

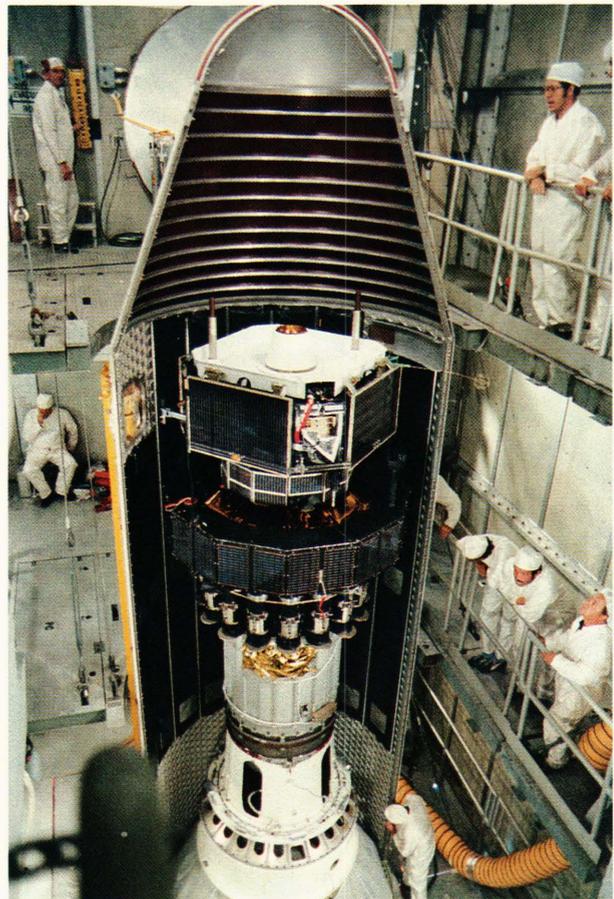
WILLIAM McCLOSKEY

PROJECT AMPTE

Satellite and rocket people learn to work at a level of perfection that would seem to obviate chance. But then sometimes, with whatever distress, they must accept the significance of a single malfunction among some thousand blissfully OK performances, and must halt an operation that represents several million dollars worth of manpower and equipment rather than risk loss or human endangerment. With a launch window of only 10 minutes a day for only 12 consecutive days, the team for the National Aeronautics and Space Administration's (NASA's) Project AMPTE scrubbed the countdown on Day One because of a faulty computer. They scrubbed another on Day Three when pieces of Mylar, shredded in the air conditioning system of the launch complex, lodged on the spacecraft. The launch occurred at Minute Six of Day Nine. This window might also have been lost when a Florida shrimp boat strayed into the solid rocket drop zone at Cape Canaveral. All operations halted until a range helicopter managed with the aid of a bullhorn to shout the boat to safety. Three years of work and ten others of planning rode on a fisherman's carelessness.

Project AMPTE—Active Magnetospheric Particle Tracer Explorers—was at last launched successfully aboard a Delta rocket from Cape Canaveral at 1048 Eastern Daylight Time, Thursday, August 16, 1984. The liftoff was attended anxiously by all those involved in the project, not only in Florida but also in Maryland and California and overseas in Germany and England. Some, like those gathered at NASA's Goddard Space Flight Center in Greenbelt, Md., were able to watch a direct transmission of the flight by TV cameras.

They shared with outdoor spectators at the Cape the sight of the immense vertical Delta, with its precious payload of three AMPTE spacecraft, as it suddenly billowed fiery gases from ground level. It lifted slowly, fire increasing to the accompaniment of a shaking roar, and shot farther and farther into the sky. The first set of burned-out solid rocket boosters jettisoned away, having done their job. (This was the point at which the vagrant shrimp boat might have received a fatal surprise.) Shortly, the second set of three boosters



The AMPTE spacecraft stack ready for launch on the Delta gantry at Cape Canaveral. On top is the American CCE, then the British UKS, and then the German IRM, connected by a payload attach fitting to the Delta third stage solid rocket motor. Among personnel are Jim Roberts and Charles Russell (partial view) of APL, far right top rail; Bill Leidig of APL, far right mid rail; members of the German IRM team beside Leidig. (Photo by Charles Owen of APL)

fell off, far enough away to be visible only to the camera eye and this only dimly. In less than a minute, Delta

and its package had become a wavering spot of smoke. From now on, the AMPTE hardware was beyond sight or touch—the very hardware that had occupied the hands-on skills of men with lathes, wrenches, sheet metal hammers, soldering irons, and all manner of microprocessed precision and computerized instruments. All contact hereafter would be remote, through telemetered commands and transmitted data.

Back on the ground, the TV cameras showed a launch pad empty, slightly charred. Only the beach spectators had felt fully the physical impact of the launch: the ear-shaking, almost supernatural roar that reached them, miles away, a few seconds after the first sight of rocket fire. Even in sunlight the rocket discharge blazed so intensely it hurt the eyes. The roar still shook the air as the rocket disappeared. When viewing a launch firsthand, it is difficult not to be moved by the immensity of the forces unleashed. With AMPTE, this was only an earth-bound prelude to the solar and magnetic forces into which it headed.

AN ACTIVE TEST OF SOLAR INFLUENCE

Great expectations ride with AMPTE. One goal of the mission is to inject tracer ions into different regions of near-earth space at selected times and locations; another is to measure the composition and energy of the natural ion populations in space in order to study several significant problems of space plasma and magnetospheric physics. The probe has several distinctions: It is the first three-nation, three-spacecraft cooperative space effort, the first *active* satellite experiment in space, one of the first probes to deliver real-time data in analyzable detail from space, and the first to provide such data from three separate sources simultaneously.

As an active experiment, AMPTE creates the conditions on which it gathers data rather than passively observing what is already there. The probe consists of three spacecraft, provided by the governments of West Germany, the United Kingdom, and the United States.

Briefly, the 705-kilogram German spacecraft, Ion Release Module (IRM), orbits from near-earth at perigee to a position at 71,000 miles apogee beyond earth's magnetic field, or magnetosphere. It releases programmed charges of vaporized lithium and barium metal, first into the solar wind and later into the magnetosphere. From some 20 miles away, the 77-kilogram British spacecraft, United Kingdom Subsatellite (UKS), monitors the discharges from the perspective of distance. (Not a large distance considering that the lithium clouds, for example, will expand to a 20,000-mile diameter before being dragged along by the solar wind.) When the sun's rays ionize the metal vapors, the solar wind drives them as newly created "tracer" ions toward the earth and into its magnetic field. The 242-kilogram United States spacecraft, Charge Composition Explorer (CCE), orbits at 31,000 miles apogee, within the magnetosphere. Its purpose is to detect and study the released ions and other particles carried by the solar wind.

Project AMPTE has three principal goals: (a) to study the entry of ionized particles from the solar wind into the earth's magnetosphere and to investigate the transport and acceleration processes that produce high-energy particles in the earth's radiation belts; (b) to study the interaction between an artificially injected cold plasma and the natural flowing space plasmas; and (c) to establish the composition, charge state, and energy spectrum of the magnetosphere's natural particle populations.

Potentially, the resulting data will answer immediate questions about near-earth phenomena related to solar activity, such as the sources of the Van Allen radiation belts and of the auroras. In the long run, the information it gathers will be basic to our view of the earth's interaction with solar wind particles and thus to the planning of other space probes in the future.

GROWTH OF A PROJECT FROM IDEA TO HARDWARE

The American portion of Project AMPTE, the CCE, was built for NASA by the Applied Physics Laboratory (APL) in Laurel, Md. The first suggestion that the solar energy project might be possible was voiced in 1971 by Stamatios M. Krimigis of the APL Space Department to Erwin R. Schmerling, NASA head of magnetospheric physics. By 1972, the discussion stage of the project had grown to include Gerhard Haerendel of the Max Planck Institute for Extraterrestrial Physics in Germany. Both Krimigis and Haerendel had been identified with solar and planetary studies for much of their careers and continue to be. Funding and concrete plans for the project became final by mid-1981 when NASA gave APL the go-ahead and signed a memorandum of understanding with the space agency of West Germany and then with Great Britain.

The launch date targeted at that time was the one that actually occurred. Initial plans were so thorough that the APL/NASA team made only a few modifications as the CCE entered development. Among these few, the CCE team, projecting a potential power deficiency during initial orbits, added a cold gas torquing system that could rapidly maneuver the spacecraft to point the solar cells toward the sun. In another modification, they increased the size of the inclination change motor. This added a few pounds extra weight, but the booster engineers had allowed for some 40 kilograms overweight. (The German spacecraft used up the largest portion of that in its gas release equipment.)

Two of the five CCE experiments were built at APL: the magnetometer, with Thomas Potemra of APL as lead investigator (LI) and Mario Acuna of NASA Goddard Space Flight Center as project scientist, and the medium energy particle analyzer, with Richard McEntire of APL as lead investigator. Working closely with NASA and APL on the other experiments, the University of Maryland developed the charge energy mass spectrometer, with George Gloeckler as LI. Lockheed Palo Alto Research Laboratory developed the hot plasma composition spectrometer, with Edward Shelley as

LI. Later in the program, Frederick Scarf of TRW was selected to fly his spare Pioneer Venus Orbiter plasma wave experiment on the CCE.

Tom Krimigis served as American Principal Investigator, with Gerhard Haerendel his German counterpart and Duncan Bryant of Rutherford Appleton Laboratory in charge of the British program. The six key managers of the American AMPTE program were: Marius Weinreb, program manager, NASA Headquarters; John Lynch, program scientist, NASA Headquarters; Gilbert Ousley, project manager, NASA Goddard; Mario Acuna, project scientist, NASA Goddard; John Dassoulas, program manager, APL; and Richard McEntire, program scientist, APL.

Three particle experiments constitute the main instrumentation of the CCE; taken together they measure the composition of the entire range of energetic particles in the earth's magnetosphere. They can also detect relatively rare tracer ions that occur either naturally or through the artificial injections of the German IRM spacecraft. The *hot plasma composition spectrometer* measures the lowest energy plasmas—from nearly zero to approximately 17,000 electronvolts for a singly charged ion (twice this for a doubly charged ion, etc.). The hot plasma composition spectrometer also contains an electron background monitor that measures electrons over a range of 50 to 25,000 electronvolts.

The *charge energy mass spectrometer* deals with a range of ions from 1000 to about 300,000 electronvolts. It measures not only the elemental composition of the energetic particles but also their charge state. In the second capacity it can, for example, differentiate between oxygen with two of its electrons removed and oxygen with only one electron removed. (It can, in fact, register an oxygen state up to eight electrons removed.) The *medium energy particle analyzer* measures the composition of plasma ions from about 10,000 electronvolts to about 6 million electronvolts per nucleon.

The *magnetometer* performs double duty in measuring the earth's magnetic field around the spacecraft: It provides data for determining the attitude of the spacecraft, and it also provides scientific information about the magnetic field that orders the energetic particle fluxes and guides their motion. The *plasma wave experiment* measures the oscillating electric field in the vicinity of the spacecraft with a frequency range of 5 hertz to 178 kilohertz, giving information on electric wave emissions within a large volume surrounding the spacecraft.

That portion of the AMPTE CCE mission designated for studying the natural environment is expected to yield more comprehensive data than ever gathered before on the composition of the near-earth natural energetic particle populations. According to CCE program scientist McEntire,

For the first time in all of man's history we will be able to measure the composition of the radiation that surrounds the earth over its full energy range. For ex-

ample, the magnetic storm time, or so-called ring current, is a large injection of energetic particles around the earth so intense that they noticeably depress the magnetic field. We have never yet been able to determine the composition of the ring current—whether it is made up of protons, or perhaps of helium or oxygen. Data from the CCE is expected to settle this controversy. Another example: the natural environment contains fairly rare species that will serve as tracers of the processes that take place in the magnetosphere. Our new ability enables us to measure the composition and relative changes of different components of the magnetosphere's energetic particles, e.g., the relative variation of natural protons, helium, iron, and oxygen. We have a powerful new tool for work in the space environment.

SCIENCE DATA CENTER RECEIVES IN REAL TIME

One major preparation involved the establishment of a Science Data Center at APL under Bruce Holland. The resulting assemblage of equipment is considered unique among satellite communication facilities in its ability to receive and display information from the orbiting CCE in real time—as events in space occur. The Center provides a computing facility for the U.S. science team and thus serves as the focal point for all data received from the CCE. (Actual commands to CCE are transmitted by NASA's Jet Propulsion Laboratory, based on recommendations made from instrument readings at the APL Center.) According to Holland, the Center "gives windows on



User room at AMPTE Science Data Center at APL, monitoring real-time data from the CCE in orbit. At consoles, left to right (all from APL except as noted) are Rob Decker, Harry Utterback, Bruce Holland (leaning over). Standing, left to right are Rob Gold, Larry Zanetti, Don Margolies (half hidden), (NASA), Dave Klumpar (facing away) (Lockheed), Tom Krimigis, and Dick McEntire. (This and the following photos are by the author.)

Work in Progress

every stage of CCE through final maneuver. There's never been such a coherent broad coverage of instrumentation, all on the same platform at the same time."

Basic to the Center is a VAX 11/780 to process actual data and to perform theoretical predictions. The material processed includes all information from the five CCE experiments as well as the multitude of data from the satellite itself such as propulsion, pressurization, attitude, and the basic housekeeping functions: electrical, thermal, and power. These data are recorded in pool files but are also separated and transmitted to numerous consoles for quick-look display as they occur. (The information takes many forms: numbers, figures, charts, diagrams, and color-coded spectrograms.) During the ion release maneuvers, the Center also provides communication links with the spacecraft teams in Germany and Great Britain as well as with the NASA team at Jet Propulsion Laboratory, and the Space Environment Laboratory in Boulder, Colo.

When Holland began putting together the Center in mid-1981, he began by establishing hardware configurations and by recruiting a team "for the duration." Early "enlistees" included Harry Utterback, responsible for the decommutation that, according to Holland, is the heart of processing, and Lee Pryor, responsible for general systems and library service programs.

The decommutation process involved reconstructing each experiment's unique telemetry frames, then routing the appropriate data stream from them to processors that are unique to the experiment. Each processor needed to be designed to provide master data files, summary data files, and numerous displays.

Other key members of the team were Stuart Nylund, responsible for hardware, systems integration, and operations; Joy Hook, communications software; and Courtney Ray, attitude determination and spacecraft maneuvering.

The next phase was "to actually acquire the hardware, get it installed, and start sending the systems programmers to school to learn their machines." In tandem with this, Holland's team needed to guarantee reliability. They ensured an uninterrupted power supply, as proof against such potentials as a lightning storm, by connecting to the McClure Computing Center's storage batteries and a diesel generator. For redundant capability on the VAX computer in the event of a breakdown, they arranged for a "hot spare" during vital operations of the CCE, running the same data on separate lines on an identical VAX belonging to the Space Physics Group in the APL Space Department.

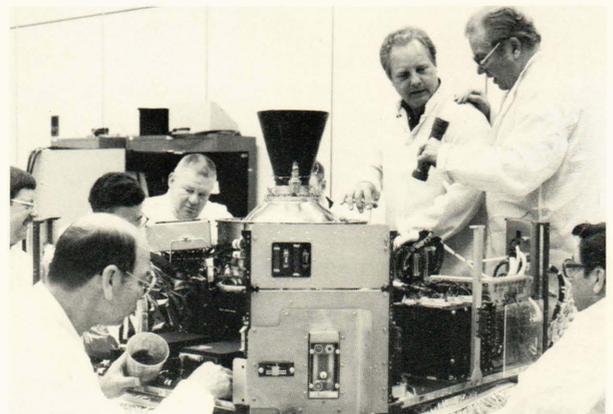
Due to the funding limitations that are part of such a project in times of a tight national budget, the critical people in the Science Data Center were not able to be duplicated with backup personnel. Holland volunteered this sobering thought: "If any of these people had been hit by a truck, we would have been wiped out. This vulnerability you accept—it's part of the way you save money."

A SPACECRAFT IN MAJESTIC STATE

During the August 1984 launch, many who watched consoles anxiously and exchanged launch event information across the Atlantic had lived with AMPTE for at least the 3 years of its development—during systems concept, design, structural fabrication, the creation of instruments and their data plans, and the delicate wedding of parts. At APL, it was possible to watch the CCE grow in various assembly shops (with increasingly stringent requirements for cleanliness) from a cross-hatch of aluminum struts to awesome congeries of wires and electronic components.

The last time I personally called on CCE, last May, it stood majestically in a white room within the new Kershner Space Building at APL. To enter the room, one needed to wear a white dust-free coat and to walk over a series of moving brushes to free shoes of dust. The spacecraft was mounted on a dais. It resembled the boiler of a small steam engine because it was topped with a discharge funnel through which would pass the fiery gases to position the vehicle in space. Bits of protective foil caught silvery and brassy gleams from the overhead lights. Most of the subsystems were already secured by protective plates, but enough instruments and multistrand wires remained visible to show the fabulous complexity of CCE.

The spacecraft had just returned from mass properties and thermal vacuum tests at NASA Goddard a few miles away, having already survived APL in-house tests for vibration. Under the surveillance of Max Peterson, assistant program manager for integration and testing, and Joe Staiger, spacecraft systems engineer, CCE was now being final-touched prior to shipment to Cape Canaveral. A dozen engineers, scientists, and technicians hovered as solicitously over their individual panels and experiments as mothers bundling their kids for the first day of school. Some were absorbed in immediate honing, with screwdrivers, tape,



The CCE spacecraft receives final touch-up in a white room at APL's Kershner Space Building following vibration tests at APL and properties and thermal vacuum tests at NASA Goddard Space Flight Center. Left to right are Dick Maurer, Dorsey Reaser (applying potting compound to lock connections in place), Jim Roberts (half hidden), Glen Bolts, Bill Leidig, Bill Henderson, and Joe Staiger.

and doping brushes. Others checked and monitored subsystems that were wired to an array of computerized panels. You could feel at once the air of cheerful excitement. Without making much noise, everybody buzzed.

ASSEMBLING AT THE CAPE: GETTING IT ALL TOGETHER

The CCE departed APL by van on June 25 and arrived at Cape Canaveral two days later for pre-launch testing and integration. John Dassoulas, APL program manager for CCE, who had squired the spacecraft through the three years of physical development, said of the operation:

We had adopted a ship-and-shoot philosophy. This essentially meant that when the CCE left APL it was as close to ready as it could be. After setting up the ground support equipment and performing routine electrical checks, the only remaining tasks to do in the field were to integrate our inclination change rocket, pressurize our cold gas system, and install and connect our ordnance pyrotechnics. But electrically the spacecraft operated at the Cape just as it had here. It was one of the smoothest field operations I've ever been on—so smooth it was spooky.

The team for the German spacecraft faced more complicated problems. To begin with, the IRM includes the canisters to discharge lithium and barium into the solar wind. The delicate loading into canisters of the thermite mixtures that would produce the metal vapors was developed by Max Planck Institute and had to be performed in Germany. The resulting 16 loaded canisters could not be shipped safely by air, so they traveled in advance by boat. The Germans and British also brought over each of their individual experiments by separate courier rather than trust everything to a single shipment. Thus at the Cape they had a larger integration job than the Americans.

An indication of how well things progressed was the ultimate ease with which the structures and systems of all three spacecraft—built at separate locations—fitted together and as a package with the Delta third stage. This was no coincidence. APL had provided an electrical interface system that connected the three spacecraft and wedded them with the separation lift-off switches of the launch vehicle. The job had included delivering sample interpayload adapters to the Germans and British at home, to assure the proper mechanical fit and electrical connections when the spacecraft reached the Cape.

COUNTDOWN PROBLEMS: COMPUTER INTERFACE AND MYLAR SCRAPS

Thursday, August 9, 1984

Day One of the AMPTE launch window that extended through August 21. The countdown at Cape Canaveral began at approximately midnight Eastern Daylight Time (EDT). For several days, the three

spacecraft had been integrated with the Delta third stage on top of the 100-foot rocket, and payload engineers worked from a gantry high above the Cape Canaveral beach. Ten days before, Bill Miles of the APL satellite crew had performed the delicate and dangerous loading of freon into the CCE cold gas jet system. One by one, the payload crews performed their final checkout—the Germans and British around 0100 EDT and the Americans at 0200. The U.S. team included some 25 people from APL and NASA as well as individuals from Lockheed, TRW, and the University of Maryland. This was to have been the final hands-on. 0315: Pad cleared. All hands descended to the ground and evacuated the launch complex. The gantry rolled back. Final countdown began.

The various steps of the Delta/AMPTE countdown fill a manual of over a hundred pages. At T-135 minutes, for example, five pages list items to be accomplished during a hold in preparation for the terminal count. Sixty-six separate steps follow for the 15 minutes of terminal count. Fuel loading commences at T-120 minutes with 62 steps (several with five to eight substeps). At T-75 minutes, the Delta rocket receives its liquid oxygen fuel. As for the three spacecraft now encased in a heat shield on top of the Delta, they also required hundreds of countdown checks performed automatically by computer.

The countdown progressed not only at Cape Canaveral but also at the centers where the three spacecraft would be monitored after launch—at the German Satellite Operation Center near Munich, at the British center of the Mullard Space Science Laboratory in Sussex, and at the U.S. station in Maryland, at APL. Also tuned in were NASA stations at Goddard Space Flight Center in Maryland and Jet Propulsion Laboratory in California, as well as U.S. tracking stations in Goldstone, Calif.; Madrid, Spain; and Woomera, Australia.

0400 EDT: The German station reported problems with its attitude control computer: a malfunction in the software-hardware interface. This would mean an inability to control the IRM spacecraft once it had been launched. The problem could not be solved at once, and the launch was scrubbed. A ground crew had to off-load the liquid oxygen from the first stage.

Saturday, August 11, 1984

IBM, which provided the German computer, had succeeded in recreating the interface problem, inventing a solution, and demonstrating that the solution worked. A new countdown began in the same time frame. 0130 EDT: As part of final "preps," payload technicians began to close access doors in the heat shield over the three spacecraft. Warning sight: A piece of aluminized Mylar clung to a tape over one of the access doors. Initially, they thought the Mylar was part of some thermal blanket insulation, but a check by APL thermal engineer Clarence Wingate discounted this possibility. On looking closer inside the nose fairing, the checkout team found scraps and sheets of the Mylar clinging like Saran Wrap to the exposed parts

of the three spacecraft. They identified the source as an umbilical duct connecting the air conditioning filter to the nose fairing. There was general distress, followed quickly by a professional assessment of the situation. The high-velocity wind blowing through the air duct must have torn off a piece of the Mylar duct liner and shredded it. The launch had to be scrubbed again.

The U.S. spacecraft fared better than the other two because all its instruments were covered except for the ion head of the medium energy particle analyzer. Unfortunately, several of the German and British experiments were exposed. Hands-on again, with camel's hair brushes and vacuum cleaners. In the 5 days that followed, the spacecraft teams disassembled, cleaned, inspected, and retested, while the Delta team changed the duct lining to seamless plastic.

THIRD COUNTDOWN: A STRAY BOAT, THEN GO

Thursday, August 16, 1984

The countdown procedure started again. Everything clicked. A built-in hold of 10 minutes commenced at T - 4 minutes (to allow for any last-minute problems without missing the launch time). At the NASA Goddard Space Flight Center, an audience (including myself) had assembled in a darkened auditorium to watch through big windows as engineers monitored the launch from several tiers of consoles.

A direct line from the Cape Canaveral blockhouse kept us in touch. An announcer declared in a quiet voice that the hold would continue because there were two problems: a boat had wandered into the drop zone, and one of the telemetry channels was warning of an improper temperature in one of the Delta launch vehicle systems. The audience collectively caught its breath. Remember that the launch window extended only from 1042 to 1052 EDT (a necessity to place the orbit of the IRM at the proper orientation). On the advice of personnel from McDonnell-Douglas (the Delta manufacturer), and with clear weather at the Cape pointing to positive conditions, the launch director decided to discount the temperature sensor information. As for the shrimp boat mentioned above, boats in the water are not noted for the speed with which they can reverse course. Tense silence. Two minutes into the 10-minute launch window the countdown resumed.

1048 EDT: Liftoff. Everybody applauded. Launch time occurred 4 minutes short of another scrub.

The launch continued with classic perfection—not all launches do—counting “up.” Nine solid propellant rockets, attached to the Delta first stage to augment its thrust, fired and jettisoned in sets of three. At 1052 EDT, the first Delta stage had spent itself and separated. The second stage fired from minute 3:56 after liftoff until minute 9:49, then coasted until a brief firing before separation at minute 69:33 (1157 EDT). The Delta third stage burned for 44 seconds. About

2 minutes later, the stack of three spacecraft separated from the Delta by means of a spring. The stack entered an elliptical orbit around the earth with an altitude of approximately 340 miles at perigee and 31,000 miles at apogee. Almost immediately thereafter, the American CCE separated from the German and British spacecraft. Both the latter continued to travel as a package.

Approximately 1200 EDT: At this point began the first initiative of the APL Science Data Center, to establish the mission orbit of CCE. If this positioning maneuver were to fail, so would the AMPTE mission. At APL, the U.S. team crowded around one man seated before a console, while interested Laboratory employees watched from the corridor outside. Courtney Ray, along with Chuck Williams, had been responsible for developing the procedure to set the final attitude (or orientation of the spin axis) of CCE. The maneuver was necessary to position CCE for firing the inclination adjust rocket (IAR or “kickmotor”) that would place it in the desired equatorial orbit. The spin axis of the spacecraft had to be precisely aimed because the IAR thrust would be along that axis. Since the IAR needed to be fired at apogee, perigee altitude would be extremely sensitive to errors in the firing. (The consequence of a lowered perigee could have been that the CCE reentered the earth's atmosphere, or, as someone put it, “hit the trees.”) The maneuver required analyzing real-time signals from instruments on CCE to deduce the spacecraft attitude at the moment and then adjusting the attitude with numerous short thrusts from on-board jets.

The end requirement, firing the IAR, would tilt the plane of the CCE's orbit into the earth's equatorial plane. (Ions released by the AMPTE IRM are expected to concentrate there since natural populations of energetic ions trapped in the earth's magnetic field tend to center at the earth's magnetic equator.) The launch orbit of CCE—28° inclined to the equator—needed to be changed to an orbit inclined no more than 5°.

Cold gas jets, triggered by a pulse whenever the spacecraft spun past the sun, performed the maneuvers. Part of the maneuver involved raising the spin rate of the spacecraft from 60 to 100 revolutions per minute to increase its stability for IAR firing. The attitude determination required readings from two CCE instruments: the solar attitude detector and the magnetometer. The solar attitude detector provided the sun's angle relative to the spacecraft's spin axis. The magnetometer measured the local magnetic field at the spacecraft's position. These measurements were used for orientation by fitting them into models of the earth's field at the CCE's position.

Time constraints left no margin for error. Because the magnetic field models become unreliable at large distances from the earth, it was necessary to re-orient the CCE before it had advanced very far on its first orbit. Thus, even though the kickmotor itself would not be fired until first apogee (about 8 hours after separation), the orientation had to be completed quickly, and within approximately a half hour.

1237 EDT: Phase One of the attitude maneuver came to a successful end with the CCE now pointing in the correct direction for firing the IAR. Cheers. Champagne.

Seven hours of intense analysis followed in order to verify that the desired attitude had been achieved. At last came time for the critical decision to fire the inclination adjust rocket. This occurred at 1942 EDT. The telemetered data showed at once that the firing had occurred. More cheers. Subsequent spacecraft tracking showed that the whole maneuver had been carried out correctly, achieving a final inclination of 4.8° to the equator.

Dick McEntire, recalling the intense work and accomplishments of several members of the APL team, spoke of AMPTE's unsung heroes, using Ray as an example among many others. During the attitude maneuver, according to McEntire, "APL was Courtney Ray, sitting there doing calculations with imperfect data from the spacecraft in real time, making a decision as to whether we should fire that rocket or not. If we fired in the wrong direction—there were many wrong directions in which CCE could have been pointing—we'd have lost the mission."

The on-board attitude control system (cold gas jets and/or magnetic torquers) will be used further throughout the mission to maintain the slow spin of the CCE and to keep its solar panels facing the sun. This array of blades generates power from solar energy to run the experiments and transmit their data. The attitude change with respect to the sun is approximately 1° a day, but a single larger adjustment can be made every few days. The CCE adjustments are the responsibility first of Wade Radford, who, at APL, is in charge of CCE post-launch operations. (Later, he will move to the JPL Control Center.)

By 10 hours after launch (approximately 2100 EDT on August 16, or 0100 Universal Time on August 17), all the CCE maneuver operations were completed. As described above, the inclination change motor had been fired at 1942 EDT to place the CCE to within the acceptable 5° tolerance zone of the equator. Later, commands relayed to the spacecraft opened its solar panels and extended its magnetometer boom (the latter at 0031 EDT). Of the on-board experiments, the magnetometer had been activated early to help in positioning. During the next 10 days, the experimenters turned on the other four CCE experiments and checked them. Before the experiments could operate fully, there needed to be a period for "outgasing" to allow the evacuation of air molecules still trapped inside the spacecraft that might have caused arcing under high voltage.

Five days after launch, Dassoulas could declare:

The spacecraft is very healthy. We've got a fully charged battery. The array is pumping out many watts of power. We also have 5 or 6 pounds of attitude gas remaining after all the maneuvers. There's nothing I know that will limit the life of the satellite. Should we run out of pressurized gas, we have a magnetic spin-

despin system to maintain spin of the spacecraft and a torquing coil to keep the solar panels oriented toward the sun.

The positioning and checkout of the German and British satellites proceeded with similar success. There followed two weeks more of settling in.

MAGNETIC STORM DELAYS FIRST ION RELEASE

Friday, September 7, 1984

At 0300 EDT, the first attempt to begin the active experiment phase of AMPTE began with a lithium release from the IRM. In Germany, whence the IRM commands would issue, the time was 7 AM, while at APL it was 3 AM, and at the Jet Propulsion Laboratory it was midnight. Despite the inconvenient hour, the APL Science Data Center was packed. In the Lab's inner compound, the Center's windows were the only ones lighted. Shirt-sleeved figures moved inside. On the door hung a manila envelope holding bets on the time of first gas release. Also, someone had posted a photo of the combined AMPTE spacecraft at the Cape, from the *Baltimore Evening Sun* of August 20. The picture, reproduced in color on the front page with the caption, "Craft of Three Nations," had unfortunately been printed upside down. A person in white cap and dust-free coat stood on his head. Scrawled across the clipping: "Let's be careful in there."

The assemblage clustered particularly around the communications lines. It included the CCE team and experimenters from NASA, APL, University of Maryland, TRW, and Lockheed. It also included, from NASA Goddard, two of the nation's authorities on the physics of the solar wind, Leonard Burlaga and



Tense 3 AM watch on September 11, 1984, in the Science Data Center at APL, as the IRM team in Germany prepares to make the first ion release of the AMPTE mission. The group at left watches a virtual real-time display of IRM hard copy and those at right an IRM plot display. Left to right, seated, are Harry Wannemacher (background, NASA), Len Burlaga and Ron Lepping (NASA), Tom Krimigis (American principal investigator, on the direct telephone line to the IRM team in Germany). Standing are Don Margolies (NASA), Dick McEntire (CCE program scientist), Marius Weinreb (NASA AMPTE program manager), Tony Lui, Rob Gold, Ed Keath, John Dassoulas (CCE program manager), and Ed Shelly (Lockheed). Those not otherwise identified are from APL.

Ronald Lepping. People drew coffee from a big urn and ate doughnuts as they listened to Krimigis and others talk by open phone to Haerendel in Germany and with colleagues in England.

The general air of expectation arose only in part from expectations of the possible IRM release. As Haerendel's slightly accented voice declared: "At present it does not look terribly good. We have a massive magnetic storm out there." Most of the people in the room had known of the magnetic disturbance for days. Len Burlaga of NASA drew illustrations for his colleagues to show the sources of disturbance from the sun and the pattern they usually follow. The consoles had begun delivering data on the magnetic storm, as it occurred, from the three AMPTE spacecraft located 30,000 and 70,000 miles from earth.

"Even if the IRM doesn't release today," said one person with obvious pleasure, "I'd say we'll have at least three scientific papers from that magnetic storm data."

Mario Acuna of Goddard was more specific: "In some respects, we know more about the environment around Jupiter than we do of that around our own planet. Early on during space exploration the emphasis shifted from earth. Now we're finding our way back." Tom Potemra of APL added: "We're doing it in real time—that's one of the exciting parts. Instead of waiting a month for data to be processed, we can watch it happening."

The window for the first series of gas releases would remain open until September 28, with the orbits of the American CCE and the combined IRM and UKS aligned at apogee approximately every 2 days. Perhaps closer to the deadline, Krimigis explained cheerfully, "We might take chances." But since the pattern of the ion releases during a magnetic storm might be less clear to read, it made good sense to wait. The sun was rising in Maryland when the release window closed and the scientists dispersed.

Sunday, September 9, 1984

Most of the same team assembled at 0200 EDT. The magnetic storm had abated, but the interplanetary magnetic field, carried outward from the sun by the solar wind, was pointing in the wrong direction so that ions released by the IRM would miss their target. A second cancellation.

Tuesday, September 11, 1984

On this day at 0100 EDT, the watch began again. Alongside the coffee urn lay a large flat cake with white sugar icing. The day before had been both Krimigis' and McEntire's birthdays.

—0215 EDT, Haerendel from Germany: "I feel we are getting closer to a situation where I would feel tempted to command the release." But, a few minutes later: "We have rather unfavorable magnetic field orientation. The situation's not so good." It began to appear that this, again, would not be the night. People drifted off into private conversations and for looks at specific data coming from the CCE spacecraft.

—0250 EDT, from Germany: Chuckles, then several voices singing "Happy birthday, Tom and Dick, happy birthday to you." General laughter, followed by a mild apology for frivolous use of the open line. Krimigis: "There's half a cake left. If you would like to come over, we'll save you some." General banter followed, with the British joining in from Sussex to offer best wishes.

—0300 EDT, from Germany: "The magnetic field is stabilizing. Maybe the singing has helped." Suddenly everyone galvanized. Within a few minutes the Germans announced that the time had come, and the Americans agreed. This meant that two canisters of lithium would be released from the IRM spacecraft.

—0315 EDT, from Germany: "We have positive indication of release." General cheers and applause.

—0325 EDT: Announcement that the canisters had successfully discharged their lithium. Cheers and applause repeated, with relieved laughter.

Every step along the way was a first step. The next cliff-hanger: When would the American CCE, 40,000 miles closer to earth than the IRM, begin to pick up readings from the discharge? *Would* it register after all? There would be plenty of data to be gained otherwise from experiments on the CCE, and significant information could be gained even from a failure to discover high energy particles at that distance.

Meanwhile, somebody wrote the exact release time on the blackboard, and the pool envelope was opened. Fred Ipavich of the University of Maryland had made the closest guess and collected the contents of the envelope.

Within a few minutes the scientists were clustered around the data consoles. After 10 years of planning and 3 more of development, the active release phase of the AMPTE mission had begun.