio and meet the 10^3 particles/cc requirement.

Lowering the dilution ratio, however, poses other problems. Flushing requirements for the expansion chamber (12 volumes at 33 liters each) yield an aerosol consumption rate of $\sim(400/\text{dilution ratio})$ liters per experiment. Thus, to store the aerosol in the bag at 10^4 particles/cc and deliver it to the expansion chamber at 10^3 particles/cc requires a dilution ratio of 10 and an aerosol consumption of 40 liters. Consequently, multiple experiments with the same aerosol would again require a larger storage bag than the 60-100 liters assumed in our baseline design. Unfortunately, overall ACPL volume budgets limit the extent to which the bag volume can be increased.

PARTICLE GENERATOR SUBSYSTEM

AEROSOL STORAGE, STABILITY AND DENSITY REQUIREMENTS:

- STORE SUFFICIENT QUANTITY FOR MULTIPLE EXPERIMENTS IN SIZE RANGE 10^{-7} CM TO 10^{-3} CM DIAMETER.
- STABILITY: < 5% CHANGE IN 2 HOURS
- DENSITY SUPPLIED TO EXPERIMENTS: $\leq 10^3$ PARTICLES/CC

AREAS OF CONCERN:

- PRELIMINARY CALCULATIONS INDICATE:
 - 1) DIFFUSION LIMITS PARTICLE SIZE TO $> 10^{-6}$ CM TO MEET STABILITY REQUIREMENT
 - 2) COAGULATION LIMITS STORAGE DENSITY TO 10^4 PARTICLES /CC TO MEET STABILITY REQUIREMENT
 - 3) AEROSOL CONSUMPTION PER EXPANSION CHAMBER EXPERIMENT \approx (400/DILUTION RATIO) LITERS.
- CANNOT MEET CURRENT REQUIREMENTS WITHOUT VERY LARGE STORAGE BAGS AND MAJOR MODIFICATION OF BASELINE FLUID SUBSYSTEM.

The Optical and Imaging Subsystem must record the droplet growth processes in the expansion chamber and SDL. The subsystem requirements, as we currently understand them, are shown on the facing page.

Our baseline concept for meeting these requirements is to use a camera, flashlamp and appropriate optics, filters, etc. Such a system will meet most of the requirements, although several areas of concern have been identified.

- A picture taking rate of one per second for 30 minutes, as called for in the expansion chamber, leads to 1800 photographs for a single experiment. This seems like an excessive amount of data for subsequent analysis.
- A picture taking rate of 16 per second in the SDL might yield even more data except that a time period has not been specified. This represents a motion picture which, although appropriate for terrestrial experiments where gravitational fallout prevails, does not appear necessary in 0-g. A lower framing rate for the SDL (≤ 3 frames/sec) might permit using the same camera for the two chambers.
- Preliminary calculations indicate that collimation problems with a flashlamp illumination source, at the illumination intensities required to detect 2μ particles, may preclude achieving the 3% SEV accuracy. In this event, a laser illumination source will be needed for improved SEV definition.

OPTICAL AND IMAGING SUBSYSTEM

REQUIREMENTS	EXPANSION CHAMBER	SDL
MINIMUM SIZE DETECTED	2 μ DIA	2 μ DIA
SENSITIVE EXPERIMENT VOLUME	$\geq 100 \text{ CM}^3$	$\geq 0.1 \text{ CM}^3$
SEV ACCURACY	< 3%	< 3%
CAMERA FRAMING RATE	1 FRAME/SEC FOR 30 MINUTES	16 FRAMES/SEC
UV AND IR ILLUMINATION	< TBD WATTS/CM ²	< TBD WATTS/CM ²

BASELINE CONCEPT:

CAMERA - FLASHLAMP

POTENTIAL PROBLEM:

< 3% SEV ACCURACY

ALTERNATE CONCEPT:

CAMERA - LASER

C-12

The discussion of ACPL Science Requirements breaks naturally into two sections: A discussion of the capabilities and components required for the first generation and subsequent generations of the laboratory, and a discussion of the scientific functional requirements for those components identified for inclusion in the initial ACPL.

SCIENTIFIC REQUIREMENTS

MARC KOLPIN

The discussion of evolutionary growth sequence has two main goals: To establish the current baseline for the initial ACPL, and to begin identifying supporting research and technology required for future growth of the laboratory. Although we have a tentative evolutionary growth sequence to present, we intend that the ensuing discussion be a mutual interchange rather than a technical presentation, and we anticipate some changes in our tentative growth scenario as a result of the discussion.

ACPL GROWTH SCENARIO

We have broken the evolutionary growth of the laboratory into three phases: First generation; second generation, including changes requiring minimal development from presently available technology; and third generation, including changes requiring significant development. The next three viewgraphs describe the requirements we used to sort each potential ACPL capability into one of these three categories.

For the first generation, detailed design will begin shortly after the completion of the Phase B study. Therefore, for scheduling reasons, it is necessary that all capabilities and components to be included in the initial ACPL be selected by the end of Phase B. We feel strongly that all components selected for inclusion in the laboratory should be "certified" by the potential users before selection. That is, the technology, design, and performance parameters must be well understood and accepted by the user community. Ideally, this certification results from development and laboratory work conducted by the users themselves.

This "certification" is important for at least two reasons: First the operator of the ACPL will, in general, not be the scientist responsible for each experiment and hence the scientist must be fully convinced of the acceptability of the apparatus and procedure. Secondly, to be fully successful, the ACPL must attract the largest possible user community.

CATEGORY 1.

CAPABILITIES POTENTIALLY SUITABLE FOR INITIAL ACPL

- THESE CAPABILITIES MUST REQUIRE COMPONENTS WHICH WILL BE "CERTIFIED" BY THE USER COMMUNITY IN THE NEAR FUTURE. INCLUDES:
 - COMPONENTS ALREADY DEVELOPED TO THE POINT OF ACCEPTANCE BY THE COMMUNITY.
 - COMPONENTS CURRENTLY UNDERGOING DEVELOPMENT WITH THE PROBABILITY OF GENERAL ACCEPTANCE BY THE END OF THE PHASE B STUDY.

We feel that the best available rule for selecting added capabilities for the second generation ACPL is derived from the amount of work necessary for "certification" and the probability of success. Hence we have placed in this category only those capabilities for which components are currently underdevelopment, or technologies upon which components may successfully be based have been identified.

CATEGORY 2.

CAPABILITIES POTENTIALLY SUITABLE FOR SECOND GENERATION ACPL

- THESE CAPABILITIES REQUIRE:
 - COMPONENTS WHICH ARE UNDER DEVELOPMENT, BUT WILL PROBABLY NOT BE "CERTIFIED" BY THE END OF THE PHASE B STUDY.
 - TECHNOLOGIES WHICH HAVE BEEN IDENTIFIED, BUT NOT DEVELOPED INTO COMPONENTS.
- NEW SUPPORTING RESEARCH AND TECHNOLOGY IS REQUIRED TO DEVELOP THESE COMPONENTS.

CATEGORY 3.

CAPABILITIES POTENTIALLY SUITABLE FOR THIRD GENERATION ACPL

- THESE CAPABILITIES REQUIRE TECHNOLOGIES WHICH HAVE NOT YET BEEN IDENTIFIED.

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The next four viewgraphs show our first attempt to sort some of the ACPL capabilities which have been identified into the three categories. The capabilities shown on these viewgraphs include those defined by existing NASA ACPL science requirements, as well as capabilities discussed at the USRA meeting of 18-19 March at Rolla, Missouri.

TENTATIVE CATEGORY 1 CAPABILITIES

CAPABILITY	COMPONENTS OR TECHNIQUES
<ul style="list-style-type: none"> ● ADIABATIC EXPANSION ABOVE 0°C FOLLOWING DRY ADIABAT, WET ADIABAT, OR ADIABAT PREDICTED FOLLOWING S_C CHARACTERIZATION OF AEROSOL. 	EXPANSION CHAMBER
<ul style="list-style-type: none"> ● ADIABATIC EXPANSION BELOW 0°C FOLLOWING DRY ADIABAT, WET ADIABAT, OR PREDETERMINED PREDICTED ADIABAT. 	EXPANSION CHAMBER
<ul style="list-style-type: none"> ● PROVIDING SAMPLE WITH KNOWN R.H. AT TEMPERATURES ABOVE 0°C AND PRESSURES NEAR S/L AMBIENT. 	HUMIDIFIER
<ul style="list-style-type: none"> ● PROVIDING A DISTRIBUTION OF SOLUBLE AEROSOLS. 	NaCl GENERATED BY EVAPORATION/ CONDENSATION TECHNIQUE
<ul style="list-style-type: none"> ● PROVIDING A DISTRIBUTION OF VERY MINUTE AEROSOLS. 	PHOTOCHEMICAL H ₂ SO ₄ DROPLET GENERATION
<ul style="list-style-type: none"> ● MEASURING SIZE DISTRIBUTION OF CCN AEROSOLS. 	WHITBY TYPE AEROSOL ANALYZER
<ul style="list-style-type: none"> ● CHARACTERIZING CRITICAL SUPERSATURATION SPECTRUM OF CCN AEROSOLS. 	CFD OR SDL

TENTATIVE CATEGORY 2 CAPABILITIES

CAPABILITY	COMPONENTS OR TECHNIQUES
● CHARACTERIZING CRITICAL SUPERSATURATION SPECTRUM OF ICE NUCLEI.	SDI
● SINGLE PARTICLE REPOSITIONING CAPABILITY.	ACOUSTIC TECHNIQUES LASER LIGHT PRESSURE ELECTROSTATIC TECHNIQUES
● PROVIDING AIR SAMPLE OF KNOWN R.H. AT TEMPERATURES BELOW 0°C AND PRESSURES AT OR NEAR S/L AMBIENT.	HUMIDIFIER USING ICE SURFACES
● PARTICLE SIZING CAPABILITY FOR EXPANSION CHAMBER	HOLOGRAPHY SCATTERING MEASUREMENTS
● SAMPLE AND RETURN OF ICE CRYSTALS.	COLD STORAGE

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TENTATIVE CATEGORY 2 CAPABILITIES

(CONTINUED)

CAPABILITY	COMPONENTS OR TECHNIQUES
● PROVIDING A DISTRIBUTION OF HYDROPHOBIC AEROSOLS	PRE-MANUFACTURED TEFLON PARTICLE DISPERSION
● RE-COMPRESSION OF EXPANSION CHAMBER	CONTROLLED STORAGE AND RE-COMPRESSION OF WITHDRAWN SAMPLE
● REMOVAL OF AITKEN NUCLEI FOR ICE EXPERIMENTS	EXTENDED STORAGE
● GROWTH OF LARGE ICE CRYSTALS	DEDICATED ICE ISOTHERMAL CHAMBER ADAPTATION OF EXPANSION CHAMBER STATIC DIFFUSION (ICE) CHAMBER
● PROVIDING A DISTRIBUTION OF INSOLUBLE AEROSOLS	Ag I GENERATION BY EVAPORATION/ CONDENSATION TECHNIQUE
● HOMOGENEOUS NUCLEATION OF WATER DROPLETS.	SUPERSONIC NOZZLE

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TENTATIVE CATEGORY 3 CAPABILITIES

CAPABILITY

The next portion of the discussion deals with the scientific functions required for the components in the initial state.

- MULTIPLE PARTICLE (CLOUD) REPOSITIONING CAPABILITY includes: the expansion chamber, the particle generation and state measurement systems as well as the static diffusion chamber, and the static diffusion chamber.
- DIRECT MEASUREMENT OF GAS TEMPERATURE INSIDE EXPANSION CHAMBER. The former has been selected for the current study.
- VENTILATION OF DROPLETS OR PARTICLES. The system and allow the derivation of engineering functions.
- INDUCED DROPLET OR PARTICLE COLLISIONS. In other cases, no quantitative requirements have been received.

- GAS-PARTICLE INTERACTIONS
- REAL-TIME MEASUREMENT OF LWC.

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The next portion of the discussion deals with the scientific functional requirements for the components in the initial ACPL that have been identified to date. These components include: the expansion chamber, the particle generation and size measurement apparatus, the continuous flow diffusion chamber, and the static diffusion (liquid) chamber.

The format that we have selected is to identify all of the requirements that we currently feel are required to specify the system and allow the derivation of engineering functional requirements for each component. In many cases, we have already received quantitative requirements; in other cases, no quantitative specification exists and additional data is requested.

SCIENTIFIC FUNCTIONAL REQUIREMENTS

FOR

INITIAL ACPL COMPONENTS

This viewgraph shows the organization of the requirements for each of the four components. A statement of operating capabilities is followed by a brief operating sequence. On subsequent viewgraphs, the scientific requirements corresponding to each step in the operating sequence are given. In some cases, general requirements which do not fit into the operating sequence are given on the final viewgraph of the corresponding section.

EXPANSION CHAMBER

CAPABILITIES PROVIDED

- ADIABATIC EXPANSION OF AEROSOL LADEN AIR SAMPLE FOLLOWING WET OR DRY ADIABAT AFTER START OF CONDENSATION

OPERATING SEQUENCE

- PREPARATION AND INJECTION OF MOIST, AEROSOL LADEN AIR SAMPLE
- ADIABATIC EXPANSION OF SAMPLE
- OBSERVATION OF WATER DROPLET/ICE CRYSTAL FORMATION AND COALESCENCE.

Preparation of the sample for the expansion chamber is partially performed by ancilliary equipment: The humidifier and the aerosol generation apparatus.

The initial pressure range and temperature range are probably correlated, with high pressures only occurring in combination with high temperatures, and low pressures with low temperatures. If so, this correlation should be specified as part of the requirement to prevent unnecessary effort that may be required to achieve physically unrealistic initial conditions.

REQUIREMENTS FOR PREPARATION AND INJECTION OF AIR SAMPLE

CONDITIONS AT START OF EXPANSION:

- TEMPERATURE RANGE 0.5 °C TO 25 °C
- PRESSURE RANGE 400 mb TO S/L AMBIENT
- RELATIVE HUMIDITY RANGE TBD
- ABSOLUTE ACCURACY OF R.H. $\pm 0.01\%$
- AEROSOL CHARACTERISTICS TBD (SEE AEROSOL SAMPLES)
- RESIDUAL VELOCITY <0.1 CM/SEC

A variation of maximum rate of change of temperature with temperature range is desirable to avoid over-sizing of the thermal control subsystem. As the expansion chamber approaches the lower end of its temperature range; the rate of cooling will be reduced unless the TCS is designed to be able to cool the chamber to a much lower ultimate temperature than required.

REQUIREMENTS FOR ADIABATIC EXPANSION OF SAMPLE

- EXPANSION RATIO $\frac{\Delta P}{P_0}$: 0 TO TBD %.

- EXPANSION RATE (MAXIMUM)
VS. EXPERIMENT DURATION

$\frac{dT}{dt}$	0.5	1.2	6	°C/MIN
t	90	30	2.5	MIN

VS. TEMPERATURE RANGE

$\frac{dT}{dt}$	0.5	1.2	6	°C MIN
T	-20 TO -25	-15 TO -20	+25 TO -15	MIN

MAXIMUM ALLOWABLE
TEMPERATURE CHANGE
WITHIN SEV DURING
CHANGE FROM CONSTANT
TEMPERATURE TO MAXIMUM
COOLING:

≤ 0.05 °C DURING TIME INTERVAL
REQUIRED TO ATTAIN TBD % OF
MAXIMUM COOLING RATE

- PRESSURE CONTROL WITHIN SEV DURING
EXPANSION:

± TBD mb OF DRY ADIABAT BEFORE
R. H. = 100%
± TBD mb OF DRY ADIABAT AFTER
WET ADIABAT
R. H. = 100%

After the relative humidity exceeds 100%, estimates of relative humidity or supersaturation are only as good as the condensation model on which they are based. Hence, accuracy requirements in this period are based on pressure and temperature, rather than relative humidity.

REQUIREMENTS FOR ADIABATIC EXPANSION OF SAMPLE

(CONTINUED)

- ABSOLUTE ACCURACY OF PRESSURE AND TEMPERATURE WITHIN SEV AT R. H. = 100%
± TBD RELATIVE TO INITIAL CONDITIONS
± TBD °C RELATIVE TO INITIAL CONDITIONS
- RELATIVE ACCURACY OF PRESSURE AND TEMPERATURE WITHIN SEV WHEN R. H. > 100%
± TBD mb RELATIVE TO R.H. = 100%
± TBD °C RELATIVE TO R.H. = 100%
- PRESSURE AND TEMPERATURE STABILITY FOR STEADY STATE OPERATION (I.E., NO EXPANSION)
± TBD mb
± TBD °C

REQUIREMENTS FOR OBSERVATION OF
WATER DROPLET/ICE CRYSTAL FORMATION

- PARTICLE DENSITY RANGE 100 TO 1000/CM³
- MAXIMUM FRAME RATE 1 PER SEC. FOR 1/2 HOUR
- ABSOLUTE ACCURACY OF NUMBER DENSITY DETERMINATION ± 3% FOR PARTICLES ABOVE MINIMUM DETECTABLE SIZE
- MINIMUM DETECTABLE PARTICLE DIAMETER 2 μm
- FORBIDDEN WAVELENGTHS NO ULTRAVIOLET OR INFRARED LIGHT INTRODUCED INTO SAMPLE VOLUME:
TBD Å

$$\int_0^{\text{TBD Å}} I d\lambda < \text{TBD WATTS/CM}^2$$

$$\int_{\text{TBD Å}}^{\infty} I d\lambda < \text{TBD WATTS/CM}^2$$

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Additional information is required concerning the sizes, shapes and materials of the devices to be inserted into the chamber. Also, the performance of the chamber will in some cases be degraded by the presence of the foreign matter, and this should be reflected by a relaxed performance specification applicable to this mode of operation.

GENERAL REQUIREMENTS FOR EXPANSION CHAMBER

- EXPANSION CHAMBER MUST PERMIT INSERTION OR EXTRACTION OF SMALL PIECES OF HARDWARE OR TEST MATERIALS.

Dilution of aerosols is combined with generation of the aerosols in the operating sequence despite the fact that dilution will most likely occur at more than one point in the sequence. This is done because the specification of total number of particles to be generated refers to the number density after dilution has taken place (i.e., the desired concentration in the test chamber).

PARTICLE GENERATION AND SIZE MEASUREMENT

CAPABILITIES PROVIDED

- PROVIDES KNOWN AEROSOL SIZE DISTRIBUTIONS TO BE INTRODUCED INTO TEST CHAMBERS.

OPERATING SEQUENCE

- GENERATION AND DILUTION OF AEROSOLS
- STORAGE OF AEROSOLS PRIOR TO USE
- MEASUREMENT OF AEROSOL SIZE DISTRIBUTION

The desired number density for the H_2SO_4 particles should be correlated with particle size to prevent unnecessary effort required to achieve unrealistic conditions.

REQUIREMENTS FOR GENERATION AND DILUTION OF AEROSOLS

- NaCl PARTICLES

CRITICAL SUPERSATURATION SPECTRUM: $N = CS^k$
 STANDARD DEVIATION FROM MEAN SPECTRUM: \pm TBD % OF N_{TOTAL}

NUMBER DENSITY RANGE:
 AFTER DILUTION $\int_0^{1\%} \frac{dN}{dS} dS = \left[\begin{array}{c} 50/CM^3 \\ TO \\ 1000/CM^3 \end{array} \right]$
 $< 10 /CM^3$ WITH DIA $\geq 0.05 \mu m$

CHARGE OF PARTICLES: PARTICLES SHALL NOT BE CHARGED.

- H₂SO₄ PARTICLES

SIZE RANGE: .001 μm TO 1 μm
 NUMBER DENSITY RANGE:
 AFTER DILUTION TBD (CORRELATED WITH SIZE).

- OTHER PARTICLES

PROVISION MUST BE MADE FOR USE OF OTHER SPECIALIZED PARTICLE GENERATORS PROVIDED BY PRINCIPAL INVESTIGATORS.

Loss of particles which nucleate outside the supersaturation range of interest appears to be of no importance and hence, should not constrain the storage technique used. The size range of interest is expected to be dependent upon material.

REQUIREMENTS FOR STORAGE OF AEROSOLS

- MAXIMUM STORAGE DURATION: 2 HOURS
- MAXIMUM TOTAL PARTICLE LOSS WITHIN SIZE RANGE TBD μm TO TBD μm DIA. DURING STORAGE: 5%

The requirement for collection and storage of aerosol samples for analysis on earth should be expanded. Additional information should include:

- Frequency of sampling and correlation with operating modes of ACPL
- Number of particles desired in each sample
- Degree to which each sample must reflect the distribution in the gas from which the sample is drawn
- Allowable degradation in the sample during storage.

REQUIREMENTS FOR MEASUREMENT OF AEROSOLS

- MEASUREMENT OF PARTICLE DIAMETER: $\delta \log_{10} d < \pm .25$
- MEASUREMENT OF NUMBER DENSITY IN EACH SIZE RANGE: $\delta \log_{10} n < \pm .3$
- MUST PROVIDE CAPABILITY FOR COLLECTION OF AEROSOL SAMPLES AND STORAGE IN INERT GAS FOR RETURN TO EARTH.

Preconditioning of the sample includes those processes necessary to avoid transient supersaturations near the entrance to the supersaturation region.

CONTINUOUS FLOW DIFFUSION CHAMBER

CAPABILITIES PROVIDED

- CAPABILITY OF EXPOSING CCN AEROSOL SAMPLES TO A KNOWN SUPERSATURATION FIELD FOR A KNOWN RESIDENCE TIME TO PERFORM GROWTH STUDIES
- CAPABILITY OF EXPOSING A CCN AEROSOL SAMPLE TO VARIOUS SUPERSATURATIONS TO DETERMINE CRITICAL SUPERSATURATION SPECTRA

OPERATING SEQUENCE

- PRECONDITIONING OF SAMPLE
- EXPOSURE TO SUPERSATURATION FIELD
- MEASUREMENT OF ACTIVATED DROPLET DENSITY

K_h is the thermal diffusivity for the gas while K_w is the diffusivity of water vapor through the gas. h is the separation between the hot and cold wet plates.

REQUIREMENTS FOR PRE-CONDITIONING OF SAMPLE

- TIME SAMPLE MUST SPEND BETWEEN DRY PLATES OF CFD: $\geq \frac{5 h^2}{\pi K_H}$
- TIME SAMPLE MUST SPEND BETWEEN DRY HOT PLATE AND WET COLD PLATE OF CFD: $\geq \frac{5 h^2}{\pi K_W}$

Droplet growth studies require exposure to a constant, known supersaturation field for a precisely known residence time.

REQUIREMENTS FOR SUPERSATURATION FIELD

- CONSTANT SUPERSATURATION FIELD (GROWTH STUDIES)

RANGE OF MAXIMUM SUPERSATURATION	0.1 TO 3%
SPATIAL VARIATION OF S ACROSS SAMPLE	1% OF $S_{MAX.}$
ABSOLUTE ACCURACY OF MAXIMUM SUPERSATURATION	$\pm 1\%$ OF $S_{MAX.}$
RESOLUTION OF MAXIMUM SUPERSATURATION	\pm TBD % OF $S_{MAX.}$
RANGE OF RESIDENCE TIMES	TBD SEC TO TBD SEC
ACCURACY OF RESIDENCE TIME MEASUREMENT	\pm TBD %
RESOLUTION OF RESIDENCE TIME	\pm TBD %

Operation of the CFD as a spectrometer requires stepping or ramping of the supersaturation to cover the range of interest while the aerosols are convected through the device with a residence time sufficient to grow the activated droplets to sizes distinctly greater than the non-nucleated droplets. Residence times need not be accurately measured for this operating mode.

REQUIREMENTS FOR SUPERSATURATION FIELD
(CONTINUED)

- VARIABLE SUPERSATURATION FIELD (SPECTROMETER)

ERROR IN MEASUREMENT OF THE
CUMULATIVE DISTRIBUTION OF
PARTICLE DENSITY VS CRITICAL
SUPERSATURATION

$$N(S_c) = \int_0^{S_c} n(S_c) dS_c$$

$$+ \text{TBD \%} \int_0^{S_{c\text{MAX}}} n(S_c) dS_c$$

The total number density of the droplets at the inlet to the CFD and the sample flow rate to the CFD combine to give the rate at which particles are convected through the optical particle counter used to monitor CFD output, and hence both parameters are important in determining the fraction of nuclei which have been activated.

Droplet size measurement is not necessary for operation as a spectrometer, except as a check to determine that the device is not sensitive to flow velocity (i.e. residence time). However, droplet size measurement and measurement accuracy become important for droplet growth studies.

REQUIREMENTS FOR ACTIVATED AEROSOL DENSITY MEASUREMENT.

- TOTAL NUMBER DENSITY OF DROPLETS
AT INLET TO CFD $10/\text{CM}^3$ TO $2000/\text{CM}^3$
- ACCURACY OF SAMPLE FLOW RATE TO CFD $\pm 1\%$
- SIZE RANGE OF DROPLETS TBD μm TO TBD μm DIA.
- ACCURACY OF DROPLET COUNT \pm TBD %
- ACCURACY OF DROPLET SIZE MEASUREMENT \pm TBD %

This is really a requirement on the particle storage and flow subsystem components. It is included here for completeness.

GENERAL REQUIREMENTS FOR CFD

- ALLOWABLE DEVIATION BETWEEN AEROSOLS FURNISHED TO CFD AND AEROSOLS FURNISHED TO EXPANSION CHAMBER: AT ANY GIVEN S_c , CUMULATIVE DISTRIBUTIONS $N(S_c)$ SHALL DIFFER BY LESS THAN TBD %.

We require more data on possible operating modes for the SDL. Are the capabilities described here sufficient for the performance of the desired experiments?

STATIC DIFFUSION CHAMBER (LIQUID)

CAPABILITIES

- EXPOSING A CCN AEROSOL SAMPLE TO AN ACCURATE, PRE-SELECTED, CONSTANT SUPERSATURATION FOR USE IN DROPLET GROWTH STUDIES OR DETERMINATION OF CRITICAL SUPERSATURATION SPECTRA.

OPERATING SEQUENCE

- INJECTION OF SAMPLE AND TRANSIENT EQUILIBRATION
- RESIDENCE OF SAMPLE WITHIN CONSTANT SUPERSATURATION
- OBSERVATION OF WATER DROPLET FORMATION.

REQUIREMENTS FOR INJECTION OF SAMPLE AND
TRANSIENT EQUILIBRATION OF SUPERSATURATION

- MAXIMUM DURATION OF EQUILIBRATION PERIOD TBD SEC.
- MAXIMUM GAS VELOCITY IN SAMPLE VOLUME TBD CM/SEC
AFTER EQUILIBRATION PERIOD
- VARIATION OF MAXIMUM SUPERSATURATION 5% OF $S_{MAX.}$
FROM STEADY STATE VALUE AFTER EQUILIBRATION
PERIOD

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The range of maximum supersaturation is broader than the range for which an accuracy requirement is specified.

The maximum period of steady state operation may not be consistent with the dwell time for typical particles within the sample volume due to phoretic effects.

REQUIREMENTS FOR STEADY STATE OPERATION

- RANGE OF MAXIMUM SUPERSATURATION 0.01% TO 6%
- SPATIAL VARIATION OF S ACROSS SAMPLE VOLUME 2% OF S_{MAX}
- ABSOLUTE ACCURACY OF S_{MAX} $\pm 5\%$ OF S_{MAX}
FOR $S_{MAX} > 0.1\%$
- RESOLUTION OF S_{MAX} \pm TBD % OF S_{MAX}
- MAXIMUM PERIOD OF STEADY STATE OPERATION 1200 SEC.

We need to know the duration of the high speed frame rate in order to determine film requirements and ACPL power budgets.

