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AMTEC **Flight Experiment Progress and Plans**

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ABSTRACT

An experiment is being developed to validate the performance of AMTEC technology in the space microgravity environment. A group of AMTEC cells have been fabricated and assembled into an experiment module and instrumented for operation. The experiment is manifested as a Hitchhiker payload on STS-88 now planned for flight in July 1998. The AMTEC cells will be operated in space for up to ten days. The microgravity developed distribution of the sodium working fluid will be frozen in place before the cells are returned to Earth. Upon return the cells will be destructively evaluated to determine the location of the sodium and to assure that the sodium has been properly controlled by the sodium control elements. This paper describes the experiment purpose, status, and plans for the flight operations and data analysis. An overview of how this experiment fits into the overall AMTEC development is also provided.

EXPERIMENT OVERVIEW

AMTEC or the Alkali Metal Thermal to Electric Converter is a thermally regenerated sodium concentration cell for the direct production of electricity from heat. Systems designs based on laboratory cell performance predict AMTEC systems will operate in the 20 % to 30% conversion efficiency range at low cost and low mass, and with the potential for long life. These properties make AMTEC attractive for use as a space power source with heat supplied from either concentrated solar energy or radioisotope decay. For these reasons, NASA, the Air Force, and the DOE are developing AMTEC for potential use in space. One key aspect of AMTEC technology development is the validation of AMTEC operation in a microgravity environment.

Experiment Purpose

AMTEC uses liquid metal sodium as the working fluid. During the cycle, this sodium must be condensed from the vapor phase and pumped against a temperature and pressure gradient. If AMTEC is to be used in space, the engineering elements that carry out these processes must control the sodium without assistance from gravity. Though AMTEC cells have been operated in all orientations relative to gravity, the microgravity operation cannot be fully validated on Earth; an experiment in space is required. Thus the AMTEC Flight Experiment (AFE) was conceived. The purposes of the (AFE) are:

- Qualify AMTEC cells for flight
- Validate AMTEC operation in microgravity
- Produce power from AMTEC in space
- Confirm AMTEC cell performance parameters in space

If successful, the AFE will achieve a critical milestone toward AMTEC system flight readiness by validating the microgravity performance of the liquid sodium control elements in AMTEC.

Experiment Concept

The experiment plan is to build and instrument four AMTEC cells in an enclosure that can be sealed in a Hitchhiker canister with appropriate control electronics for operation aboard the Space Shuttle. Figure 1 shows the basic experiment assembly. Once in Earth orbit in the Space Shuttle cargo bay, the AMTEC cells will be heated electrically to a series of operating points. At each temperature the cell performance will be measured for comparison with similar data collected earlier in the laboratory. Cells performing as predicted on orbit will provide a key validation that the sodium is being properly circulated. After the required performance data is collected, the cells will be operated at high current until steady state operation is reached. The cells will then be allowed to cool thus freezing the sodium in place. Back in the laboratory, the microgravity developed sodium distribution within the cells will be evaluated as a final check of the adequacy of the sodium control elements.

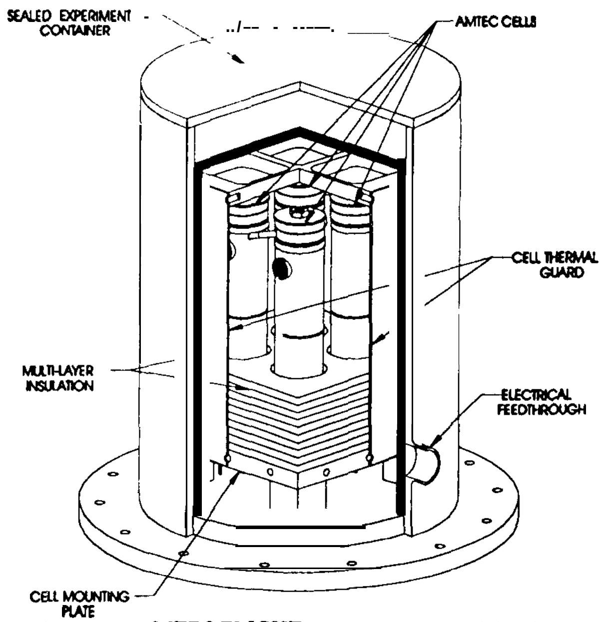

FIGURE 1: AMTEC FLIGHT EXPERIMENT CONCEPT

AMTEC Description

At the heart of an AMTEC cell is the ceramic known as beta" alumina solid electrolyte (BASE) which is a sodium ion conductor. In a high temperature region (700 to 900 "C), the BASE is a separator between high pressure (up to 1 atm) sodium and a low pressure region (see Fig. 2). The pressure (or activity) gradient creates a potential (or voltage) that drives the AMTEC cycle. Because BASE is an ionic conductor but an electrical insulator, the potential difference drives positive sodium ions into the BASE while electrons travel through an external electrical circuit producing work. At the low pressure side of the BASE, electrons neutralize sodium ions emerging from the BASE. The resulting sodium evaporates from the surface, travels to a remote condenser that is held at 100-350 C. Condensed sodium circulates back to the high temperature region and is pressurized by capillary forces in a high performance wick. It is the behavior of the condenser that must be validated in space. In particular the AFE will confirm that the condenser properly collects all the condensing sodium and feeds it into the capillary artery.

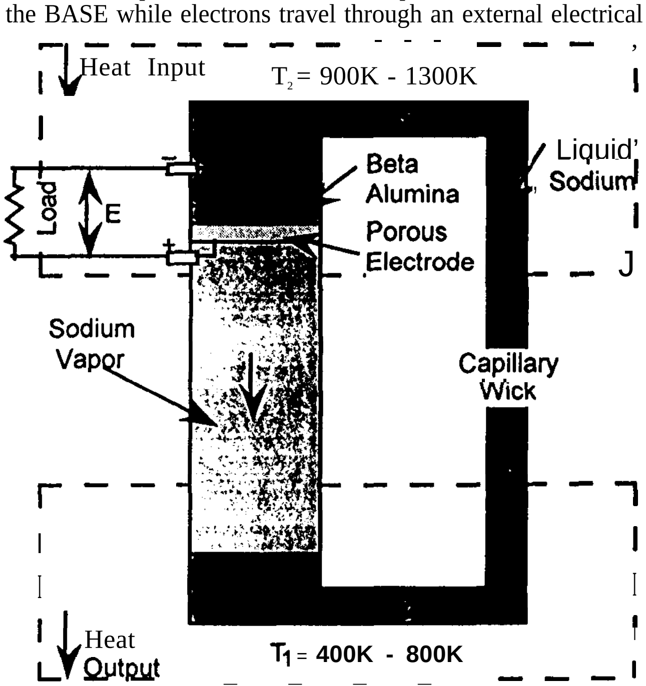

FIGURE 2: AMTEC OPERATING CYCLE

A complete description of the AMTEC cycle can be found in Cole (1983). Descriptions of modem AMTEC cells designed for operation in space can be found in Sievers (1997).

Experiment History

While several attempts were made to establish an AMTEC flight experiment, the current experiment was initially approved as a piggy back on an existing experiment called the Automated Wafer Cartridge System or AWCS. Piggy backing AMTEC on AWCS allowed significant cost and schedule savings. Initially, the experiment was to done from authorization to proceed to launch aboard the Space Shuttle in 9 months,

In 1995, AWCS was being developed by AMPS under a NASA SBIR funding. AWCS was to fly as a cooperative experiment on the Wake Shield Facility (WSF-3) cross bay bridge as part of STS-80 in November 1996. The experiment occupied one and one half, experiment cans, leaving one half of a five cubic foot can empty.

Concurrent with the development of AWCS, another division of AMPS was developing AMTEC. With the WSF open to an additional cooperative experiment, JPL was able to secure NASA funding for the experiment in February 1996. The AMTEC experiment was added to the empty half experiment canister and integrated into the existing avionics. Thus, two independent experiments became conjoined twins, joined at the electronics, software, and ground system.

When the WSF decided to drop several cooperative experiments in June, 1996, the AMTEC/AWCS twins were orphaned, without a carrier, Later, the experiments were picked up as a Hitchhiker payload and manifested on STS-88 as part of the MightySat payload. The primary mission of STS-88 is the first International Space Station assembly flight. Due to the delays in the Space Station assembly schedule, this flight is now planned for July 1998.

The AMTEC experiment and the avionics known as the Experiment Control System 11 (ECS-II) are described in remainder of this paper.

EXPERIMENT DESIGN

The AFE hardware and software are in the final qualification and testing phase at AMPS. There are four major elements: the AMTEC cells, the AMTEC Enclosure, the Experiment Control Module II (ECS-II), and the Chill System. An Exploded view of the assembly is shown in Figure 3.

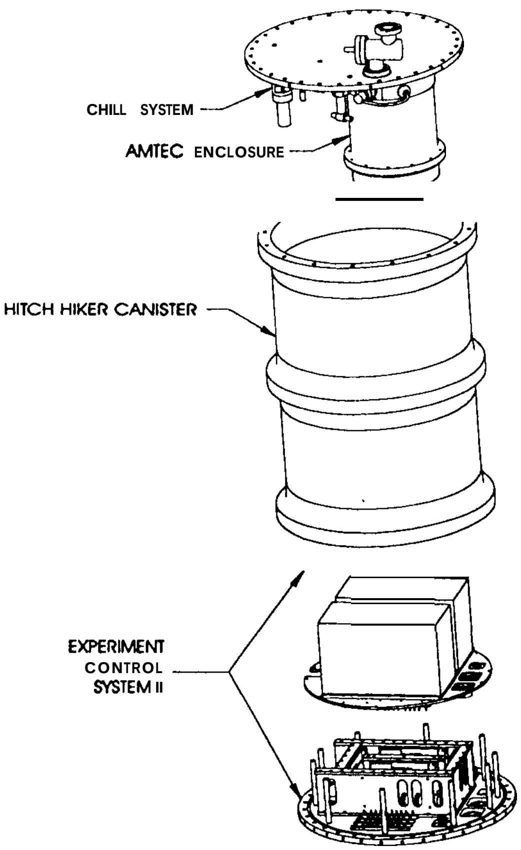

FIGURE 3: APE HARDWARE EXPLODED VIEW

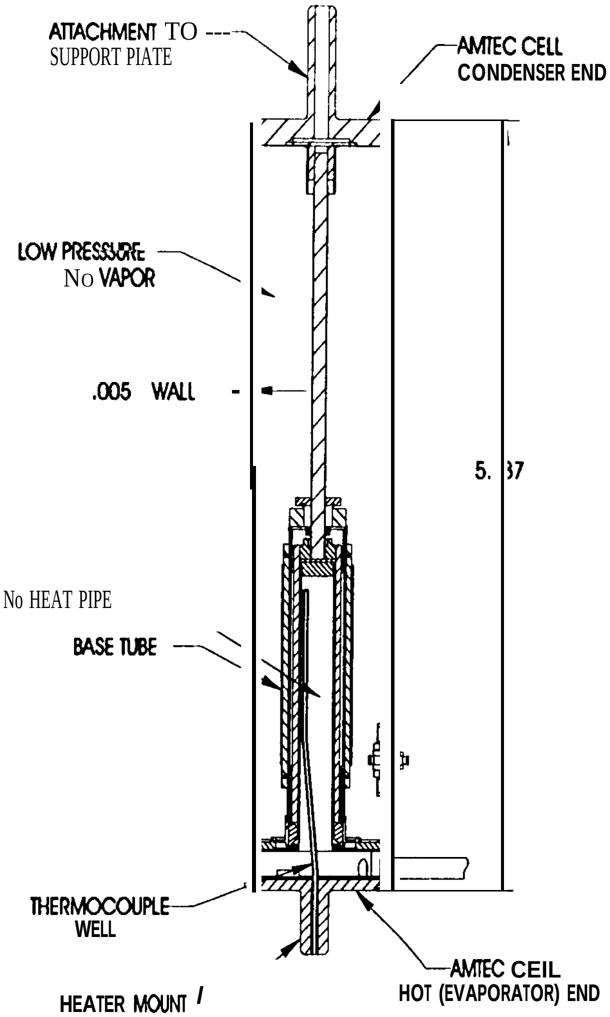

FIGURE 4: AMTEC CELL DIAGRAM
DIMENSIONS ARE IN INCHES

AMTEC Cell Description

Single tube, liquid fed AMTEC cells are used in the APE. Figure 4 is a diagram of one ceil. The cells incorporate two different heat shield designs and two different condenser impiementations.

AMTEC Enclosure Description

The AMTEC enclosure is designed to house and thermally insulate the AMTEC cells, provide the needed heater power and instrumentation, and assure containment of any sodium that breeches the containment of the AMTEC ceils (see Fig 5). individual, custom heaters provide the needed heat to each of four AMTEC ceils surrounded by Durablanket 2600 high temperature insulation. Each cell is fitted with six thermocouples to measure temperatures at key locations. Tire heater and thermocouple leads penetrate the enclosure housing through three hermetic electrical feed throughs. The enclosure is sealed and evacuated. Getters near the hot end of the assembly are used to absorb any residual gasses.

Experiment Control Module II (ECS-II)

The ECS-II integrates commercial hardware and software that have been ruggedized by AMPS to create a space qualified experiment control and monitoring system. The compliment of cards includes 286 and 386 computers, DSP motion control boards, a data acquisition system, and several serial interface and "glue logic" cards. The software includes the VRTX-86 reai time kernel, the SCL Spacecraft Control Language expert system that allows the use of scripts and rules to automatically manage the experiment, and the EasyLab commercial scripting language used to control the automation system on AWCS. The flexibility and open architecture of the ECS-II system allowed the AMTEC experiment to be integrates into the existing AWCS program in just a few months.

The AMTEC and AWCS experiments are both controlled with one ECS-II package. The high level SCL language allows tire user to switch between experiments seamlessly. The SCL computer interfaces with the Hitchhiker command and telemetry systems. AMTEC uses SCL and the DSP card to drive heater and ioad controllers. AWCS uses SCL, EasyLab, and the DSP card to control it's mechanisms. Both experiments gather temperatures, currents, and other data.

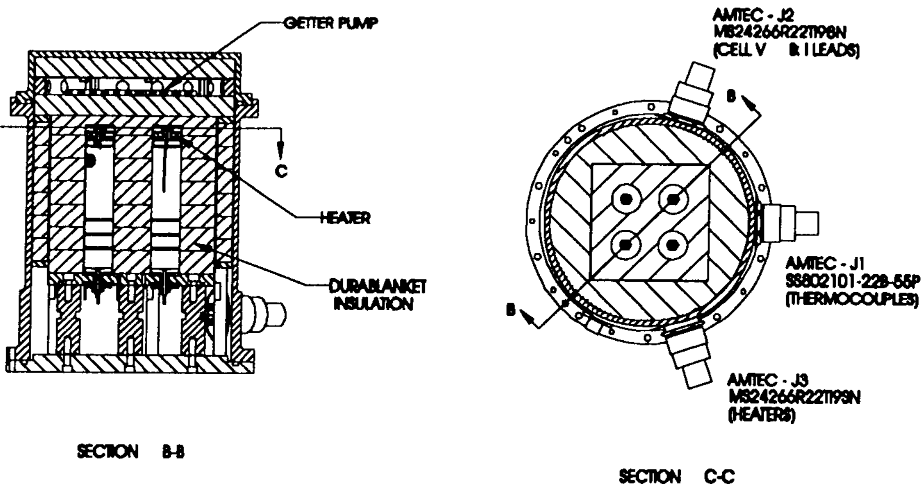

FIGURE 5: **AMTEC ENCLOSURE** DIAGRAM

The **AMTEC** and AWCS experiments arc both controlled with one **ECS-II** package. The high level SCL language **allows** the user to switch between experiments **seamlessly.** The SCL computer **interfaces with the Hitchhiker command and** telemetry systems. **AMTEC** uses SCL and the DSP card to drive heater and load **controllers.** AWCS uses SCL, EasyLab, and the DSP card to control it's **mechanisms.** Both experiments gather temperatures, currents, and other data.

Chill System

At the end of the in flight operations, a chill system

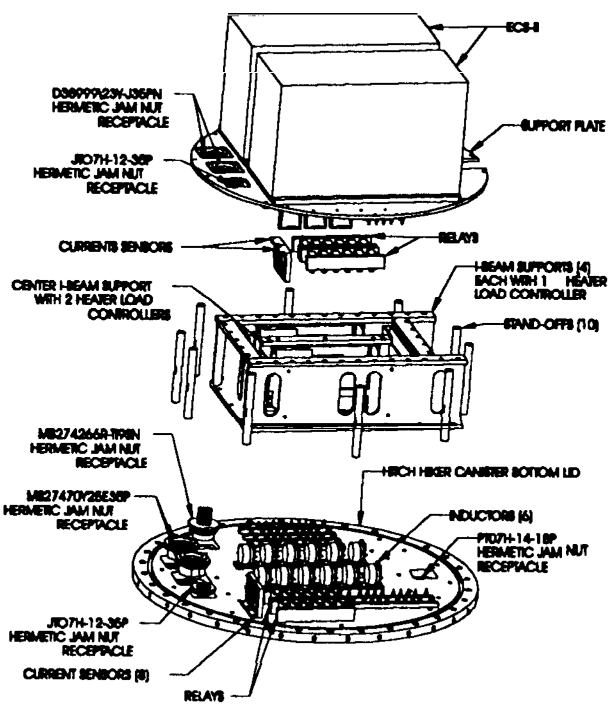

FIGURE 6: **ECS-II** DIAGRAM

activates to flood the **AMTEC** enclosure with dry nitrogen. **This gas will** reduce the effectiveness of the insulation and thus help the **AMTEC** cells cool more quickly. The chill system is an unregulated, restricted flow nitrogen system activated by a motorized valve. A diagram is in Figure 7.

PLANS FOR COMPLETION

The **AMTEC** experiment will be delivered to GSFC **(HH payload manager)** by December **1997. The** Phase **III Safety** Review will be scheduled for that same month followed by delivery of the experiment hardware to **KSC** in January 1998. After the flight in July 1998, the experiment **will** be returned to the AMPS for post test evaluations. **The final** report should be complete by October 1998.

Operations Plan

Once activated aboard the Space Shuttle, AMTEC will be operated from the NASA GSFC Payload operations and Control Center (P(XC). The same computer terminals that were used to operate the experiment in the laboratory **will** be installed in the POCC for on orbit operations. After experiment check out, cell temperatures will be ramped up to various operating points where the cells will be characterized electrically and thermally. This phase is **expected** to last 3 to 4 days. Cell temperature versus current and voltage will be compared near real time with **data collected** during laboratory mission simulations. Significant deviations may bean indication that the cells are not performing as expected under **microgravity** conditions.

Once these data are complete, the high current mode will be initiated pushing the cells to maximum current for up to six days. When maximum operating time is **reached,** the heaters will be turned off and the chill system activated.

Several contingency modes may **be** used during the experiment. These include a low power mode to prevent activation of safety inhibits should the canister begin to over heat.

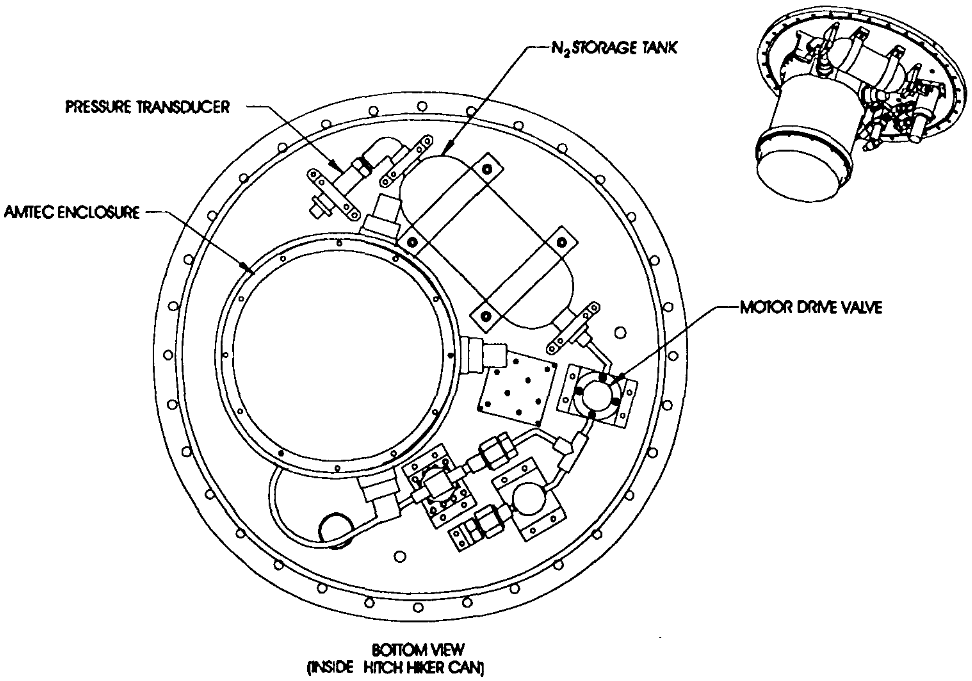

FIGURE 7: CHILL SYSTEM DIAGRAM

EXPERIMENT CELLS COMPARED TO FUTURE FLIGHT CELLS

The cells that will be used for the AFE are an older design than is currently planned for near term power systems. These cells use a single BASE tube and liquid feed of the sodium. Newer cell designs use 5 to 7 series connected **BASE** tubes and a vapor feed of the sodium. The newer cells have a better *efficiency,* a higher power *to* mass ratio, and produce higher voltages.

Despite these differences, the sodium control elements are essentially the same. The condenser and wick are unchanged for the newer designs, and the experiment cells include different of heat shield types to cover a range of what may actually be used in power systems. Because of the commonality in the sodium control elements, the AFE will validate sodium control for the newer cell designs as well as the older ones.

CONCLUSIONS

The AMTEC Flight experiment is on track as a Hitchhiker payload for launch on STS-88 in July 1998. This paper has described the history of the experiment, its sharing of electronics, software, and ground systems with another experiment, and some of the details of the experiment hardware.

Successful completion of this experiment will complete one critical milestone toward deployment of AMTEC power systems in space.

ACKNOWLEDGMENTS

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